

Design of a Compact UWB/MIMO Antenna with High Isolation and Gain

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Abstract—The design of a compact two elements ultra-wideband (UWB) multiple-input-multiple-output (MIMO) planar antenna is presented. It consists of two symmetrically circular patch antenna components. The overall size of the antenna is $30 \times 60 \times 1.6\text{mm}^3$ and is printed on the FR4 substrate. The proposed antenna exhibits UWB qualities from 2.6 – 12GHz with the isolation of less than 20dB. The total active reflection coefficient (TARC), the data rate that can be supported in a particular channel (CCL), and a factor that signifies higher pattern diversity are presented, which are useful for portable UWB applications.

Keywords—ultra-wideband (UWB), multiple-input-multiple-output (MIMO), mutual coupling, signal to noise ratio (SNR)

I. INTRODUCTION

Nowadays, designing a MIMO system that supports high data rate and multiple wireless metric capabilities with effective electromagnetic spectrum utilization is needed. Ultra-wideband technology incorporates MIMO techniques such as diversity, multiplexing, and beamforming have been proved to enhance wireless system performance in an environment where interference, fading. Multipath tends to degrade the signal quality, reduce the effective data rate and many subscribers in the cell [1-5]. Why MIMO? It is all about the channel capacity of the system whereby the channel capacity depends on bandwidth and signal to noise ratio [6]. How do we increase the channel capacity of the system, is either we increase the bandwidth of the system, which sometimes is not accessible due to resource limitations, or we can work on the signal to noise ratio; these two options are amendable to increase the channel capacity of the system [7-9].

Employing multiple antenna technology gives us some hints on a signal to noise ratio. Imagine a single antenna system in which we have an antenna that transmits and receive a signal. There are some multipath propagation and channel fading condition which will deteriorate the signal to noise ratio (SNR). If we employ more than one microwave circuit (antenna) simultaneously, all the antenna will operate simultaneously, receive the signal and transmit the signal independently of one another, what will happen is that the channel fading, and multipath propagation will get reduced. When this happens, we will have the improvement of SNR, and that is why MIMO is so vital in achieving the higher

channel capacity in the modern wireless communication system.

II. RELATED WORK

In-state art literature, many designs of antennas for UWB application have been researched [10-12]. A letter is presented in [13] whereby the author embedded different types of slots and slits on the radiating element. The author in [14] proposed UWB-MIMO sensing in which some diodes have been used for that purpose. The pin diodes are turned on with a reversed biased of 0V for two varactor diodes. A band notched UWB antenna with band rejection ability is presented in [15]. An open-circuited stub has been added at the edge of each radiator for rejection ability. Another UWB-MIMO antenna without a decoupling structure is shown in [16]. The author employed a stub loading technique at the ground plane for impedance matching improvement.

In this paper, a 2×2 MIMO antenna is designed on the FR4 substrate with a thickness of 1.6mm. The MIMO antenna transmits in UWB frequency. The rest of the study is sorted out as follows. Section III explains the evolution of the antenna. Section IV is about the parametric analysis of the design, Section V discusses the simulation results, Section VI is on the MIMO metric, and finally Section VII presented the conclusion of the study. Throughout this article, we will focus on the MIMO antenna design within a limited space. Because of mutual coupling effects, all the antennas need to be considered as a single aperture, whether they are physically connected or not.

III. DESIGN EVOLUTION

The geometry of the two components, circular MIMO monopole, is pictured in Fig. 1(a, b). The model was actualized utilizing computer simulation technology (CST) version 2017. The patch array antenna is configured on a 1.6mm thick FR4 substrate with dielectric constant (4.3), and $\tan \delta = 0.025$. The framework comprises of two printed round patches on top isolated by an edge separation. Four slots were employed in both the upper layer and the bottom layer for improving the MIMO performance. Table 1 presented the optimized parameters of the antenna.

IV. PARAMETRIC ANALYSIS OF THE DESIGN

The parametric examination is displayed utilizing different values of R_s that is the radius of the slots from Fig. 1 to have an optimum value 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 various radius of the slot as can be seen from the plot. When the value of R_s is 2.6mm, the resulting S_{11} is perfect at that value. Therefore, we used 2.6mm as the radius of the slots for both the two reception apparatus. Even though the remaining plots are also within the range of -10dB, and can also have a good result. Still, with 2.6mm as the value of the radius, the performance has improved that's why the value is taken as the final value for the design and analysis of the proposed reception apparatus. 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.

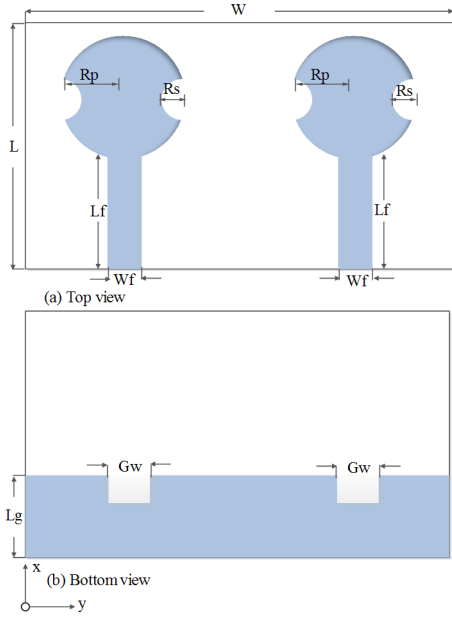


Fig. 1. System model; (a) top view, (b) bottom view

TABLE I. MIMO ANTENNA PARAMETERS

Optimized Antenna parameters			
Parameter	Size (mm)	Parameter	Size (mm)
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

Maintaining the isolation level throughout the UWB distance is one of the challenging tasks in the design and analysis of the UWB MIMO system. A physical limit is considered in which a proper distance between each element is presented, as shown in Fig. 1.

V. RESULTS AND DISCUSSION

The proposed two $\times$ two MIMO antenna is simulated using CST version 2017. The simulated impedance width is 2.7-12 GHz, as shown in Fig. 3. Fig. 4 is the simulated VSWR of the MIMO antenna; as can be seen, the result is less than two and

greater than 1. Fig. 5 is the simulated S_{21} of the 2 $\times$ 2 MIMO antenna, which is less than -15dB. The far-field radiation properties of the proposed UWB MIMO antenna are taken at 2.8 GHz, 4.5 GHz, 5.8 GHz, and 9.5 GHz, as presented in Fig. 6. We can see that the antenna radiation pattern is nearly omnidirectional.

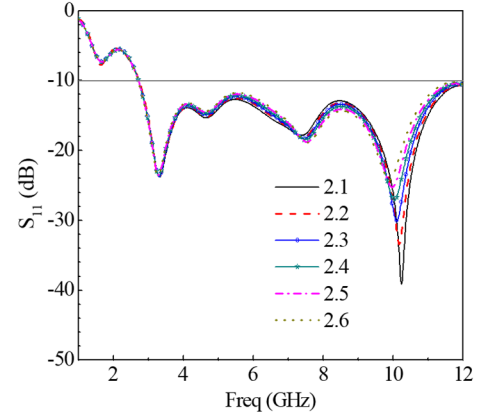


Fig. 2. S_{11} plot for various radius R_s (mm)

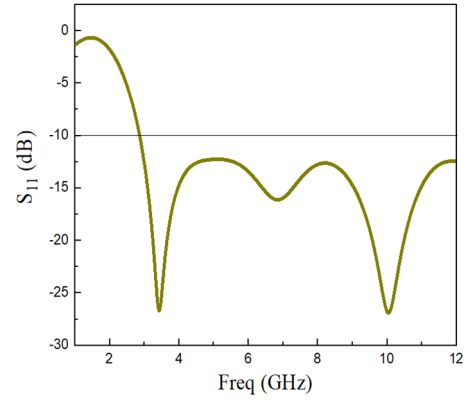


Fig. 3. Simulated S_{11} for the proposed antenna design

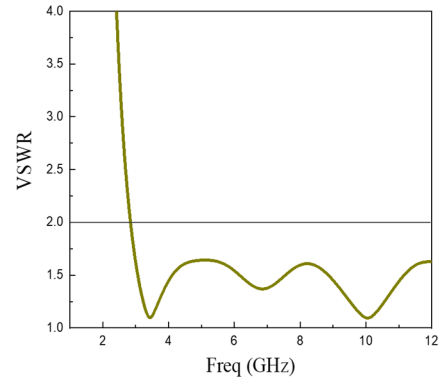


Fig. 4. Simulated value of VSWR for the proposed antenna design

VI. MIMO METRIC

In this section, several figures of merits are used to evaluate the performance of the proposed UWB/MIMO antenna. These are the Envelope correlation coefficient, total active reflection coefficient, channel capacity loss, and diversity gain. They are evaluated using the S-parameters that has been extracted from the electromagnetic solver.

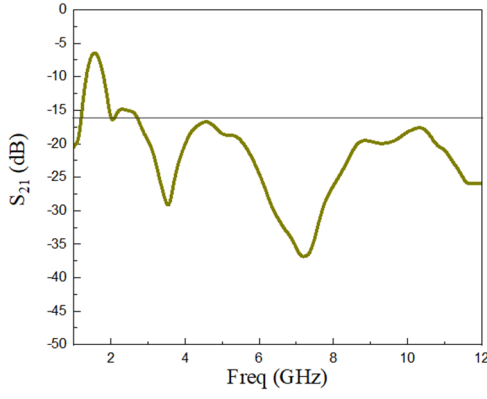


Fig. 5. Simulated S_{21} of the proposed antenna design

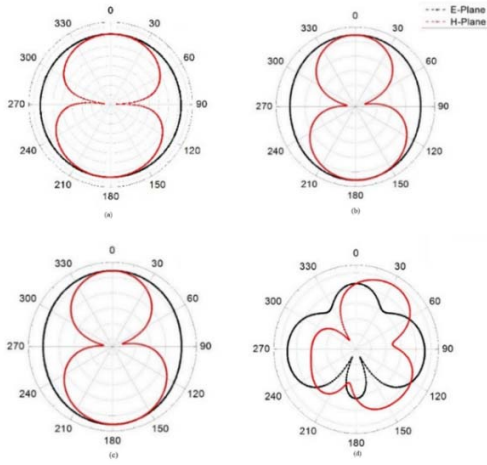


Fig. 6. Radiation pattern for circular shaped UWB antenna; (a) 2.8GHz, (b) 4.5GHz, (c) 5.8GHz, (d) 9.5GHz

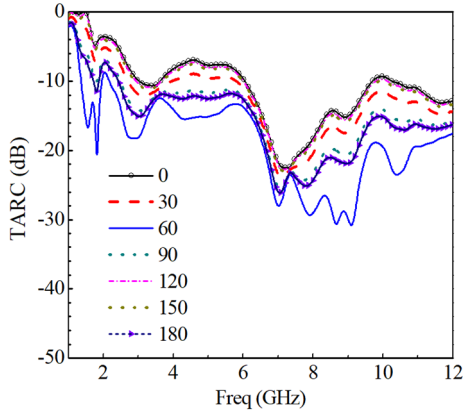


Fig. 7. TARC of MIMO antenna system when θ changed from 0 to 180°

To secure the capability of MIMO antenna, ECC and TARC are essential parameters to quantify signal interference between MIMO channels [17].

TARC can be computed for a 2×2 MIMO antenna using the following equation:

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

$$TARC = \frac{\sqrt{|S_{11} + S_{12}e^{j\theta}|^2 + |S_{22} + S_{21}e^{j\theta}|^2}}{\sqrt{2}} \quad (2)$$

where θ is the phase difference between the excitation difference of our MIMO antenna, the TARC plot of the MIMO antenna is given in Fig. 7, with a difference of θ from 0° to 180° with an interval of 30°. The plot reveals that

$0 \leq \Gamma_a^t \leq 1$. The ECC is computed from the S-parameter as calculated in equation (3).

$$ECC = \frac{|S_{11}^* S_{12} + S_{21}^* + S_{21}^* S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))(1 - (|S_{22}|^2 + |S_{12}|^2))} \quad (3)$$

Where S_{11} , S_{12} , S_{21} , and S_{22} is the parameter of the MIMO array. The proposed MIMO antenna ECC was calculated from 1 GHz to 12 GHz, as shown in Fig. 8, it can be observed that the value of ECC is less than 0.002 through the UWB bandwidth, which fulfils a good diversity standard for a MIMO system.

Channel capacity can be defined as a data rate that can be supported in a channel, and that channel is a fading environment [18]. Considering a high SNR value, CCL has been evaluated from simulated S-parameters using the equation (4) below [19].

$$CCL = -\log_2 \det(\psi^R) \quad (4)$$

ψ^R is the 2x2 correlation matrix in terms of S-parameters, which is,

$$\psi^R = \begin{bmatrix} \psi_{11} & \psi_{12} \\ \psi_{21} & \psi_{22} \end{bmatrix} \quad (5)$$

$$\psi_{11} = 1 - (|S_{11}|^2 + |S_{12}|^2) \quad (6)$$

$$\psi_{22} = 1 - (|S_{11}|^2 + |S_{21}|^2) \quad (7)$$

$$\psi_{12} = S_{11}^* S_{12} + S_{21}^* S_{12} \quad (8)$$

$$\psi_{21} = S_{22}^* S_{21} + S_{12}^* S_{21} \quad (9)$$

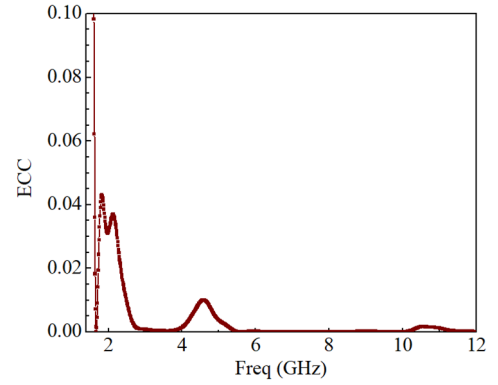


Fig. 8. ECC of the proposed antenna design

Based on the measured S-parameter, which is plotted in Fig. 9. The plot uncovers that the channel capacity loss is less than 0.35 over the whole UWB span, for the fact that in practical $CCL < 0.4 \text{ bps/Hz}$. The diversity gain of MIMO antennas can be computed from ECC using the relation [19].

$$DG = 10\sqrt{1 - ECC^2} \quad (10)$$

In Fig. 10, the diversity gain of nearly 10dB is depicted; this signifies that the antenna has low polarization diversity that can give low mutual coupling. Fig. 11 is the maximum gain through the whole ultra-wideband frequency.

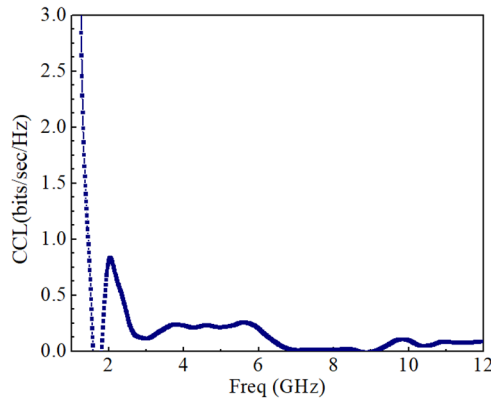


Fig. 9. CCL of the proposed antenna design

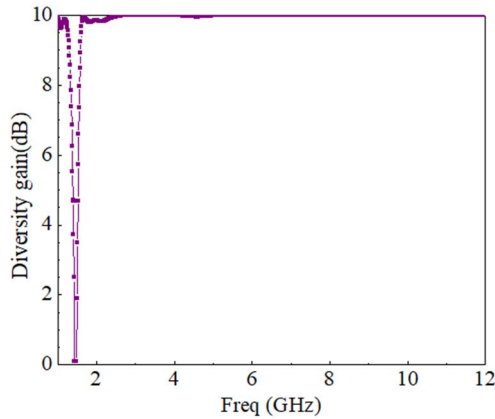


Fig. 10. Diversity gain of UWB/MIMO proposed antenna

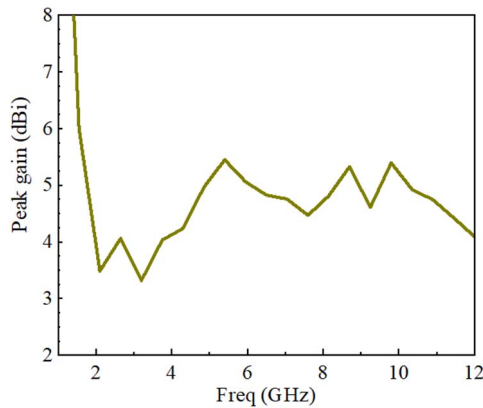


Fig. 11. Peak gain vs frequency

VII. CONCLUSION

This study presents a 2×2 UWB/MIMO antenna. The use of slots and the defected ground structure helps in improving the impedance matching and isolation of the antenna. Several diversity metrics such as ECC, DG, TARC, and CCL are found to be within acceptable limits. The proposed microwave circuit (antenna) is suitable for portable UWB wireless communication applications.

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