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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Isolated Magnetic Dipole MIMO Antenna with Linear Port Configuration for Wireless Applications

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DOI: https://doi.org/10.30880/ijie.2020.12.07.027
Received 3 September 2020; Accepted 12 October 2020; Available online 31 October 2020

Abstract: This paper is presenting preliminary research to design Isolated Magnetic Dipole MIMO Antenna for wireless application. Isolated Magnetic Dipole (IMD) structure is one of the unique geometries that offers compact and low damaging electrical current at the ground surface. However, less attention in discussing design the MIMO antenna using IMD structure. The two elements MIMO antenna using IMD with linear port configuration has constructed at 2.4 GHz. Then simulated and analyzed to validate the feasibility of the IMD-MIMO antenna. The simulation and analysis cover S-Parameters, radiation, Gain, Correlation coefficient, and diversity gain. In addition, simple Semi-circle structure etched on the ground layer to improve the isolation of MIMO antenna. From the simulation results, the IMD-MIMO antenna has better results and highly recommended for designing compact MIMO antenna.

Keywords: Simulation, Linear Configuration, Wireless, Semi-circle, MIMO

1. Introduction

Wireless communications have seen tremendously increased in the past few decades. Online meetings, online document transfer, and play games on many portable devices have become a reality. On the other hand, wireless applications for IoT also received high attention in creating versatile mobile application systems [1]. Today rapid technological advancements have taken place, and now everybody needs high speed internet data rates and portable wireless devices to remain connected worldwide. Meanwhile, healthcare wireless application also slowly developed for remote diagnostic [2]. To meet the high-speed requirement for mobile communication, a multiple-input-multiple-output (MIMO) technology has developed to effectively increase the channel capacity of the communication system in large scattering environments. Recently, many research papers are focusing on developing a MIMO antenna for mobile devices.

Designing a MIMO antenna is a challenging task mainly in minimizing the physical size, improving isolation, and offer low envelope correlation coefficient to utilize limited space and circuit board of mobile devices. Therefore, most of the multiple radiating elements the MIMO antenna are designing close to each and share the ground layer [3]–[6]. Consequently, it causes strong mutual coupling between radiating elements and contributes to low efficiency and gain degradation.

In the past few years, many compact MIMO antennas have proposed and accompanied by several isolation techniques [7]–[9]. The Dual-port single wideband Planar Inverted-F MIMO antenna has implemented by [10], where rectangular slot etched on the ground layer to minimize mutual coupling. Yagi-Uda structure with Folded Strip PIFA Driven Element proposed in [11]. The antenna can generate a dipole pattern through the back-to-back director and reflector elements.

However, the multiple lengths of the antenna element should design appropriately to differentiate the director and reflector elements. Another small size of MIMO antenna also presented using the meander-line structure and creates Split Ring Resonator (SRR) on the sides of each component to form a shorted ring at the antenna center for isolation improvement [12]. Meanwhile, S. Nandi et al. [13] proposed a slot antenna accompanied by two narrow and wide slots

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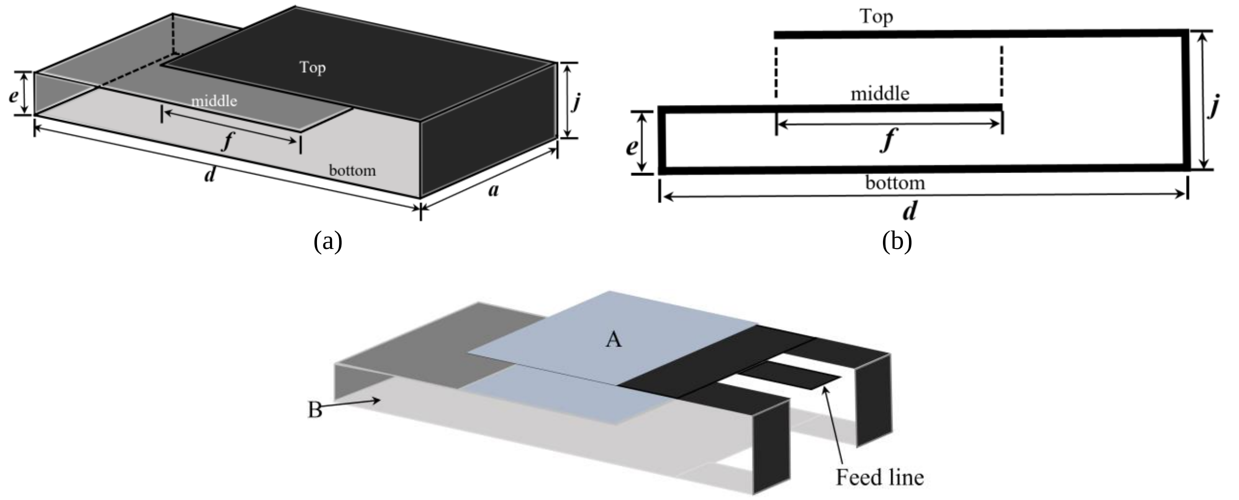
on the ground layer for isolation improvement. However, some of the proposed antennas must design precisely, need more decoupling structure on the ground layer. From our review, Isolated Magnetic Dipole (IMD) structure has the potential to offer a compact size of antennas, and strongly confined electric field, and high efficiency [14]. As a result, less damage electrical current on the ground will provide a simple isolation enhancement technique to minimize mutual coupling for close spaced MIMO radiating elements. However, only a few papers obtained in designing antenna using IMD geometry [15].

Based on a good background of the IMD antenna structure, this paper presents the MIMO antenna with a simple semi-circle slot on the ground layer to improve the isolation for the proposed antenna. However, this preliminary work is focusing on designing, simulating and optimizing a MIMO antenna using IMD structure with linear port configuration.

2. Antenna Design

Basically, the fundamental structure of the IMD antenna is referring to the idea that introduced by Rowson et al. [16]. This antenna contains a G-shape like. It is a folded metal strip with a three-layer structure, top, middle, and bottom, as shown in Figure 1(a) and (b). The antenna structure considered as a capacitive load and inductive loop. The capacitive load is depicted by the two overlap plates between area A and the middle area C, while inductive loop B formed by the connection of the bottom, middle, and top layers in Figure 1(c). Meanwhile, to create a proper current return, the antenna's base layer is directly connected to the ground, and the feed line is linked to the top layer. This geometry made the IMD produce damaging electrical current at the ground surface compared with PIFA antenna design.



(a) (b)

(c)

Fig. 1 - Proposed Structure of the IMD antenna; (a) Dimension used to determine the resonant frequency of the antenna; (b) Side view of the antenna to create opposite G shape; (c) Illustration of the Isolated Magnetic Dipole Antenna

From Figure 1 resonant frequency of the antenna can be predicted based on physical structure as shown in Figure 1 (c), and L and C equivalent circuits are obtainable from the following equations:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Where

$$L = \mu t\left(\frac{d}{a}\right) \tag{2}$$

$$C = \varepsilon\frac{af}{e} \tag{3}$$

Substitute equation (2) and (3) into equation (1), then:

$$f = \frac{1}{2\pi\sqrt{\varepsilon\mu\frac{dfj}{e}}} \tag{4}$$

From equation (4), the resonant frequency dominantly relies on the value of ***d, f, j***, and ***e***. while any changing of value ***a*** would not influence the antenna performance and resonance frequency.

3. Simulation and Optimization of MIMO Antenna

The MIMO antenna was modeled and simulated using CST Electromagnetic simulation software. Figure 2 depicts the single element of the radiating patch. Without significant modification, the structure is referring to the original pattern by Rowson et al. and using FR4 dielectric layer with a thickness of 1.575 mm and permittivity 3.7. The antenna was simulated and optimized to determine optimal size so that workable at frequency 2.4 GHz. Figure 2(a) represents the antenna without substrate, while Figure 2(b) shows the proposed IMD-MIMO antenna with two elements.

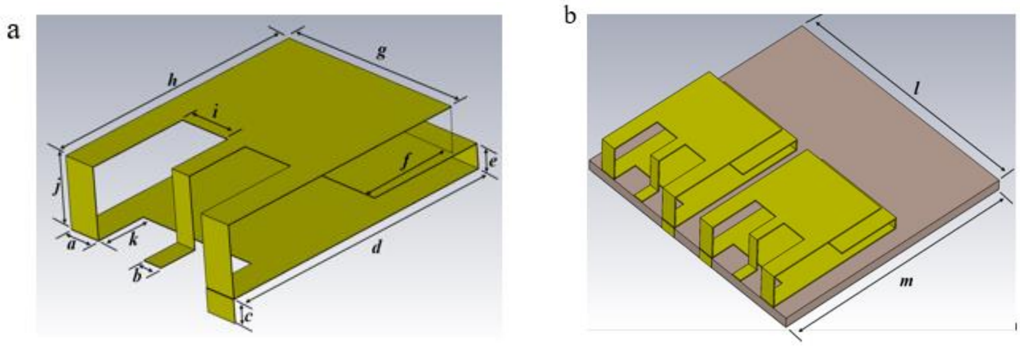


Fig. 2 - Physical dimensions of patch antenna; (a) Antenna structure; (b) Antenna structure with the substrate layer

For the initial research, the antenna designed operates at 2.4 GHz for wireless systems. Table 1 is listing the total dimension of the proposed MIMO antenna.

Table 1 - Dimensions of the physical antenna

Symbol	Dimension (mm)
a	2.50
b	1.60
c	1.60
d	22.97
e	1.90
f	7.63
g	15.00
h	20.00
i	4.20
j	5.04
k	4.00
l	35.00
m	40.00

4. Result and Discussion

The research findings from the simulation and optimization of the proposed MIMO antenna will discuss in this section. The discussion will cover S-parameters, Antenna propagation, gain, diversity gain, and correlation coefficient. Figure 3 shows the result of S-parameters, S_{11}, S_{22}, S_{12}, and S_{21}. Figure.3 shows that the antenna is resonant at 2.4 GHz by covering the frequency range from 2.284 GHz until 2.542 GHz. Also, it has proper matching by referring to the value of S_{11} and S_{22}.

From the simulation and optimization process, values of S1 and S22 are nearing to -40 dB. Meanwhile, S_{12} and S_{21} both are below -20 dB at space between two elements at 5.21mm. Based on the values of S_{12} and S_{21}, it indicates that the MIMO antenna has low mutual coupling, and this level is agreed with pervious papers as an essential requirement for the MIMO antenna.

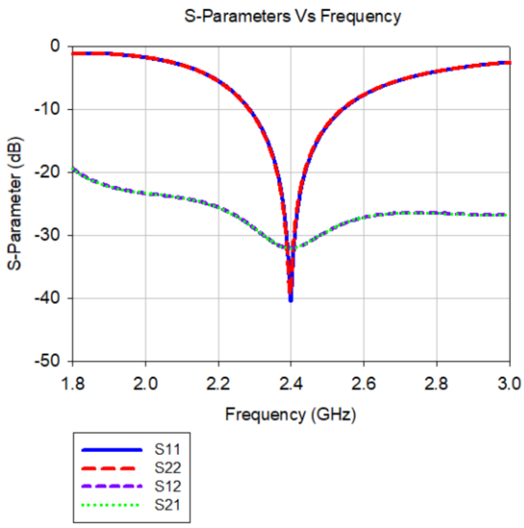


Fig. 3 - The values S-Parameters MIMO Antenna

The simulation results of the radiation pattern for the proposed antenna are illustrated in Figure 4 for E field and Figure 5 for H field. These results show the E and H fields for antenna 1 and antenna 2 at 2.4 GHz operating frequency. In Figure 4 and Figure 5, the radiation pattern slightly tilted $\pm$ 12 degrees based on the current distribution for each port excitation of antenna 1 and antenna 2.

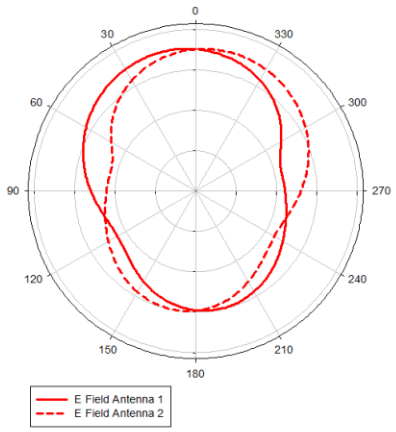


Fig. 4 - E Fields for MIMO Antenna

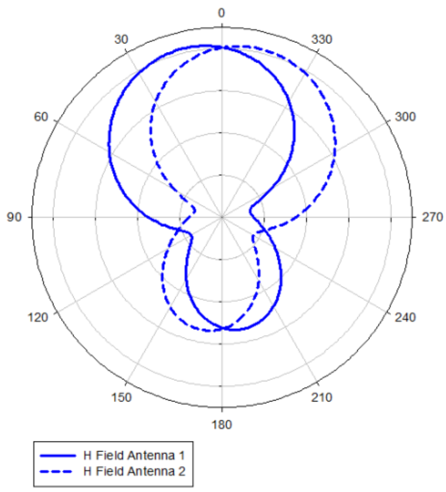


Fig. 5 - H Fields for MIMO Antenna

The conjunction with the radiation results from Figures 4 and 5, antenna 1, and antenna 2 generate gain nearly close to each other, as shown in Figure 6. Specifically, each antenna produces gain 2.98 dB and 2.96 dB, respectively. Meanwhile, the efficiency from antenna 1 is 96.8%, and antenna 2 is 96.7%.

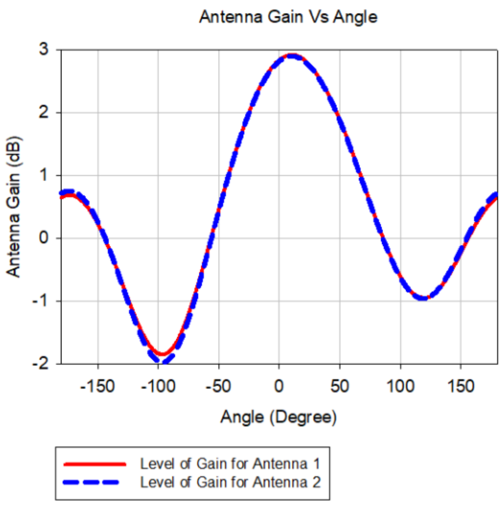


Fig. 6 - Antenna Gain for MIMO Antenna

As the mutual coupling between the antenna elements deteriorates the efficiency and gain of the MIMO antenna system, decoupling structures are utilized between the antenna elements to enhance isolations. Commonly, several approaches have been introduced in improving the antenna isolation of MIMO antenna, such as decoupling networks, neutralization lines, Defected Ground Structure (DGS), and so on. Even though IMD structure has low damaging electrical current at the ground surface to provide small structure, the mutual coupling effect still exists due to the very close space between antenna 1 and antenna 2. This high mutual coupling is illustrated by values of S_{12} and S_{22} in Figure 7, from the figure, both S-Parameters S_{12} and $S_{22,}$ almost at -10.52 dB, which is out of the minimum requirement for isolation at -15 dB.

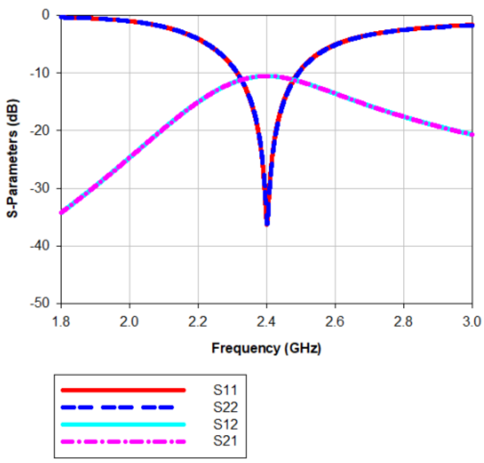


Fig. 7 - S-Parameters without semi-circle slot on the ground layer

However, the good background of IMD structure could help in designing uncomplicated DGS geometry to improve antenna isolation. Therefore, in this paper, a simple semi-circle slot structure proposed and simulated to minimize the mutual coupling effect between two antennas. Figure 8 shows the semi-circle slot structure etched on the ground surface of the MIMO antenna. The dimension of the semi-circle slot structure (*dm*) is 0.8 mm radius, where outer radius (*od*) 20 mm and inner radius (*id*) 19.20 mm. The simple slot structure able to isolate the energy from port antenna 1 and antenna 2.

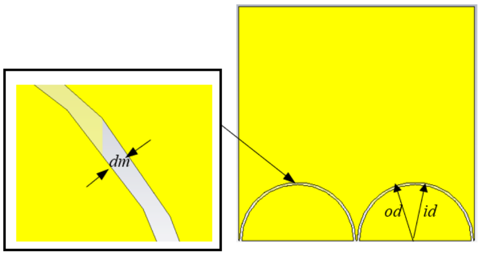


Fig. 8 - Semi-circle slot structure etched on the ground layer

The isolation performance of the proposed antenna also has verified by investigating the surface current distribution of the antenna. Figure 9(a) shows the port 1 excited, while port 2 terminated. Inversely, Figure 9(b) shows the port 2 excited and port 1 is terminated. Notice that this condition is presenting the proposed antenna without the semi-circle structure. From the figures, it can observe that the high mutual coupling exists between the two antennas if port 1 and vise-versa. By adding two semi-circle slots on the ground layer, the mutual coupling is extremely reducible, if port 1 and port 2 are interchange excited and this response is depicted in Figure 10 (a) and (b).

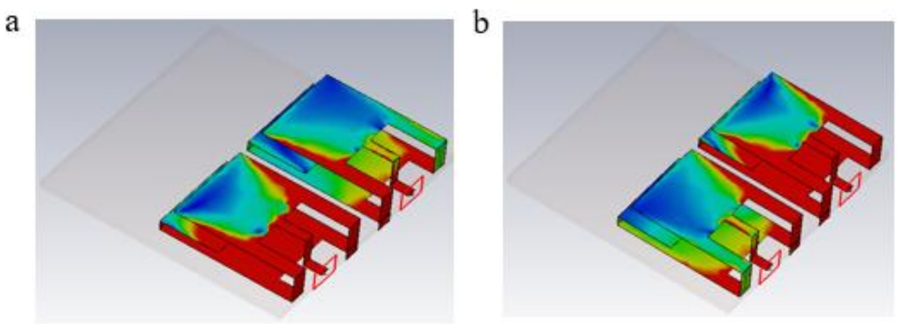


Fig. 9 - Surface current of the antenna; (a) Antenna 1; (b) Antenna 2 without defective ground structure

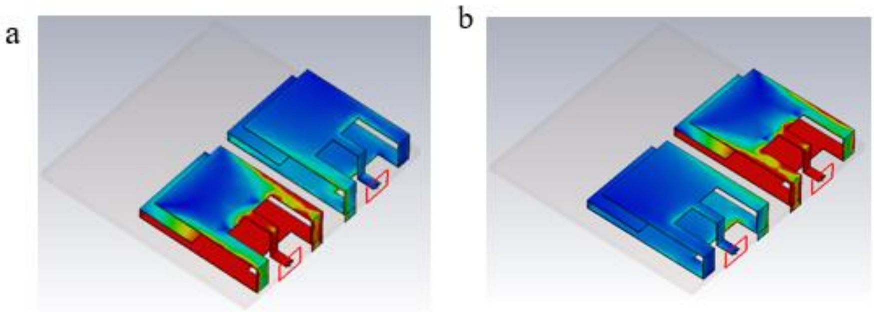


Fig. 10 – Surface current of the antenna; (a) Antenna 1; (b) Antenna 2 with semi-circle slot

The performance of the proposed MIMO antenna is further evaluated by plotting correlation coefficient and diversity gain. Correlation coefficient is purposely to correlate the element spacing in order to ensure port 1 and port 2 have low correlation to minimize gain degradation. Meanwhile, diversity gain is importance to identify the ratio of gain to interference of the antenna with two ports. As shown in Figure 11, diversity gain near to 10, while the correlation coefficient below 0.00051 between 2.284 GHz – 2.542 GHz.

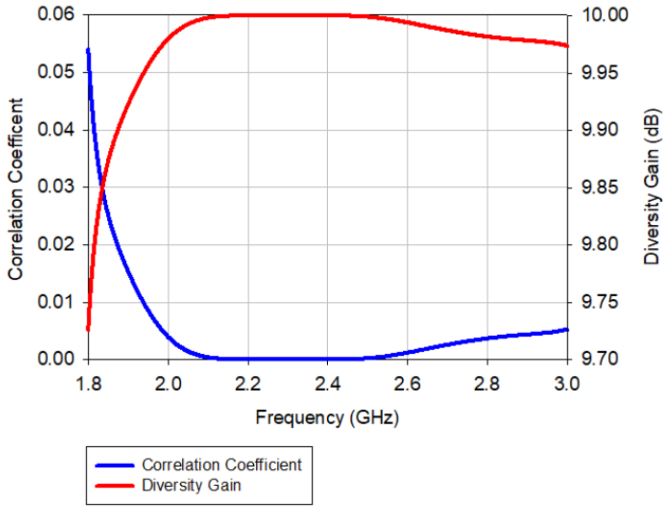


Fig. 11 - Correlation Coefficient and Diversity Gain for MIMO antenna

5. Conclusion

In the initial research, the small size of MIMO antenna has designed using IMD structure with a simple semi-circle slot structure on the ground layer purposely to improve isolation between two elements of the radiating patch. Aimed at the operating frequency of 2.4 GHz, the results of S-Parameters, radiation, and Gain that obtained from simulation show that the antenna performs well. Meanwhile, simulation results for the Correlation coefficient and diversity gain indicate that two antennas can work independently. Moreover, two simple semi-circle slots etched on the ground layer promise technique to improve the isolation between two radiating elements. However, additional characteristics to verify the capability of MIMO antenna physically still not discussed, and it will be the next task in the research.

Acknowledgment

This study was granted by Department of Research and Industrial Linkages, Universiti Teknologi MARA Terengganu Branch under the Dana Kecemerlangan SIG with the project code 600-UiTMCTKD (PJI/RMU/ST/DANA SIG 5/2/2) Dst (08/2019).

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