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Development of MIMO antenna with decoupling structure for ultra-wideband application

Muhammad Aslam Hasin, M. T. Ali, Hamizan Yong, Bazilah Baharom, Hadi Jumaat
Antenna Research Centre (ARC), Faculty of Electrical Engineering, University Teknologi Mara (UiTM), Malaysia

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ABSTRACT

This paper presents the design of a double-sided Multiple-Input Multiple-Output (MIMO) antenna with a decoupling structure for Ultra-WideBand (UWB) applications. The proposed antenna consists of four square radiating elements printed on FR-4 substrate with partial slotted ground. The substrate consists of two sides and each side are consisting of two slotted partial ground and two square radiator antennas. The elements of the front side are orthogonal to the elements of the back side because it was to increase the isolation of the antenna. The front and back sides of the substrate were also presented with the decoupling structure to avoid the mutual coupling of each antenna. The results of simulated and measured of the proposed UWB MIMO antenna are observed and analyzed. The objective of the UWB MIMO antenna was achieved that large bandwidth of return loss below than -10 dB from 3.3 GHz to 11GHz with an insertion loss lower than -20 dB within the required frequency band. The proposed MIMO antennas exhibits a nearly Omni-directional radiation pattern with average gain value 4.36 dBi.

Corresponding Author:

Muhammad Aslam Bin Hasin,
Antenna Research Centre (ARC),
Faculty of Electrical Engineering,
University Teknologi MARA (UiTM),
40450, Shah Alam, Selangor Darul Ehsan, Malaysia.
Email: aslam7484@gmail.com

1. INTRODUCTION

In the development of modern communication, the ultra-wide band (UWB) technology play an interest to the researcher since the high data rate demand with a limited range in lower power spectral level [1] in order to protect the interference of UWB system from other existed wireless systems [2-3]. In numerous wireless applications, the technology of UWB becomes more tempting and bring attention to all researchers as the Federal Communication Commission (FCC) released the ultra-wide band (UWB) technology that operates from 3.1 to 10.6 GHz [1-2]. Larger bandwidth with stable radiation, compact size, and low profile are the challenges in order to design UWB antenna [5-7]. Moreover, when dealing with the compact size of the MIMO antenna, it will introduce mutual coupling that will limit the channel capacity of the system [4-6]. Multiple-input Multiple-output (MIMO) technology was used to overcome the Multipath fading that is one of the main problems that causes the performance of the UWB system to be downgraded [11-13]. The distance between elements of the MIMO system should be more than half lamda of the lowest operating frequency in order to avoid the mutual coupling between elements [14-16]. However, this method also increases the size of the MIMO antenna. For the proper performance in a MIMO system, the isolation between elements must be less than -15 dB [14], [17-18].

In this paper, four elements have been mounted on a 4 cm × 4 cm on a FR4 substrate of compact MIMO_UWB antenna. This is done to ensure that the allocated bandwidth for application of UWB from 3.3 GHz until 11.0 GHz has been satisfy. After decoupling structure between elements on the top and bottom layers has been placed, the insertion loss exceeds -20 dB has been achieved throughout the entire UWB frequency. The antenna was designed, optimized and simulated using CST Microwave Studio software. The antenna measurement system was used to measure the impedance and radiation of experimentally fabricated antenna characteristics. The proposed MIMO-UWB antenna was confirmed of having a wider impedance bandwidth and higher isolation by the simulated and measured results performance thus make it appropriate for the UWB systems.

2. RESEARCH METHOD

2.1. The Single Element of UWB Antenna

The single-element of the ultra-wideband antenna is shown in Figure 1. The antenna with small size 2 cm x 2 cm was designed and simulated by using CST Microwave Studio 2015. The FR-4 was used as the substrate material of the antenna with dielectric-constant = 4.4 and thickness = 1.6 mm. From Figure 1(a), it shows that the microstrip patch antenna consists the square shape of radiating element and the microstrip line feed as the feeding method was chosen since it is simple to match and easy to analyze [19-20]. From Figure 1(b), it shows that the back view of the antenna that consists of the partial ground with a slotted rectangular shape in order to increase the bandwidth of the antenna [21-23]. The simulated result of the return loss of the single-element of the antenna is shown in Figure 2. From Figure 2, it shows that the antenna has a large bandwidth of 6.7 GHz that can operate from frequency of 4.3 GHz to 11 GHz with the magnitude of return loss below than -10dB between that range. Therefore, it was claimed that the range of operating frequency of the antenna was the ultra-wideband.

(a) Front view (b) Back view

Figure 1. 2D structure of the UWB single antenna

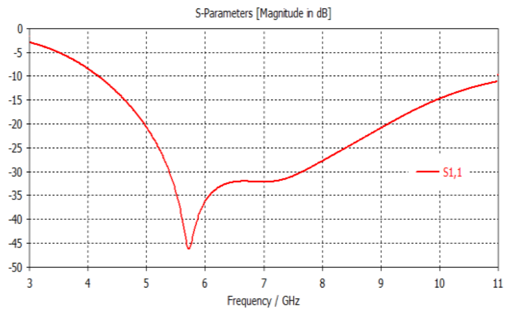


Figure 2. Return loss [dB] of single antenna

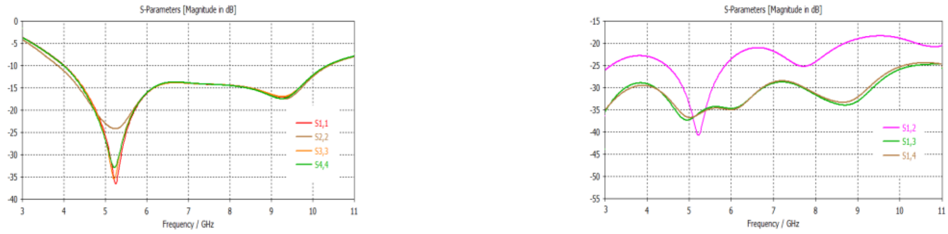
2.2. The Multi-Element of UWB Antenna

The multi-element of the ultra-wideband antenna is shown in Figure 3. The single-element design from Figure 1 was duplicated into four elements to make the multi-element of UWB antenna. The same design and material of the substrate are used that makes the size of the antenna increase to 4 cm x 4 cm. From Figure 3, it shows that the double-sided antenna with the arrangement of each element is orthogonal to each other. Two square radiating elements which are port 1 and port 2 shows in Figure 3(a) was placed at the front of the antenna and another two square radiating elements, port 3 and port 4 are placed at the back side of the antenna as shown at Figure 3(b). The multiple radiating elements of the antenna for the ultra-wideband application is called UWB_MIMO antenna.

(a) Front view (b) Back view

Figure 3. 2D structure of the UWB_MIMO antenna

The simulated result of s-parameter for UWB_MIMO antenna shown in Figure 4. Based on Figure 4(a), it clearly shows that the return loss with a magnitude below than -10dB is from 4 GHz to 10.4 GHz with a bandwidth of 7 GHz. It also shows that the operating frequency for all port (1,2,3,4) is similar since it is the same design. The insertion loss [dB] for UWB_MIMO antenna is shown in Figure 4(b). From Figure 4(b), it is obviously shows that the insertion loss [dB] between port 1 to port 2 (S1,2), port 1 to port 3 (S1,3), and port 1 to port 4 (S1,4) is below than -15 dB for all operating frequency which means the good isolation between radiating element.



(a) Return loss at port 1 (b) Insertion Loss at port 1

Figure 4. S-Parameter of the UWB_MIMO antenna

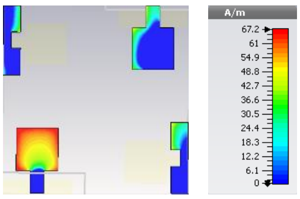


Figure 5. Surface current distribution of the antenna Port 1 at 5.25 GHz

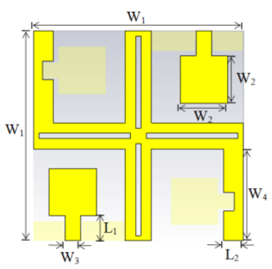
The distribution of the surface current between each element was observed in Figure 5. Based of Figure 5, it shows that when port 1 is excited, the amount of surface current also distributes to the port 2. This situation was known as mutual coupling since the antenna has a multi-radiating element on a compact size of the antenna [24-26]. When dealing with MIMO, it also deals with the mutual coupling that will affect the performance of UWB_MIMO antenna.

2.3. The Proposed UWB_MIMO Antenna with Decoupling Structure

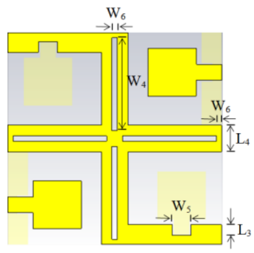
The decoupling structure is one of the methods to prevent the antenna from the mutual coupling [27-28] that detected in Figure 5. The proposed UWB_MIMO antenna with the decoupling structure was shown in Figure 6 and the parameter of each shape also shown in Table 1. From Figure 6, it shows that the decoupling structure consists of four rectangular removed slots in order to block the distribution of surface current to other port. As seen in Figure 6(a), it shows that the decoupling structure is connecting to the partial_slotted ground at port 3 and 4. While the decoupling structure on the back side of the antenna was connected to the partial_slotted ground at port 1 and 2 is shown in Figure 6(b). The purpose of connected the decoupling structure to the ground is to neutralize the surface current and increase the gain of the antenna.

Table 1. The Dimensions of the Proposed UWB_MIMO Antenna

W_1	W_2	W_3	W_4	W_5	W_6	L_1	L_2	L_3	L_4
40	9	3.943	17.5	3.5	1	4.75	3.75	2	5



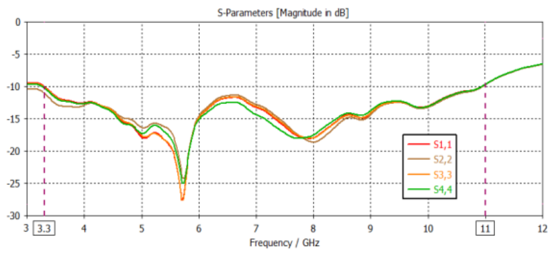
(a) Front view



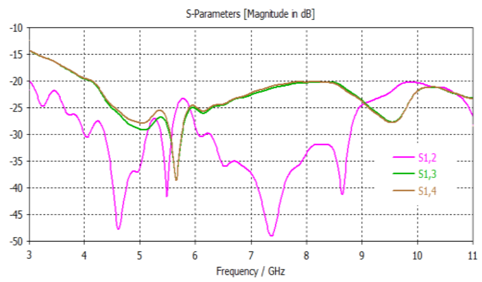
(b) Back view

Figure 6. 2D structure of the proposed UWB_MIMO antenna

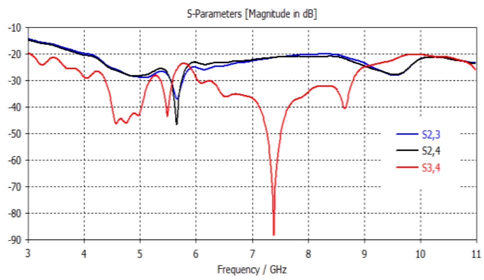
The simulated result of S-Parameters is shown in Figure 7. From Figure 7(a), it shows that the return loss that below than -10 dB is from 3.3 GHz to 11 GHz for all port (1, 2, 3, 4). It is proved that return loss signal pattern is similar between each other port and the bandwidth also increase by 7.7 GHz. Figure 7(b) and 7(c) also show the insertion loss of the proposed UWB_MIMO antenna. From Figure 7(b), it shows that when port 1 is excited and another port is connected to 50 *Ω* matched load, the isolation is below than -20 dB for entire operating frequency. The same result also notice at Figure 7(c) when the excitation at port 2, 3, and 4, the isolation also below than -20 dB for the entire operating frequency.



(a) Return loss [dB] of the proposed UWB_MIMO antenna for port 1, 2, 3, and 4



(b) The insertion loss [dB] excitation at port 1



(c) The insertion loss [dB] excitation at port 2, 3, 4

Figure 7. S-Parameter of the proposed UWB_MIMO antenna

The surface current of the proposed UWB_MIMO antenna at 5.7 GHz of port 1 was shown in Figure 8. From Figure 8, it clearly can be noticed that when antenna 1 is excited, the surface current did not distribute to the port 2. It shows that the design of the decoupling structure reduces the mutual coupling of the MIMO antenna. The comparison of simulated gain before and after applying the decoupling structure is shown in Figure 9. From Figure 9, it can be concluded that the decoupling structure also increases the gain of the antenna.

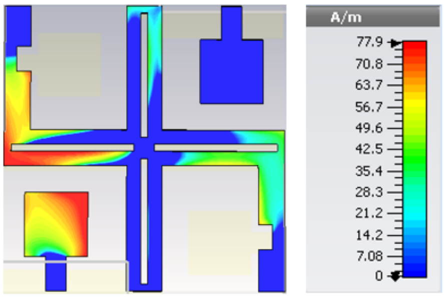


Figure 8. Surface current distributions of the proposed UWB_MIMO antenna at 5.7 GHz

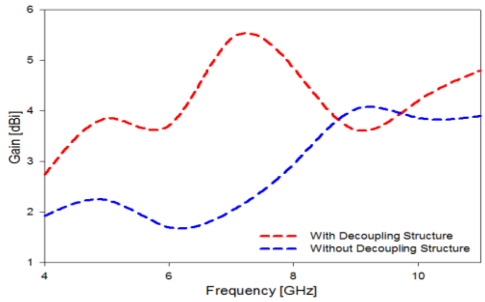


Figure 9. The simulated gain of the antenna at port 1 with and without using the decoupling structure

3. RESULTS AND ANALYSIS

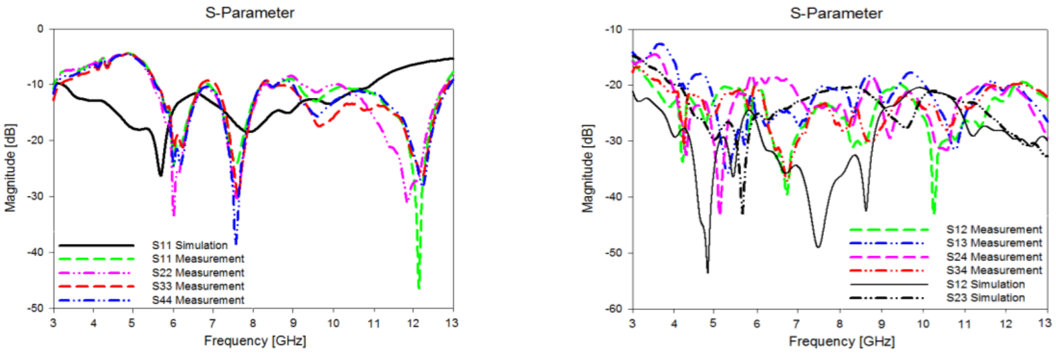
3.1. Performance Measurement of the Proposed UWB_MIMO Antenna

The FR-4 board is chosen as the substrate material of the antenna with dielectric-constant = 4.4 and thickness = 1.6 mm. The final design has been fabricated as shown in Figure 10. From Figure 10, the antenna was soldered to a 50 *Ω* SMA connector port for connect to the external devices such as measurement devices.

(a) Front view (b) Back view

Figure 10. The fabricated of the proposed UWB_MIMO antenna

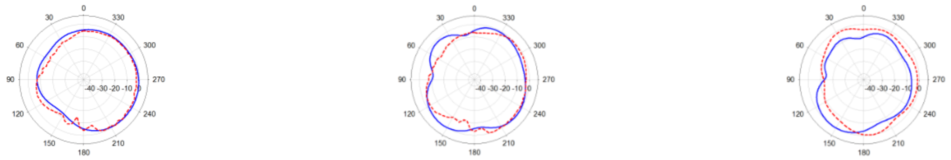
The magnitude of S-Parameters of the antenna has been tested by using Vector Network Analyzer (VNA) and the comparison between simulated and a measurement result are shown in Figure 11. From Figure 11(a), it shows that the measured proposed UWB_MIMO antenna with a magnitude that below -10 dB can operate from 5.6 GHz to 12.8 GHz for all port (1, 2, 3, 4) with the bandwidth of 7.2 GHz. The return loss of the measured was shifted to the right compared to the simulated result due to error accuracy of the fabrication process. The size of a radiated element on fabricated MIMO antenna was decreased by a few millimeters during the fabrication process. Therefore, the operating frequency of UWB_MIMO antenna also changes from 5.6 GHz to 12.8 GHz. Theoretically, the smaller size of the radiating element will increase the frequency. From Figure 11(b), it shows the insertion loss of measured result is below than -18dB for all operating frequency which means that it is good isolation between elements.



(a) The return loss (b) The Insertion loss

Figure 11. The S-Parameters of the proposed UWB_MIMO antenna

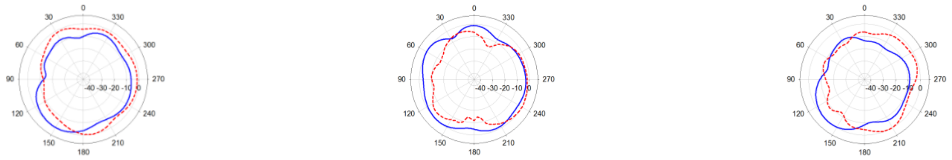
The radiation pattern measurement has been done using a chamber room with a range of operating frequency from 6 GHz to 11 GHz. The 2D polar plot of the radiation pattern at frequency 6 GHz, 7.5 GHz, and 9.5 GHz are shown in Figures 12, 13 and 14. From Figures 12, 13 and 14, it shows three different planes of simulated and measured for the radiation pattern. The measured result is quite similar to the simulated result that has the radiation pattern nearly to the omnidirectional that is good for UWB application.



(a) XZ_Plane (b) YZ_Plane (c) XY_Plane

Measurement - - - - - - Simulation ———

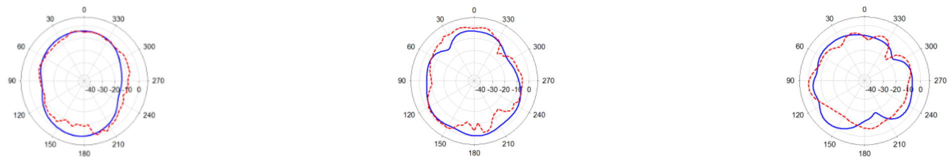
Figure 12. The 2D polar plot radiation pattern at 6 GHz of port 1 for proposed UWB_MIMO antenna



(a) XZ_Plane (b) YZ_Plane (c) XY_Plane

Measurement - - - - - - Simulation ———

Figure 13. The 2D polar plot radiation pattern at 7.5 GHz of port 1 for proposed UWB_MIMO antenna



(a) XZ_Plane **(b)** YZ_Plane **(c)** XY_Plane

Measurement Simulation

Figure 14. The 2D polar plot radiation pattern at 9.5 GHz of port 1 for proposed UWB_MIMO antenna

The comparison between the measured and simulated peak gain is shown in Figure 15. Since the simulated operating frequency is from 3.3 GHz to 11 GHz while the measured operating frequency is from 5.6 GHz to 12.8 GHz, therefore the range of operating frequency from 6 GHz to 11 GHz is chosen because it is easy to compare. From Figure 15, it shows that the peak gain of simulated and measured was similar. The average gain for measured is 4.36 dBi while the average gain for simulated is 4.44 dBi.

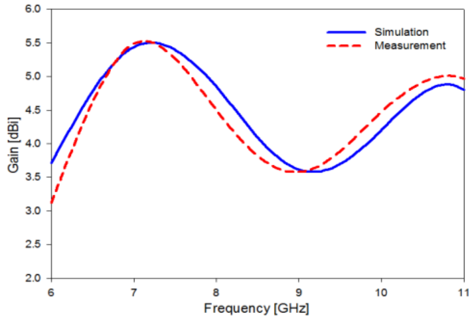


Figure 15. The peak gain of simulated and measured UWB_MIMO antenna

4. CONCLUSION

Development of MIMO Antenna with decoupling structure for Ultra-Wideband Application has been proposed with small size 4 cm x 4 cm. Each radiating elements and ground are orthogonal to each other for both sides of the substrate. The decoupling structure has been designing and connected to the two-slotted partial ground at both sides of the substrate to decrease the mutual coupling and increase the gain performance of the antenna. The simulated and measured result has been observed and analyzed in term of the reflection coefficient, insertion loss, surface current, gain, and radiation pattern to see the performance of the antenna. The bandwidth for simulated and measured was within 7 GHz is achieved, hence, it is still in the criteria of the ultra-wideband application. The insertion loss of simulated and measured antenna is below than -18dB for the entire operating frequency with the average gain value 4.36 dBi.

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BIOGRAPHIES OF AUTHORS

Muhammad Aslam Hasin was born in Kuala Terengganu on February 17, 1995. He received the Diploma in Electrical Engineering (Power) from Universiti Teknologi MARA (UiTM) Dungun, Terengganu, Malaysia in 2015. In 2019, he completed his Bachelor Degree in Electronic Engineering (Communication) from Universiti Teknologi MARA (UiTM) Shah Alam, Selangor, Malaysia. Now he is working as Research Assistant at Antenna Research Centre (ARC) Faculty of Electrical Engineering, Universiti Teknologi MARA.

Mohd Tarmizi Ali received the B.Eng. degree in electrical engineering from the Universiti Teknologi Mara (UiTM), Shah Alam, Malaysia, in 1996, the M.Sc. degree in electrical engineering from the University of Leeds, Leeds, U.K., in 2002, and the Ph.D. degree in electrical engineering from the Universiti Teknologi Malaysia (UTM), Johor, Malaysia, in 2010. On October 2018, he has been a Professor with the Faculty of Electrical Engineering (FKE), UiTM, and since 2011 he has been appointed as the Group Leader of the Antenna Research Center (ARC), FKE UiTM. He is a senior member for the IEEE and the member for the Antenna Propagation/Microwave Theory and Technology/Electromagnetic Compatibility (AP/MTT/ECM) Joint Chapter. His research interests include the areas of communication antenna design, radio astronomy antennas, satellite antennas, and electromagnetic radiation analysis.

Hamizan Yon was born in Muar Johor on February 07, 1980. He received the Bachelor Information Technology with Network Computing from Open University Malaysia in 2013. In 2017, he completed his Master in Electrical Engineering (Communication) with Antenna Research Centre (ARC) Faculty of Electrical Engineering, Universiti Teknologi MARA. Now he pursuing his PhD at Antenna Research Centre (ARC) Faculty of Electrical Engineering, Universiti Teknologi MARA. In 2009 he join Universiti Teknologi MARA at Shah Alam campus as Assistant Lecturer. Active in research activates, he is one of the members of fundamental research grant (FRGS) under Minister of Higher Education and UiTM Lestari grant. As academician, Hamizan also member of The Institution of Engineering and Technology that actively presenting and publishing research activities at national and international levels.

Bazilah Baharom born in Penang, Malaysia on September 5, 1994. She received a Bachelor Engineering degree (HONS) Electronic Engineering from Universiti Teknologi MARA, Malaysia in 2018. Now she pursuing her Master of Science (Electrical Engineering) at Antenna Research Centre (ARC) Faculty of Electrical Engineering, Universiti Teknologi MARA. Currently, she is active in research activities and interests are on antennas and she is one of the members of a fundamental research grant (FRGS) under Minister of Higher Education grant

Hadi Jumaat is a student at the Universiti Teknologi MARA (UiTM), Selangor, Malaysia. He received the B. degree in engineering electronics (communication) (2012) and M.Sc. degree in electrical engineering (2015) from the Universiti Teknologi MARA (UiTM), Selangor, Malaysia. He is currently working towards the Ph. D. degree in electrical engineering at Universiti Teknologi MARA. His research interests are in communication antenna design.