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A MIMO ANTENNA DESIGN CHALLENGES FOR UWB APPLICATION

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Abstract—This paper proposes a compact printed ultra-wideband (UWB) multiple-input-multiple-output (MIMO) antenna with a dimension of $38 \times 91\,\mathrm{mm}^2$. The presented UWB-MIMO antenna comprises two identical patch elements with D separation distance on the same substrate. The basic single antenna structure has a novel design comprising seven circles surrounding a center circle with partial ground plane implementation. Furthermore, the experimental antenna has peak gain of 5.3 dBi between an operating frequency of 2.8 GHz and 8.0 GHz under a minimum reflection coefficient of less than −10 dB ($S_{11} < -10$ dB). Moreover, the antenna successfully achieved mutual coupling minimization of < -17 dB, eventually resulting in enhancement of radiation efficiency. Besides, the UWB-MIMO's correlation coefficient was effectively reduced to less than −22 dB, which reflected an improvement in the antenna's diversity. In this paper, the proposed antenna is examined both numerically and experimentally.

1. INTRODUCTION

UWB communications have received a lot of publicity in terms of future technology regarding high data rate and short-range transmission [1–5]. Moreover, the UWB spectrum released in April 2002 by the

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Federal Communication Commission (FCC) in the United States is the required technology that fulfills the needs of healthcare provision. Permitted commercial UWB devices must be considered for a working spectrum frequency of 3.1 GHz to 10.6 GHz with a low-power spectral density (PSD) not exceeding −41.3 dBm/MHz [6].

Recently, a lot of UWB antennas have been developed and established. A novel compact UWB antenna with high impedance bandwidth with the idea of a rectangular waveguide has been introduced [7]. A planar dipole antenna consisting of two semi-elliptical-ended arms connected by a shorting bridge capable of enhancing the antenna's impedance and gain throughout UWB operating bandwidth is studied [8]. The interesting approach of implemented RF switches (PIN diode) at the feed line achieves a reconfigurable planar monopole antenna [9]. A microstrip square-ring slot antenna (MSRSA) attains UWB frequency range by splitting the square-ring slot and optimizing the feeding network [10].

Owing to its high capacity and high-speed wireless communication concentration, many researchers have focused on the multiple-input-multiple-output (MIMO) antenna [11, 12]. MIMO requires several transmitter and receiver antennas that function simultaneously. The development of the MIMO antenna functioning on a UWB spectrum frequency helps to overcome multipath propagation with non-line-of-sight (NLOS), eventually resulting in the attainment of more accurate data. Moreover, the MIMO antenna enhances channel capacity (bits/Hz) by increasing the spectrum efficiency of the channel using Equation (1) [13, 14].

$$C_{MIMO} = \log\left[\det\left(I_{M_R} + \frac{SINR}{M_T} HH^H\right)\right] \tag{1}$$

M_T and M_R are the numbers of transmitters and receivers, respectively. While I_{MR} is the identity matrix, $M_R \times M_R$, and H is a $M_T \times M_T$ matrix. Referring to Equation (1), the capacity of MIMO can be increased because of the increase in transmitter and receiver antenna.

However, significant issues need to be overcome to enhance the effectiveness of MIMO. These include very low mutual coupling, low correlation, high diversity gain, and low total active reflection coefficient (TARC) [15–17]. As in [18], the performance of two equal antennas is discussed in terms of the antennas positioning effect of 0°, 90°, and 180° towards mutual coupling, correlation coefficient, and radiation pattern. The two non-symmetrical antennas with minimum distance achieve low mutual coupling preserving UWB operating frequency according to FCC standards.

This research proposes a compact MIMO antenna with two port symmetrical radiating elements on the same substrate. The antenna's radiating element consists of seven small circles surrounding the center single circle with a $50\,\Omega$ microstrip line feed. The seven small circles (7 filters) function as a filter. In [19, 20], such filters developed from the external circuit eventually increase the antenna's complexity and dimensions. To the author's knowledge, so far, there have been no such antennas that merge a filter into the antenna's design. Furthermore, the 7-filters dimensions significantly influence the antenna's impedance matching. For this design, the partial ground plane function as tuning circuit for the antenna's matching network.

The MIMO antenna has successfully functioned for UWB operating frequency of 2.8 GHz to 8 GHz, with good impedance matching of −54 dB. Besides, the attainable UWB-MIMO's gain of 6dBi is considered high compared to conventional antenna [21]. Moreover, the UWB-MIMO antenna with its advantages of high bandwidth, and handy and compact size (91 mm × 38 mm) is accessible for wireless communication systems [22–26]. To the authors' knowledge, the MIMO antenna's reflection coefficient, mutual coupling, and correlation coefficient need to be analyzed collectively as they are intimately related to each other. Hence, this research focuses on the minimization of the mutual coupling and the correlation coefficient since a lower mutual coupling increases radiation efficiency while a lower correlation coefficient improves antenna diversity. Moreover, this paper presents a parameter optimization routine on the inter element spacing (IES) varying from 0 mm to 40 mm towards reflection coefficient, mutual coupling, and correlation coefficient. The three parameters' optimum results reflect the ultimate antenna configuration.

Based on the simulation result performance, the IES is set to 15 mm with low mutual coupling of < -17 dB and a minimum correlation coefficient of < -22 dB compared to that presented in [16, 19, 27]. Then, the antenna is fabricated and measured on impedance performance, radiation performance, and correlation coefficient performance. The success of the experimental antenna performances means that the antenna is suitable as a future candidate for radar and military application.

This paper is organized as follows: Section 2 discusses the antenna structure and experimental setup. The numerical study on the effect of IES towards the reflection coefficient, mutual coupling, and correlation coefficient is presented in Section 3. The experimental result of IES = 15 mm on the S-parameter, radiation pattern, gain, and correlation coefficient are shown as well. Section 4 presents the conclusion.

2. ANTENNA STRUCTURE AND EXPERIMENTAL SETUP

Figure 1 and Figure 2 illustrate the proposed UWB-MIMO antenna's geometry and prototype, respectively. The UWB-MIMO antenna presented consists of a combination of two identical antennas on the same substrate. The novel antenna is developed by integrating seven small circles surrounding the center circle. The circles have a diameter of R_s and R_{in}, respectively. The impedance matching of the microstrip feed line is fixed to $50\,\Omega$ with a feed width of W_f. The structure of the antenna element has been fabricated on the Taconic TLY-5 substrate with a thickness of 1.5748 mm, dielectric permittivity, ε_r, of 2.2 and tangent loss, $\tan\delta$, of 0.0009.

The unique design of the proposed UWB antenna basically comes from a single circle structure as in [28]. Since more current distributes

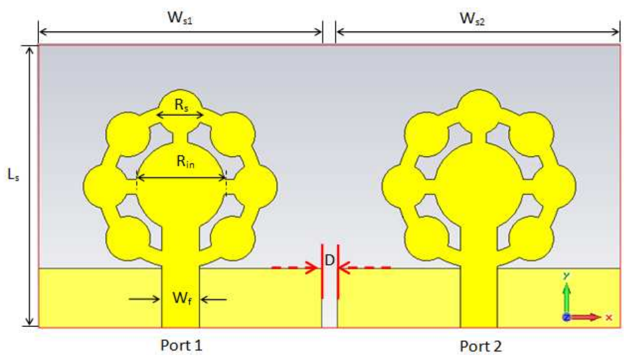

Figure 1. The simulated geometry of the proposed UWB MIMO antenna.

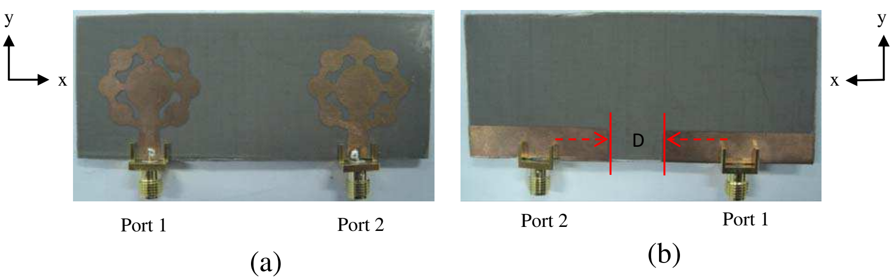

Figure 2. The fabricated geometry of the proposed UWB MIMO antenna. (a) Front view. (b) Back view.

near the edge of the circle, this research reduces the inner circle diameter and introduces a ring with 1 mm size surrounding the circle. This eventually allows the ring to cater for the entire required current distribution. However, the antenna's S_{11} performance still failed to achieve a UWB application. Therefore, seven small circles (7-circle) have been implemented on the ring and three bridges connected to the 7-circle are drawn as in Figure 1 and Figure 2. As a result, the proposed antenna's design has successfully achieved a UWB frequency operating.

The single antenna with the dimensions of $L_s \times W_{s1}$ is developed. Then, a second antenna is drawn by replicating the first antenna structure on the same substrate. With a few of optimization routines, the final geometrical results are: $L_s = 38$ mm, $W_f = 5$ mm, $R_{in} = 12$ mm, $R_s = 6$ mm, $W_{s1} = 38$ mm, and $W_{s2} = 38$ mm. The distance between both antennas symbolized by D will be analyzed in the sense of achieving minimum mutual coupling and low reflection coefficient that conserve the UWB frequency standard. All designs and simulations have been completed using CST Microwave Studio, commercial electronics simulation software.

All measurement processes have been carried out in the research cluster of the Universiti Malaysia Perlis (UniMAP) with the help of Agilent Technologies E83628 PNA Network Analyzer and 2D Anechoic Chamber as visualized in Figure 3. The horn antenna performed as a transmitter is competent to function from 1 GHz to 18 GHz. The antenna being tested (UWB-MIMO antenna) executes as a receiver. Both antennas are placed about 1 m apart.

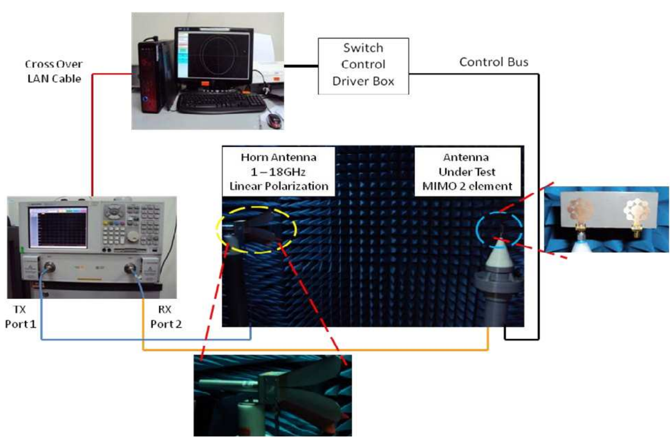

Figure 3. Agilent 2D PNA antenna test system.

3. RESULTS AND DISCUSSION

Figure 4 illustrates the simulated UWB MIMO antenna's return loss with a variety of 7-filters dimension; 5 mm, 6 mm, 7 mm and 8 mm. It can be seen that the 7-filter has a major influence on the upper frequency and minor influence on the lower frequency. The 7-filter's diameter increment of 5 mm to 8 mm has reduced the bandwidth ratio from 4.51 to 3.64 with 2.11 GHz of frequency operating blocked. This proved that the proposed antenna is naturally capable of functioning as a filter. Besides, the antenna is more miniature than conventional antennas that integrate an external filter circuit.

A study on the effect of IES represented by D towards the input reflection coefficient is performed. Figure 5 illustrates the simulated MIMO antenna's return loss with various D values: 0 mm, 6 mm, 10 mm, 15 mm, 20 mm and 40 mm. From Figure 5, all D variables have three dominant frequencies that successfully function between 3.1 GHz and 10.6 GHz. As $D = 0$ mm, the impedance matching is optimum at a particular frequency of 6 GHz. Meanwhile, the increment of D values reflects a perfect match at a resonant frequency of 9 GHz.

Correlation coefficient and diversity gain are closely interrelated. The lower is the correlation value, the better is the diversity gain. The relationship between them can be expressed mathematically [29] as in Equation (2),

$$G_{app} = 10 * \sqrt{(1 - |\rho|)} \tag{2}$$

The lower correlation coefficient reflects higher antenna diversity [13]. In the MIMO system, the minimum value of correlation is significant in determining antenna diversity performance. Instead of using radiation

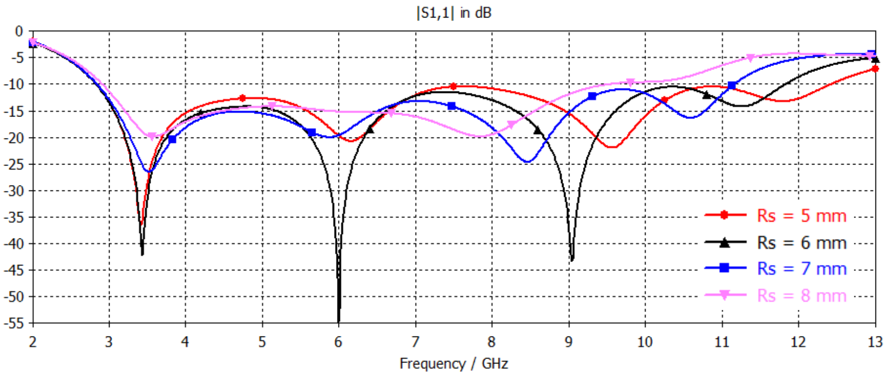

Figure 4. Simulated UWB-MIMO antenna's returns loss on 7-filters dimensions effect.

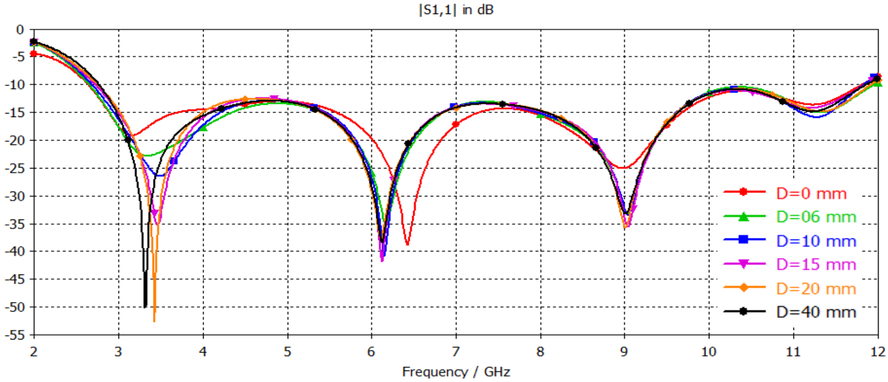

Figure 5. Simulated UWB-MIMO antenna's returns loss on IES effect.

pattern, the scattering parameters via Equation (3) are also capable of the intended correlation coefficient [30].

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

One of the significant ways of reducing the correlation coefficient is to determine the IES. It can be observed in [12] that a good arrangement will reflect to the lower reflection coefficient to the extent of 0.05. Figure 6 demonstrates that UWB-MIMO's correlation differs significantly among the various Ds. Compared to other Ds, $D = 40\,\text{mm}$ successfully achieves minimum correlation coefficient under the targeted operating frequency, except at a resonant frequency of 6.2 GHz, while $D = 0\,\text{mm}$ indicates the maximum correlation coefficient against other D values.

Therefore, considering the MIMO antenna efficiency, which preserves antenna compaction, the ultimate D value is set to 15 mm, with a maximum correlation coefficient of -22 dB.

The proposed UWB MIMO antenna is fabricated with an IES of 15 mm. All measurements have been made by Agilent Technologies E83628 PNA Network Analyzer. Figure 7 illustrates the measured and simulated S-parameters for the presented antenna. As reflected by the measured result, the reflection coefficient of less than -10 dB ($S_{11} < -10\,\text{dB}$) has successfully achieved UWB band of 2.8 GHz to 8.0 GHz. $S_{11} < -10\,\text{dB}$ indicates 90% of power is transmitted, and only 10% of power is reflected. Both forward transmission coefficient, S_{12}, and reverse transmission coefficient, S_{21}, represent a mutual coupling performance [15, 16]. The mutual coupling is the effect that exists

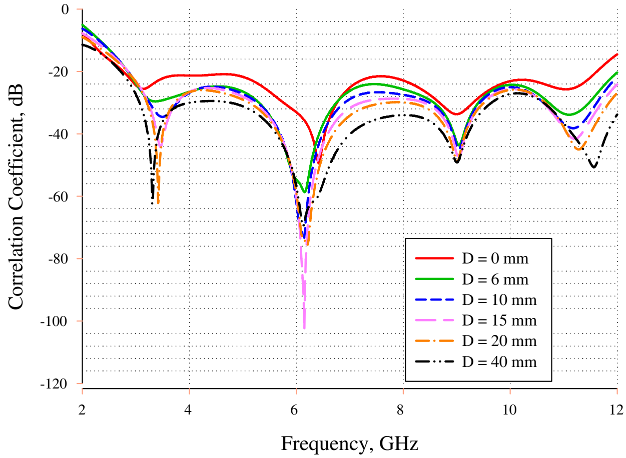

Figure 6. Simulated UWB MIMO antenna's correlation coefficient on IES effect.

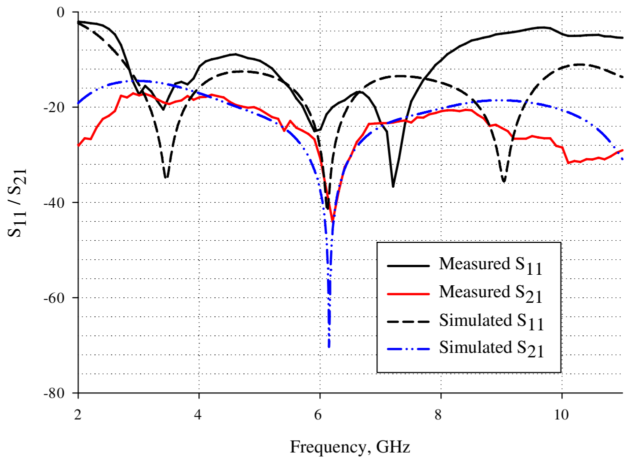

Figure 7. Measured and simulated S-parameters of the proposed UWB MIMO antenna.

due to the electromagnetic (EM) interaction between adjacent antenna elements. The decrement of mutual coupling results in an improvement in radiation efficiency and vice versa [15]. As in Figure 7, the measured mutual coupling (S_{21}) effectively achieves a maximum of -17 dB, which is considered better than [15, 16, 19, 25].

To further elaborate the electromagnetic interactions of the adjacent circuit, the proposed antenna's isolation can be observed by the surface current distribution. Figure 8 shows two cases of current distributions at two frequencies of 6 GHz and 9 GHz. The 1st case is when Port 1 is excited while Port 2 is terminated with a load impedance of 50 Ω, and the 2nd case is vice versa. Both cases show that less current has been attracted to the adjacent element eventually reduced the mutual coupling effect and increased the radiation efficiency. As in Figure 9, the proposed antenna has great radiation and total (antenna) efficiency throughout the desired frequency operating. Generally, total efficiency is smaller than radiation efficiency due to the reflection loss instead of dielectric and copper loss. The total efficiency increases up to 50% from 2 GHz to 3 GHz. A proposed UWB-MIMO antenna

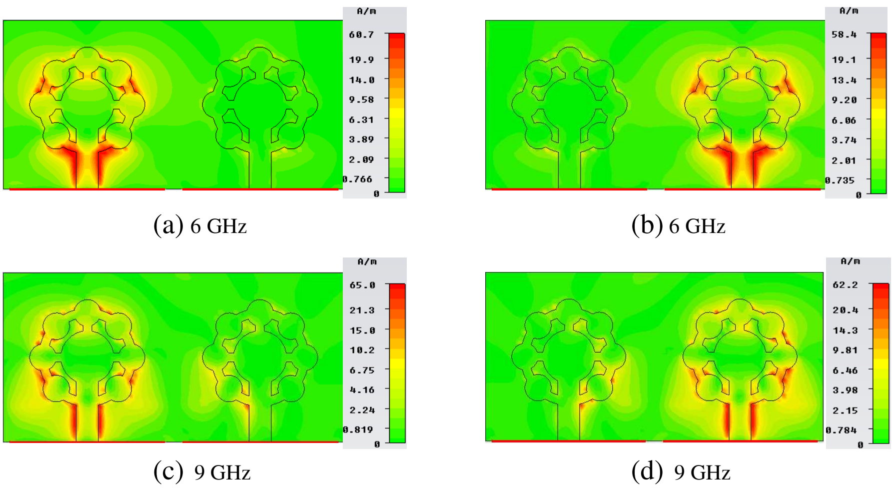

Figure 8. Surface current distributions (contour) of antenna. (a) and (c) when Port 1 is excited. (b) and (d) when Port 2 is excited.

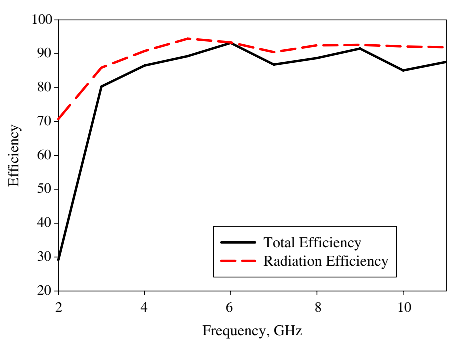

Figure 9. Simulated efficiency of the proposed antenna.

has successfully achieved total efficiency of 80% to 92% as depicted in Figure 9. This contributes to the lower of mutual coupling effect.

Figure 10 indicates a measured UWB-MIMO antenna's E-plane (yz-plane) of co-polar and cross-polar radiation patterns at the specified frequencies of $f_1 = 4\,\text{GHz}$, $f_2 = 7\,\text{GHz}$ and $f_3 = 10\,\text{GHz}$. The measured cross-polar is slightly different from the co-polar, which shows a non-stable linear polarization. As the proposed antenna is of identical design, the radiation and total antenna efficiency are similar for both ports. Therefore, the measurement is carried out with Port 1 excited while Port 2 is terminated to $50\,\Omega$ load impedance.

The antenna's gain is approximately the same in both identical antenna designs. The measurement was performed only by excited Port 1, while Port 2 was terminated with $50\,\Omega$ load. Figure 12 compares the measured and simulated UWB MIMO antenna's gain against the

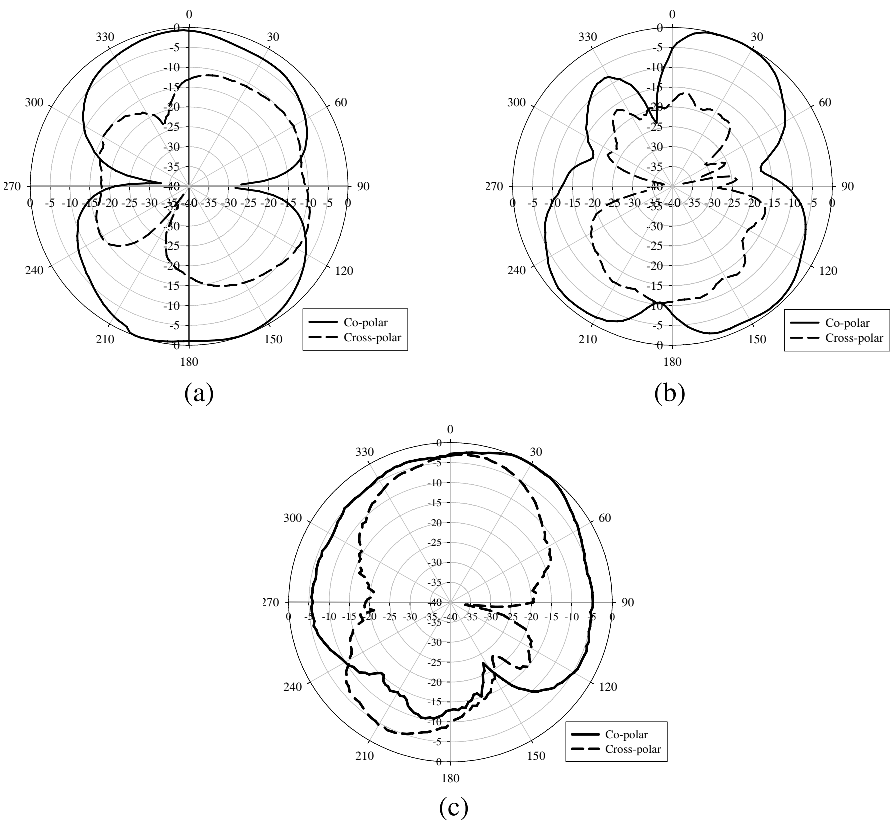

Figure 10. Measured UWB MIMO antenna's E-plane (yz-plane) radiation pattern (a) 4 GHz. (b) 7 GHz. (c) 10 GHz.

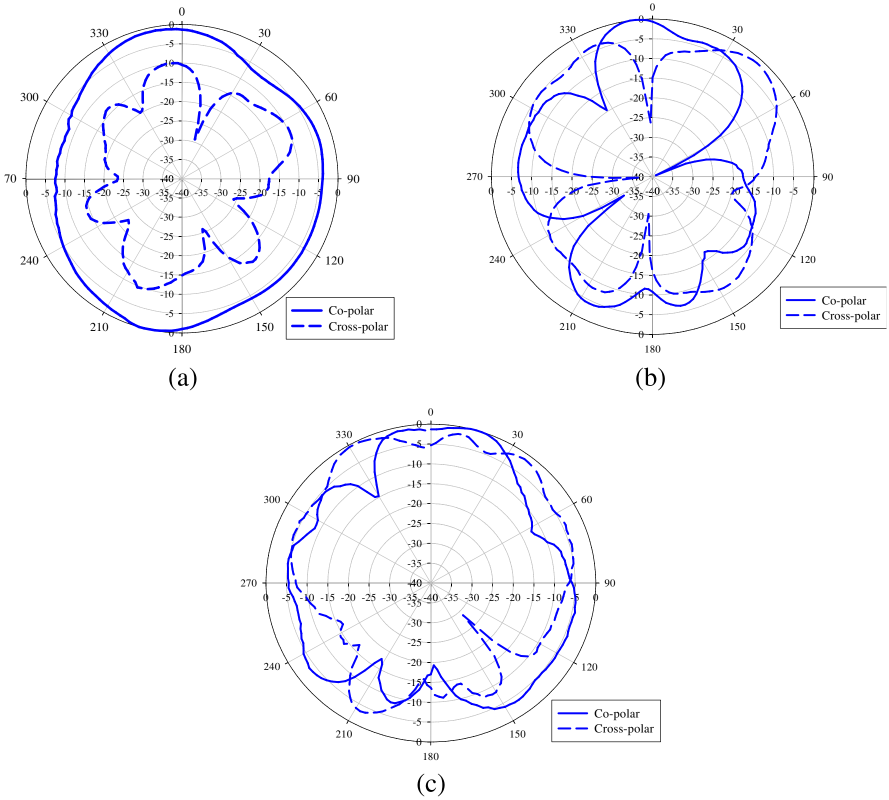

Figure 11. Measured UWB MIMO antenna's *H*-plane radiation pattern (a) 4 GHz. (b) 7 GHz. (c) 10 GHz.

UWB operating frequency (2 GHz to 11 GHz). Both results have small differences due to minor fabrication tolerance. The measured gain instantly increases from 2.8 dBi to 5.2 dBi between 3 GHz to 7 GHz. At 7 GHz to 9 GHz, the UWB-MIMO antenna has peak and constant gain of 5.2 dBi. The gain slopes from 5.2 dBi at 9 GHz to 4.1 dBi at 11 GHz.

The correlation coefficient is the crucial parameter to determine MIMO antenna diversity performance and can be accessible by solved Equation (3). The obtainable reflection coefficient generated by measured *S*-parameter is illustrated in Figure 13. From the figure, the proposed antenna has a minimum measured correlation coefficient of -60 dB, eventually resulting in high diversity gain. Hence, the presented correlation coefficient is suitable for mobile communication with a minimum acceptable correlation coefficient of 0.5 [15, 16].

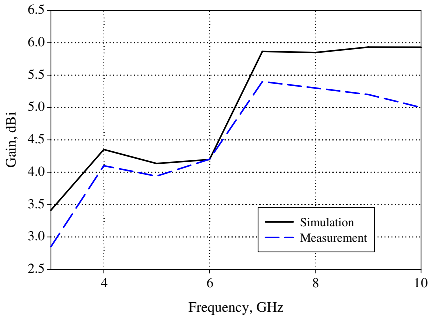

Figure 12. Measured and simulated UWB MIMO antenna's gain.

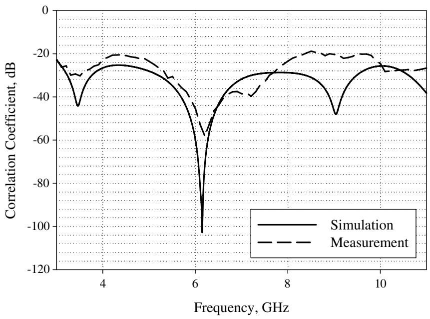

Figure 13. Measured and simulated UWB MIMO antenna's correlation coefficient.

4. CONCLUSION

This paper presents a novel design of two identical MIMO antennas operated for UWB applications. We discuss the UWB-MIMO antenna's characteristics of reflection coefficient, mutual coupling, correlation coefficient, gain, and radiation pattern, and analyze the antenna's novel design, which gives the antenna optimum functionality. We perform collective analysis on reflection coefficient, mutual coupling, and correlation coefficient towards various IES effects. The research successfully accomplishes the development of a prototype of compact UWB-MIMO antenna with a minimum input reflection coefficient of -10 dB, high gain of 6 dBi, low mutual coupling of < -17 dB, and low correlation coefficient of < -22 dB. These indicate that the proposed antenna is suitable for a UWB-MIMO antenna system and future communications devices. Future research will focus on the UWB MIMO positioning effect, which improves the mutual coupling parameter. Such a model might be constructive for developing universal guidelines for UWB-MIMO antenna systems incorporated on miniature terminals.

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REFERENCES

1. Mokhtaari, M. and J. Bornemann, "Directional ultra-wideband antennas in planar technologies," *38th Microwave European Conference, EuMC 2008*, 885–888, 2008.
2. Chen, D. and C. H. Cheng, "A novel compact ultra wideband (UWB) wide slot antenna with via holes," *Progress In Electromagnetics Research*, Vol. 94, 343–349, 2009.
3. Lee, J. N. and J. K. Park, "Compact UWB chip antenna design using the coupling concept," *Progress In Electromagnetics Research*, Vol. 90, 341–351, 2009.
4. Choi, S. H., J. K. Park, S. K. Kim, and J. Y. Park, "A new ultra-wideband antenna for UWB applications," *Microwave and Optical Technology Letters*, Vol. 40, No. 5, Mar. 5, 2004.
5. Sadat, S., M. Houshmand, and M. Roshandel, "Design of a microstrip square-ring slot antenna filled by an H-shape slot for UWB applications," *Progress In Electromagnetic Research*, Vol. 70, 131–198, 2007.
6. www.fcc.gov.my.
7. Ge, J. and W. Yanagisawa, "A novel compact ultrawideband antenna," *IEEE Transactions on Antennas and Propogation*, Vol. 57, No. 2, Feb. 2009.
8. Low, X. N., Z. N. Chen, and T. S. P. See, "A UWB dipole antenna with enhanced impedance and gain performance," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 10, Oct. 2009.
9. Ghanem, F., J. R. Kelly, and P. S. Hall, "Switched UWB to narrowband planar monopole antenna," *European Conference on Antennas and Propagation*, 12–16, Barcelona, Apr. 2010.
10. Sadat, S., M. Fardis, F. G. Geran, and G. R. Dadashzadeh, "A compact microstrip square-ring slot antenna for UWB applications," *Progress In Electromagnetic Research*, Vol. 67, 173–179, 2007.
11. Dong, L., H. Choo, R. W. Heath, Jr., and H. Ling, "Simulation of MIMO channel capacity with antenna polarization diversity," *IEEE Transactions on Wireless Communication*, Vol. 4, No. 4, Jul. 2005.

12. Manteuffel, D., "MIMO antenna design challenges," *2009 Loughborough Antennas & Propagation Conference*, Loughborough, UK, Nov. 16–17, 2009.
13. See, T. S. P., A. M. L. Swee, and Z. N. Chen, "Correlation analysis of UWB MIMO antenna system configurations," *Proceedings of the 2008 IEEE International Conference on Ultra-wideband (ICUWB2008)*, Vol. 2, 2008.
14. Abou-Rjeily, C., "Pulse antenna permutation and pulse antenna modulation: Two novel diversity schemes for achieving very high data-rates with unipolar MIMO-UWB communications," *IEEE Journal on Selected Areas in Communications*, Vol. 27, No. 8, Oct. 2009.
15. Zhou, X., R. Li, and M. M. Tentzeris, "A compact broadband MIMO antenna for mobile handset applications," *Antennas and Propagation Society International Symposium (APSURSI)*, 2010.
16. Najam, A. I., Y. Duroc, and S. Tedjini, "Design & characterization of an antenna system for UWB-MIMO communications systems," *Antennas and Propagation (EuCAP), Proceedings of the Fourth European Conference*, 2010.
17. Manteghi, M. and Y. Rahmat, "Multiport characteristics of a wide-band cavity backed annular patch antenna for multipolarization operations," *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 1, Jan. 2005.
18. Najam, A. I., Y. Duroc, J. F. A. Leao, and S. Tedjini, "A novel co-located antennas system for UWB-MIMO applications," *Proc. IEEE Radio and Wireless Symposium*, Jan. 2009.
19. Panda, J. R., P. Kakumanu, and R. S. Kshetrimayum, "A wide-band monopole antenna in combination with a UWB microwave band-pass filter for application in UWB communication system," *2010 Annual IEEE India Conference (INDICON)*, 2010.
20. Yoon, J., D. Kim, and C. Park, "Implementation of UWB antenna with bnadpass filter using microstrip-to-CPW transition matching," *Microwave Conference, APMC 2009*, Asia Pacific, 2009.
21. Najam, A. I., Y. Duroc, and S. Tedjni, "UWB-MIMO antenna with novel stub structure," *Progress In Electromagnetics Research C*, Vol. 19, 245–257, 2011.
22. See, T. S. P., A. M. L. Swee, and Z. N. Chen, "Correlation analysis of UWB MIMO antenna system configurations," *Proceedings of the 2008, IEEE International Conference on Ultra-wideband (ICUWB2008)*, Vol. 2, 2008.

23. Jamlos, M. F., O. A. Aziz, T. A. Rahman, M. R. Kamarudin, P. Saad, M. T. Ali, and M. N. Md Tan, "A beam steering radial line slot array (RLSA) antenna with reconfigurable operating frequency," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 8–9, 1079–1088, 2010.
24. Jamlos, M. F., T. A. Rahman, M. R. Kamarudin, P. Saad, M. A. Shamsudin, and A. M. M. Dahlan, "A novel adaptive Wi-Fi system with RFID," *Progress In Electromagnetics Research*, Vol. 108, 417–432, 2010.
25. Jamlos, M. F., O. A. Aziz, T. A. Rahman, M. R. Kamarudin, P. Saad, M. T. Ali, and M. N. Md Tan, "A reconfigurable radial line slot array (RLSA) antenna for beam shape and broadside application," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 8–9, 1171–1182, 2010.
26. Jamlos, M. F., T. B. A. Rahman, M. R. B. Kamarudin, P. Saad, O. Abdul Aziz, and M. A. Shamsudin, "Adaptive beam steering of RLSA antenna with RFID technology," *Progress In Electromagnetics Research*, Vol. 108, 65–80, 2010.
27. Zhang, S., Z. Ying, J. Xiong, and S. He, "Ultrawideband MIMO/diversity antennas with a tree-like structure to enhance wideband isolation," *IEEE Antennas and Wireless Propagation Letters,* Vol. 8, 2009.
28. Mokhtaari, M. and J. Bornemann, "Directional ultra-wideband antennas for planar technologies," *Proceedings of the 38th European Microwave Conference*, 2008.
29. Rosengren, K. and P.-S. Kildal, "Radiation efficiency, correlation, diversity gain and capacity of a six monopole antenna array for a MIMO system: Theory, simulation and measurement in reverberation chamber," *IEE Proceedings Microwaves, Antennas and Propagation*, Vol. 153, No. 6, 2006.
30. Ko, S. C. K. and R. D. Murch, "Compact integrated diversity antenna for wireless communications," *IEEE Transactions and Antennas Propagation*, Vol. 49, No. 6, 954–960, 2001.