International Journal of Microwave and Wireless Technologies, 2017, 9(3), 573–580. © Cambridge University Press and the European Microwave Association, 2016
doi:10.1017/S175907871500135X

RESEARCH PAPER

UWB MIMO antenna with common radiator

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A compact printed 2 × 2 ultrawideband (UWB) multiple input multiple output (MIMO) antenna with a single circular patch as a common radiator for both the antenna elements is presented in this paper. A single circular patch is excited by two tapered CPW feeds for dual polarization. To improve the isolation between two ports, a rectangular slot of dimension $L_1 \times W_1$ is created in the radiator. The UWB MIMO antenna has impedance bandwidth of 3–12 GHz with a isolation better than 17 dB between the two ports. The envelope correlation coefficient and the capacity loss are evaluated to ensure the good diversity performance of UWB MIMO antenna. The antenna has a compact size of 45 × 45 mm² and is fabricated on low cost FR4 substrate and measured using Agilent VNA. The simulated and measured results show that the proposed UWB antenna is good candidate for UWB MIMO applications.

Keywords: UWB MIMO antenna, Envelope correlation coefficient, Capacity loss

Received 11 April 2015; Revised 5 August 2015; Accepted 7 August 2015; first published online 7 March 2016

I. INTRODUCTION

In wireless communication systems, the involvement of multiple antenna at both the transmitter and receiver i.e. multiple input multiple output (MIMO) systems is used to significantly increase the channel capacity. Recently, ultrawideband (UWB) systems are used for high speed low power data communication. However, UWB technology faces severe challenges such as multipath fading. This challenge can be overcome by using UWB MIMO systems. UWB MIMO system employs multiple antennas in a smaller area for portable applications. The high isolation among the antenna elements is a basic requirement for good diversity performance. Several UWB MIMO antennas are proposed in the literature [1–4]. The UWB MIMO antenna discussed in [1] uses the meander lines to enhance the isolation between the antenna elements. Nevertheless, this will increase the system dimensions and its complexity. In [2, 3], uniplanar UWB MIMO antennas are presented having rectangular strip for isolation enhancement between the antenna elements. In [4], UWB MIMO antenna is realized without any decoupling network by simply using the orthogonal orientation of antenna elements for good isolation. However, the size of antenna presented in [4] is quite large. Thus, designing a UWB MIMO antenna with compact size and good isolation is a challenging task.

In this paper, a uniplanar UWB MIMO antenna is presented. The presented antenna can be used for wireless personal area network (WPAN), wireless body area network (WBAN) and other applications which operates in FCC specified UWB spectrum, wherever there is a problem of multipath fading. This MIMO antenna has single common circular radiator for both the antenna elements. These antenna elements are fed by two tapered CPW feeding structures. The isolation between them is achieved by introducing a rectangular slot in the common radiator. In Section II, the geometry of the proposed antenna is explained in detail. The parametric analysis of the antenna design parameters are presented in Section III. The simulated and measured results are presented in Section IV in order to verify the present approach. Finally, a comparison has been made with the existing state of art UWB MIMO/diversity antennas for the above applications.

II. ANTENNA CONFIGURATION

The configuration of the proposed 2 × 2 UWB MIMO antenna is shown in Fig. 1. The proposed antenna is designed on inexpensive FR4 substrate of dielectric constant 4.4, loss tangent 0.02 and thickness 0.8 mm. The size of the proposed UWB MIMO antenna is 45 × 45 mm². The radiating element is common circular radiator for both the UWB antennas. This common radiator is fed by two tapered CPW structures and is designated as Port 1 and Port 2. The dual polarization is achieved by two simple orthogonally oriented feeds. The single common radiator helps to reduce the overall size of the UWB MIMO antenna. The UWB MIMO antenna has an L-shaped ground plane present on the same side of the substrate.

The simulated impedance bandwidth of the antenna is 3–12 GHz which covers the overall UWB spectrum. It has three resonant frequencies. The isolation between the two antenna elements of MIMO structure is 11 dB (lower band of frequencies of UWB spectrum) without rectangular slot

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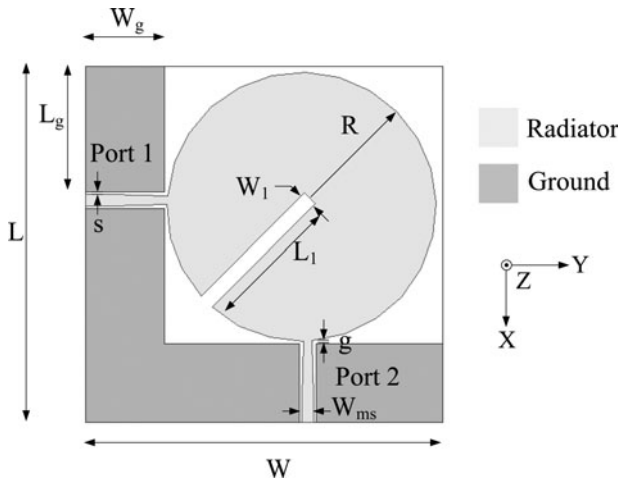


Fig. 1. Configuration of the proposed UWB MIMO antenna.

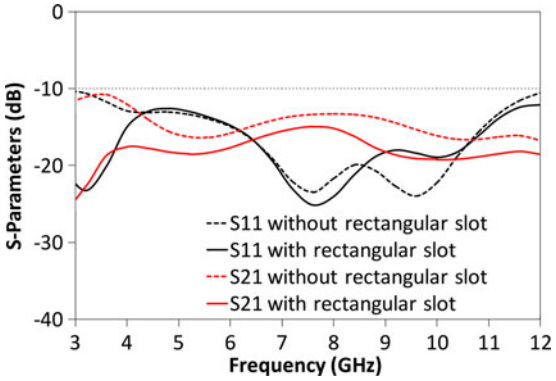


Fig. 2. S-parameters of UWB MIMO antenna without rectangular slot and with rectangular slot in the common radiator.

in the radiator as shown in Fig. 2. However, for good diversity performance the isolation must be better than 15 dB [2, 5] in the entire UWB spectrum. High isolation ($\geq$15 dB) between the antenna elements is achieved by creating a rectangular slot of dimensions $L_1 \times W_1$ in the common radiator at an angle of $\phi = 45^\circ$ (Fig. 2).

Figure 3 represents the symbolic equivalent circuit of the proposed UWB MIMO antenna. The multiple resonances in the reflection coefficient of single UWB antenna can be modeled as parallel combination of R-L-C circuit shown in Fig. 3. The rectangular slot is introduced in the circular radiator to enhance the isolation between the two ports of the UWB MIMO antenna. This quarter wavelength long rectangular slot creates a resonance at 3.1 GHz, which in turn results in low mutual coupling between the two ports. The rectangular slot can be modeled as a combination of Rs-Ls-Cs as shown in Fig. 3.

The isolation enhancement phenomenon can be better explained in terms of surface current distributions. Figure 4(a) shows the surface current distribution at 3.1 GHz if Port 1 is excited and Port 2 is terminated with matched load of 50 Ω. When the Port 1 is excited then there is some amount of surface current present at port 2 through the common radiator and the ground plane. In order to reduce this surface current present at Port 2, a rectangular slot is introduced in the common radiator as shown in Fig. 4(b). The surface currents are mainly confined in the rectangular slot at 3.1 GHz, which thereby significantly reduce the mutual coupling between the two ports.

III. PARAMETRIC ANALYSIS OF ANTENNA DESIGN PARAMETERS

A parametric analysis is performed for different design parameters to obtain the desired antenna performance.

A) Effect of *R*

The simulated S_{11} parameters for different values of R (radius of UWB MIMO antenna) are shown in Fig. 5. As the value of R increases from 15 to 19 mm, in steps of 2 mm, the S_{11} characteristics gets improved at the expense of overall size of the antenna. Thus, $R = 17$ mm is chosen as an optimum design parameter with acceptable S_{11} characteristics.

B) Effect of W_g

The simulated S_{11} parameters for different values of W_g (ground plane width) are shown in Fig. 6. It is clear from the figure, for $W_g = 10$ mm, S_{11} parameter is well below -10 dB for the entire UWB spectrum. Hence, $W_g = 10$ mm is chosen as optimized design parameter.

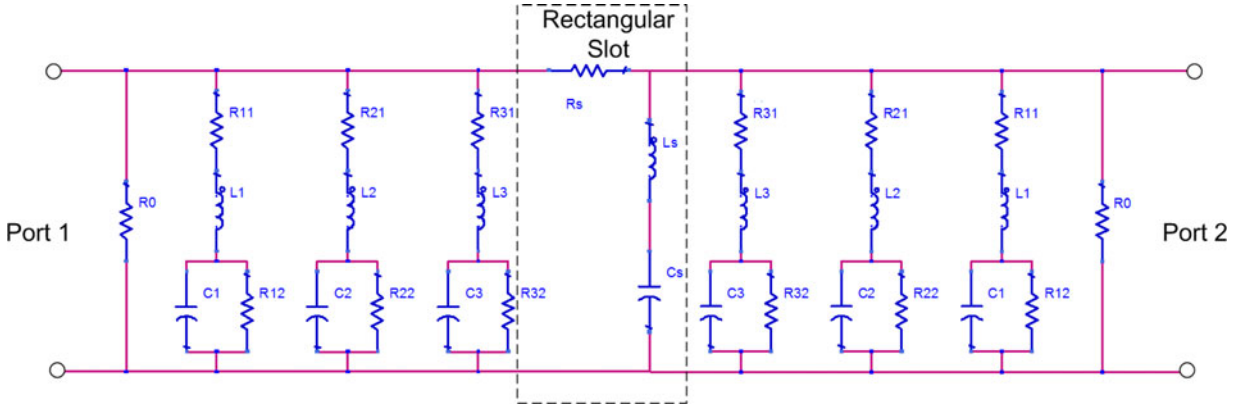


Fig. 3. Symbolic equivalent circuit of the proposed UWB MIMO antenna.

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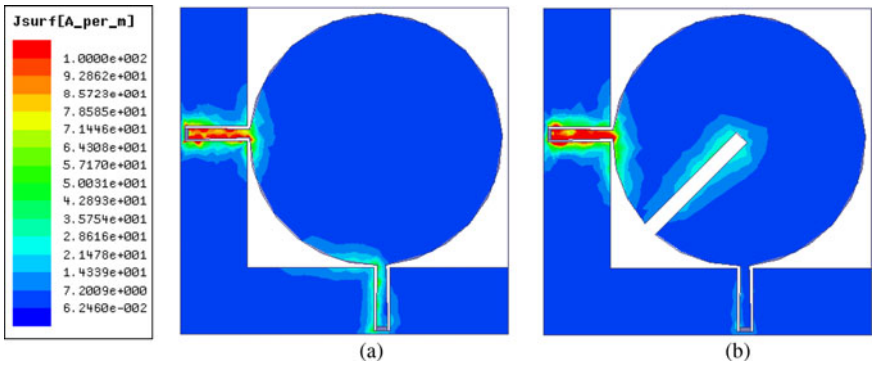


Fig. 4. Surface current distribution of UWB MIMO antenna at 3.1 GHz (a) without rectangular slot (b) with rectangular slot in the common radiator.

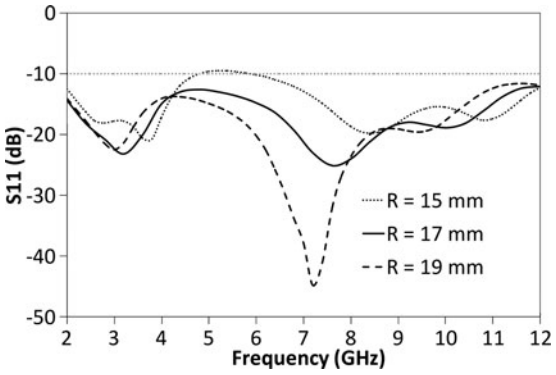


Fig. 5. Simulated S_{11} parameters for different values of R of the proposed UWB MIMO antenna.

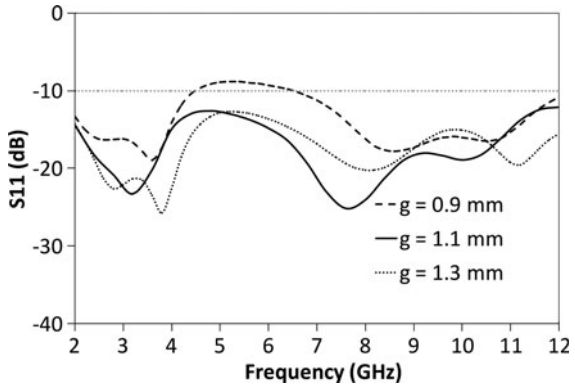


Fig. 7. Simulated S_{11} parameters for different values of g of the proposed UWB MIMO antenna.

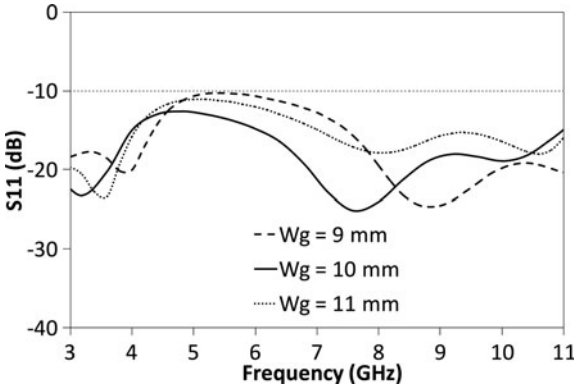


Fig. 6. Simulated S_{11} parameters for different values of W_g of the proposed UWB MIMO antenna.

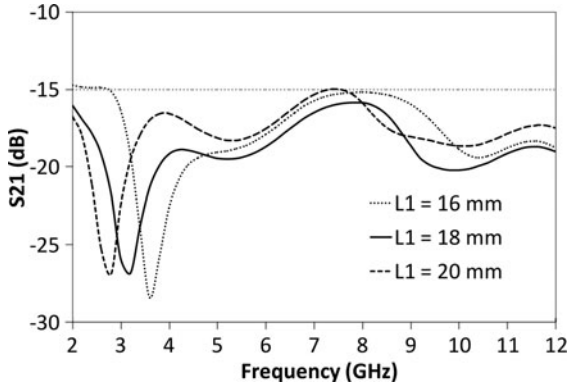


Fig. 8. Simulated S_{11} parameters for different values of L_1 of the proposed UWB MIMO antenna.

C) Effect of g

The gap between the circular radiator and the ground plane is also a critical parameter hence its parametric study is required for UWB antenna design. For $g = 1.1$ mm and $g = 1.3$ mm, the S_{11} parameter is below -10 dB which ensures good radiation performance as shown in Fig. 7. Thus, for compact size and good antenna performance, $g = 1.1$ mm is chosen as antenna design parameters.

D) Effect of L_1 and W_1

The parametric analysis for different lengths of the rectangular slot is depicted in Fig. 8. The isolation (S_{21}) is better than 15 dB for all the three values of L_1. But, for $L_1 = 18$ mm, the isolation is better than 17 dB for the entire UWB spectrum. Also, the parametric study has been performed for different widths of the rectangular slot. As can be seen from Fig. 9, $W_1 = 2$ mm provides isolation better than 17 dB for the whole UWB spectrum. Hence, $L_1 = 18$ mm and $W_1 = 2$ mm are chosen as an optimum design parameters of the rectangular slot.

The final optimized dimensions of the proposed UWB MIMO antenna are as follows: $L = 45$ mm, $W = 45$ mm, $R = 17$ mm, $g = 1.1$ mm, $L_g = 16$ mm, $W_g = 10$ mm, $L_1 = 18$ mm, $W_1 = 2$ mm, $W_{ms} = 1.5$ mm, $s = 0.3$ mm.

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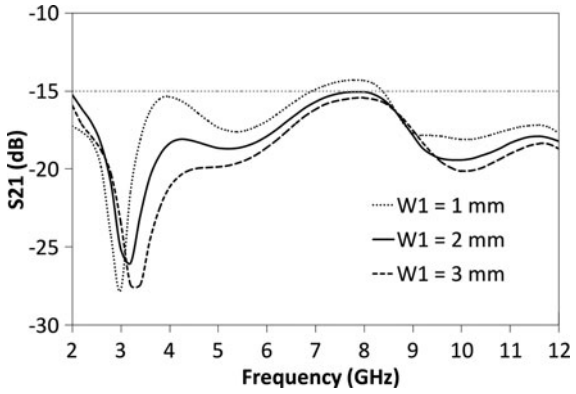


Fig. 9. Simulated S_{11} parameters for different values of W_1 of the proposed UWB MIMO antenna.

IV. RESULTS AND DISCUSSIONS

The proposed UWB MIMO antenna is fabricated on low cost FR4 substrate as shown in Fig. 10 in order to verify the present approach of antenna design. This designed antenna is measured on Agilent VNA E5071C. The size of the UWB MIMO antenna is 45×45 mm^2. Figure 11 shows the simulated return loss characteristics with tangent loss of 0.02 and 0. It can be observed from Fig. 11 that the loss of the UWB antenna with loss tangent of 0 is lower than that of 0.02 inevitably at the higher frequencies. The substrate dielectric loss reduces the port reflection coefficient especially at higher frequencies (above 8 GHz), it is due to the fact large amount of energy gets lost in the lossy dielectric substrate. Figure 12 shows simulated and measured S-parameters of the fabricated UWB MIMO antenna. The simulated impedance bandwidth is 3–12 GHz which covers the whole UWB spectrum. The simulated S_{21} is well below −17 dB for the UWB bandwidth. From Fig. 12, it is clear that the measured impedance bandwidth is from 3 to 12 GHz. The measured isolation is better

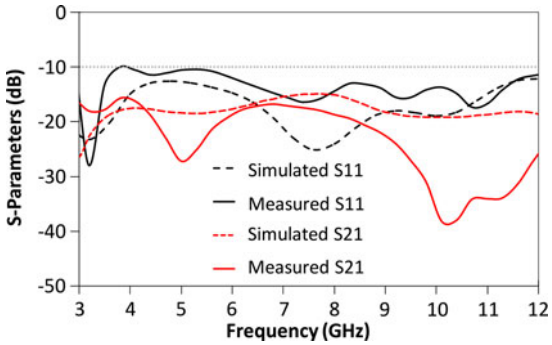


Fig. 12. Simulated and measured S-parameters of UWB MIMO antenna.

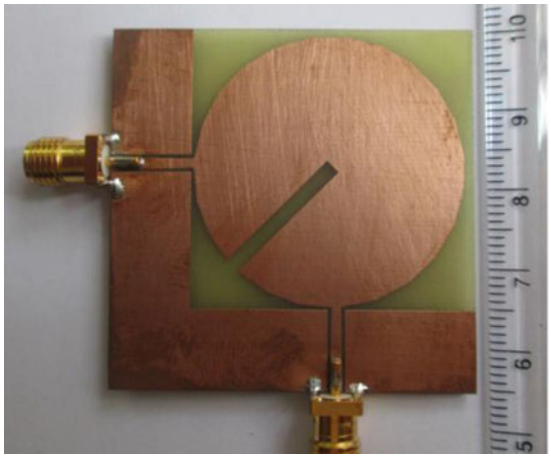


Fig. 10. Photograph of the fabricated UWB MIMO antenna.

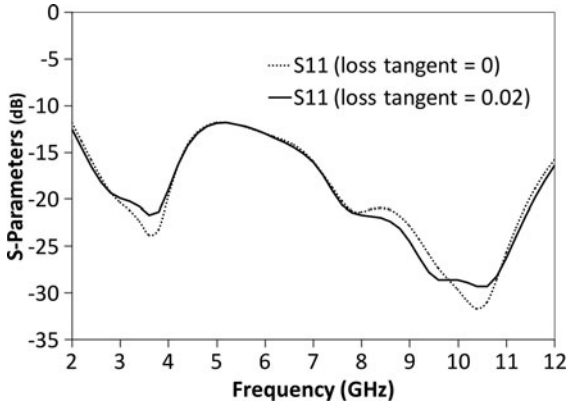


Fig. 11. Simulated S_{11} parameters for different values of loss tangent of FR4 substrate for proposed UWB MIMO antenna.

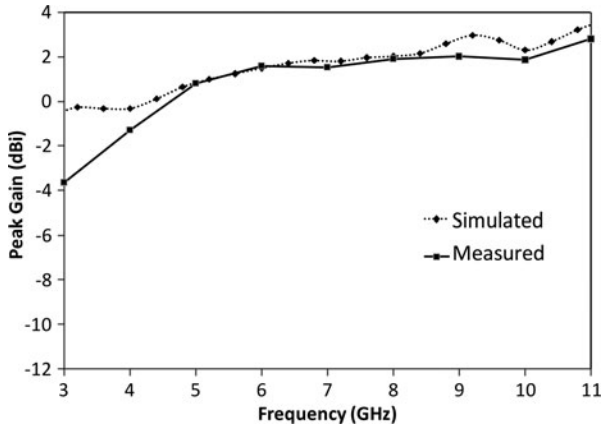


Fig. 13. Simulated and measured peak gain of UWB MIMO antenna.

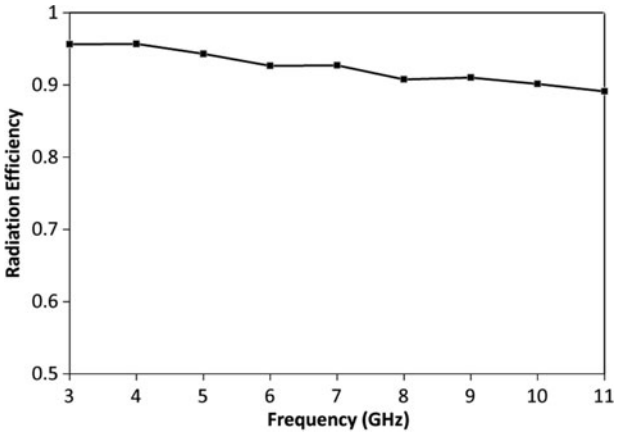


Fig. 14. Radiation efficiency of UWB MIMO antenna.

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than 17 dB for the whole UWB spectrum. There is a good agreement between the measured and simulated results. However, there are some disparities, which can be attributed to SMA connector losses, fabrication tolerances, measuring environment, etc. which are not considered during the simulations.

Figure 13 shows the simulated and measured peak gain of the proposed UWB MIMO antenna. The peak gain is nearly constant for the entire UWB frequency band except for the lower frequencies. Figure 14 shows the simulated radiation efficiency of the proposed antenna. It can be observed from figure that the simulated radiation efficiency of the proposed UWB MIMO antenna are very high in lower and middle band of UWB spectrum, but it decreases at higher frequencies of UWB spectrum. The reduction in simulated radiation efficiency at higher frequencies can be due to finite loss tangent ($\tan\,\delta = 0.02$) of FR4 substrate.

Figures 15 and 16 shows the simulated and measured radiation patterns of the proposed UWB MIMO antenna in *xy*- and *yz*-plane at three resonant frequencies (4.5, 6.5, and 8 GHz), respectively. Figures 15(a)–15(c) shows the radiation pattern if Port 1 is excited and Port 2 is terminated with matched load, whereas Figs 15(d)–15(f) shows the radiation pattern if Port 2 is excited and Port 1 is terminated with matched load in *xy*-plane. It is clear from the figure that the two antenna elements in the proposed UWB MIMO antenna have orthogonal radiation pattern. Figure 16 depicts that the radiation patterns of both the antenna elements in *yz*-plane are nearly omni-directional.

Envelope correlation coefficient (ECC) and channel capacity loss (CCL) are the major parameters which characterize the diversity performance of a UWB MIMO antenna. The ECC can be defined in terms of S-parameters as follows [6]:

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

Figure 17 shows the simulated and measured ECC performance of the proposed UWB MIMO antenna. Both of them are below their acceptable limit of 0.5 [7], which depicts that there is very low mutual coupling between the MIMO antenna elements.

Along with ECC, the CCL (b/s/Hz) is also a vital parameter that influences the quality of MIMO antenna. It is the upper limit of information rate at which reliable communications happen over the channel. For good MIMO performance, it must be within the acceptable limit of 0.4 b/s/Hz [8, 9]. It is calculated with the use of correlation matrix defined in [10] and is expressed as follows:

$$CL_{loss} = -\log_2 \det(\Psi_R), \quad (2)$$

where Ψ_R is the correlation matrix of receiving antenna and the elements ρ_{ij} are the correlation coefficients and defined as follows:

$$\rho_{ii} = 1 - |S_{ii}|^2 - |S_{ij}|^2 \text{ and}$$

$$\rho_{ij} = -(S_{ii}^* S_{ij} + S_{ji}^* S_{jj}) \text{ for } i, j = 1 \text{ or } 2.$$

Figure 18 shows the measured CCL of UWB MIMO antenna and it is well below the limit of 0.4 b/s/Hz for the entire UWB spectrum.

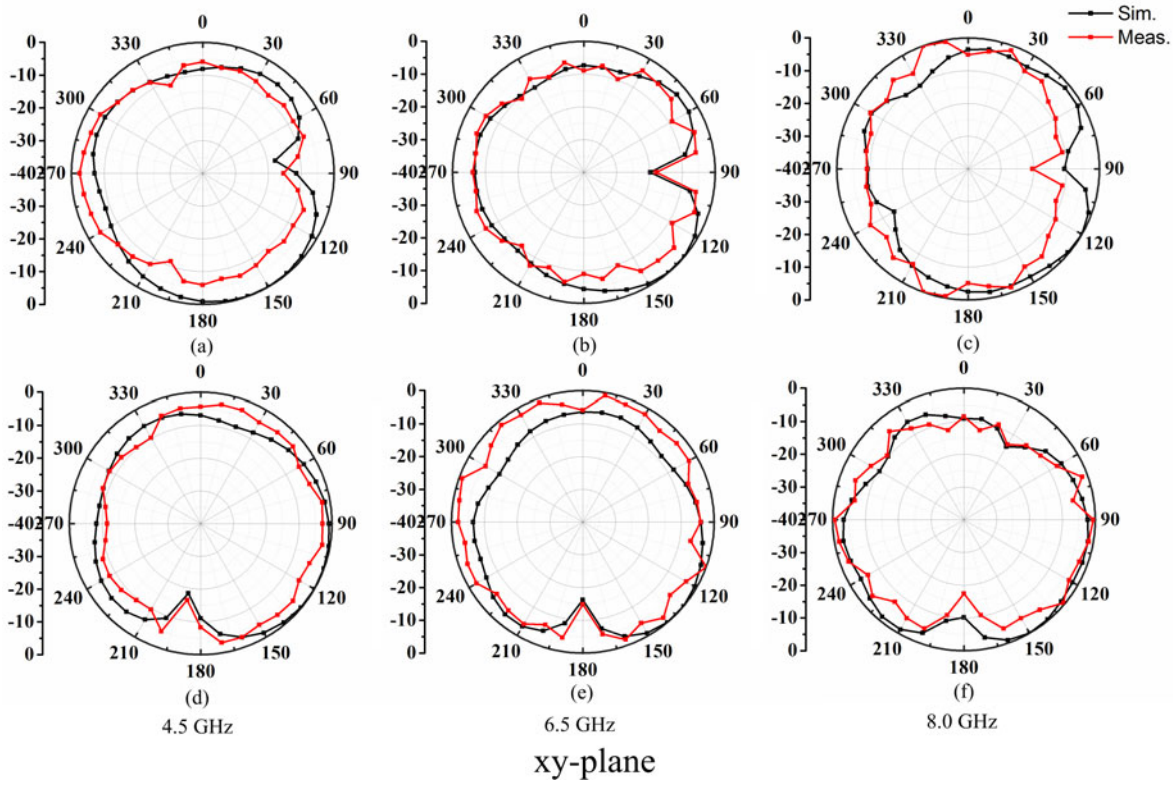


Fig. 15. Simulated and measured radiation pattern of UWB MIMO antenna in *xy*-plane. Port 1 is excited at (a) 4.5 GHz, (b) 6.5 GHz, and (c) 8 GHz and port 2 is excited at (a) 4.5 GHz, (b) 6.5 GHz, and (c) 8 GHz (other port is terminated with matched load).

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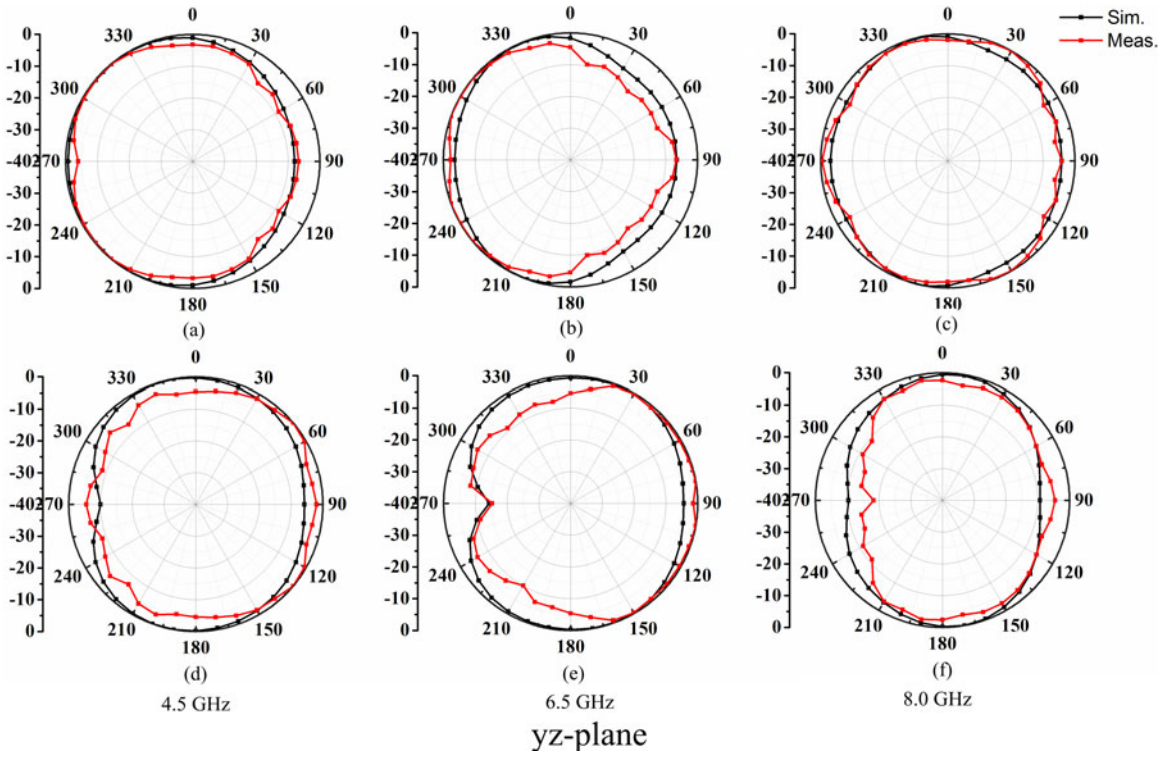


Fig. 16. Simulated and measured radiation pattern of UWB MIMO antenna in *yz*-plane. Port 1 is excited at (a) 4.5 GHz, (b) 6.5 GHz, and (c) 8 GHz and port 2 is excited at (a) 4.5 GHz, (b) 6.5 GHz, and (c) 8 GHz (other port is terminated with matched load).

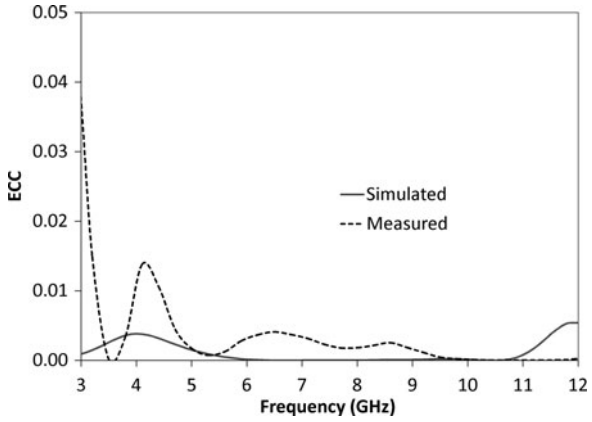


Fig. 17. Simulated and measured ECC of UWB MIMO antenna.

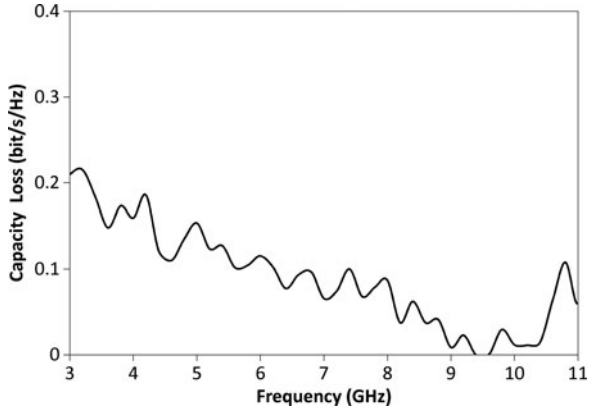


Fig. 18. Measured CCL of UWB MIMO antenna.

Table 1. Comparison of UWB MIMO/diversity antennas.

		Size of the antenna (mm^2)	Impedance bandwidth (GHz)	Isolation (dB)
1	This work	45 × 45	3–12	≥17
2	[1]	86.5 × 55	1.9–10.6	≥15
3	[2]	48 × 48	2.5–12	≥15
4	[3]	50 × 50	2.76–10.75	≥15
5	[11]	68 × 40	3.2–10.6	≥15
6	[12]	48 × 115	2.3–7.7	≥20
7	[13]	80 × 60	2.27–10.2	≥20

In Table 1, a comparison has been presented with the existing UWB MIMO/diversity antenna. It is clear from the table that the proposed UWB MIMO antenna has the compact dimensions, wide impedance bandwidth along with good isolation than the antennas reported in the references.

V. CONCLUSION

In this paper, a 2 × 2 UWB MIMO antenna having common radiator is presented. The common radiator is circular shaped and is fed by two orthogonally oriented tapered CPW structures. In order to have better isolation between the antenna elements, a rectangular slot is introduced in the circular radiator. The proposed MIMO antenna have the measured impedance bandwidth of 3–12 GHz with the isolation better than 17 dB for the entire UWB spectrum. To get better insight of antenna performance, a parametric analysis of different antenna design parameters is performed. The proposed

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antenna is fabricated, and measured in order to verify the present approach. The radiation pattern of the UWB MIMO antenna is measured in *xy*- and *yz*-plane. The measured results are in good agreement with the simulated results. The detailed investigation of diversity performance in terms of ECC and capacity loss is presented in this paper. Both of them are within their acceptable limits, which make it suitable candidate for WPAN and WBAN applications.

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He has been credited to publish more than 120 research papers with more than 280 citations with h-index of 10 in peer-reviewed journals and conferences. He has supervised 45 M.Tech. and three Ph.D. research scholars in the field of microwave engineering. He is a reviewer of several journals of international repute i.e. IET Microwaves, Antennas & Propagation, IEEE Antennas and Wireless Propagation Letters, Wireless Personal Communications, Journal of Electromagnetic Wave and Application, Indian Journal of Radio and Space Physics, IETE Technical Review, International Journal of Electronics, International Journal of Engineering Science, IEEE Transactions on Antennas and Propagation, AEU-International Journal of Electronics and Communication, International Journal of Microwave and Wireless Technologies, etc. Dr., Kanaujia has successfully executed four research projects sponsored by several agencies of Government of India i.e. DRDO, DST, AICTE, and ISRO. He is also a member of several academic and professional bodies i.e. IEEE, Institution of Engineers (India), Indian Society for Technical Education, and The Institute of Electronics and Telecommunication Engineers of India.



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https://doi.org/10.1017/S175907871500135X Published online by Cambridge University Press

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https://doi.org/10.1017/S175907871500135X Published online by Cambridge University Press