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Research Article

Compact UWB Antenna Design for MIMO Applications

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Abstract: In this study, a compact printed Multiple-Input-Multiple-Output (MIMO) antenna with a dimension of 32×70 mm^2 has been proposed for Ultra-Wideband (UWB) systems applications. The design constitutes of two identical UWB antenna elements, which is etched onto a Taconic TLC-30 printed circuit board. The proposed antenna has been designed and simulated using computer simulation software. For validation purposes, antenna prototype is fabricated and tested. The UWB-MIMO antenna yields an impedance bandwidth of 2.9 to 12 GHz with a return loss of less than-10 dB. Furthermore, the isolation characteristic between the two antenna elements is more than 15 dB within the operating frequency range. The designed structure is found to provide good MIMO/diversity characteristic across the UWB band.

Keywords: Antenna diversity, correlation coefficients, Multiple-Input-Multiple-Output (MIMO) antenna, mutual coupling, planar antenna array, Ultra Wideband (UWB) systems

INTRODUCTION

Current communication technologies have significantly increased the capacity to access the multimedia contents which placing larger bandwidth demands for mobile devices. Short range high-data-rate Ultra Wideband (UWB) radio technology has been suggested as a suitable technology for wireless personal area network applications. Owing to its good multipath immunity and precise ranging, feasible design and implementation of UWB subsystems has received great attention from various researchers in telecommunication fields. The bandwidth of UWB transmission technology is defined by Federal Communications Commission (FCC) to have a range from 3.1 to 10.6 GHz for commercial applications. However, power spectral density for portable devices using this license free technology must be limited to a maximum of -41.3 dBm/MHz (FCC, 2002). This will hinder the development of UWB communication systems with very high data rates or covering larger distances. It is therefore essential to find a solution to overcome this scenario.

One possible solution is to design UWB systems with multiple antennas which can increase the channel capacity or the range significantly. It is interesting to note that Multiple Input Multiple Output (MIMO) radio system uses multiple antennas to transmit several parallel data streams simultaneously. Thus, the MIMO concept can be applied to the UWB systems to improve the link reliability, capacity or the range of the channel (Foschini and Gans, 1998; Shiu *et al*., 2000). The antenna is considered an important component in the UWB-MIMO technology which affects the overall performance of the proposed system. Planar antennas are widely used in UWB applications because of its light weight, conformal nature, easy to fabricate and to integrate with other microwave devices (Shin *et al*., 2008; Chung *et al*., 2009; Sim *et al*., 2010; Chahat *et al*., 2011; Huang and Chen, 2012).

In practice, due to limitations on the physical size of the portable radio devices, the distances between multiple antennas are small. However, closely packed radiating elements inevitably leads to mutual coupling effect which degrades the arrays performances. Several studies about UWB-MIMO antenna array have been reported recently. In literature (See *et al*., 2008), two suspended UWB plate antennas are designed for MIMO applications. However, the design is unable to satisfy the entire UWB spectrum. Najam *et al*. (2010) suggest a planar antenna systems based on two heterogeneous antenna elements for UWB-MIMO technology. In another design (Phairat and Chanchai, 2011), a quasi rhomboid shaped element bowtie antenna for MIMO applications is proposed.

This study presents a compact UWB-MIMO antenna array. The structure comprises of two identical UWB antenna elements. The designed antenna is compact as compared to those in Najam *et al*. (2010) and Phairat and Chanchai (2011). The mutual coupling

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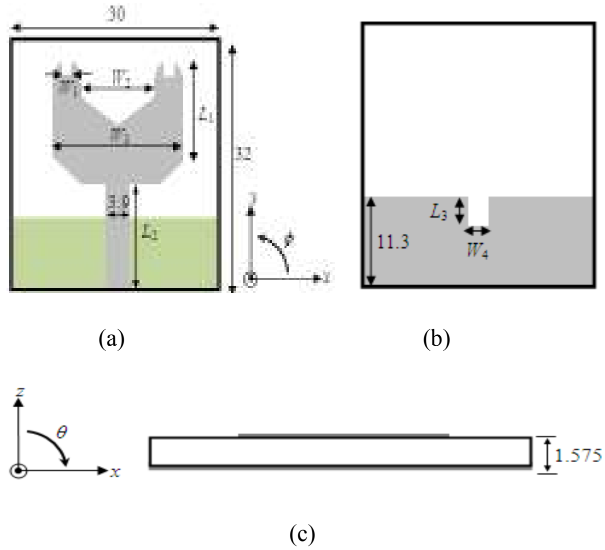


Fig. 1: Geometry of the UWB antenna element (Units in mm); (a) Front view; (b) Rear view; (c) Side view

Fig. 2: Fabricated antenna element photograph

and envelope correlation between the antenna elements are investigated to provide insights into the operation of the MIMO array. Experimental and simulated results of the fabricated prototype are presented.

SINGLE ELEMENT

Figure 1 illustrates a general schematic of the UWB antenna element. It is located in the *x*-*y* plane and the normal direction is parallel to the *z*-axis. The antenna is constructed on Taconic TLC-30 substrate with thickness approximately 1.575 mm and relative dielectric constant of 3. The radiator with dimensions 30×32 mm^2 is excited via a 50-Ω micro strip feed line that is connected to a Sub-Miniature version A (SMA) connector at the edge of a substrate board. The simulation results were obtained from the commercially available Computer Simulation Technology (CST) Microwave Studio package, which is based on the finite integration technique for electromagnetic computation. As seen in Fig. 2, a prototype of the single element UWB printed antenna is fabricated using the optimized parameter values tabulated in Table 1.

Table 1: Parameter values of the fabricated antenna

Parameter	W_1	W_2	W_3	W_4	L_1	L_2	L_3
Value (mm)	2	4	20	4	11	12	3.5

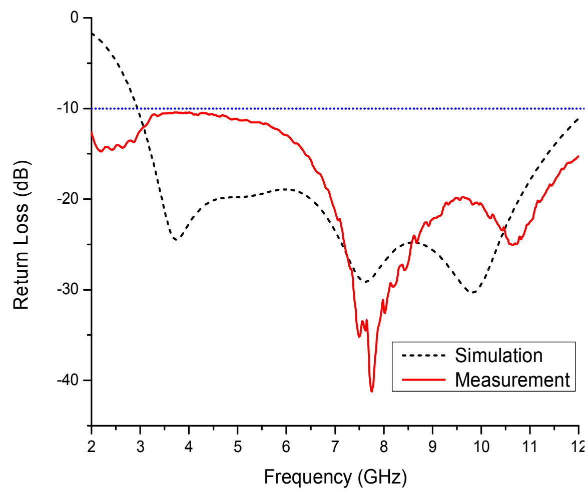
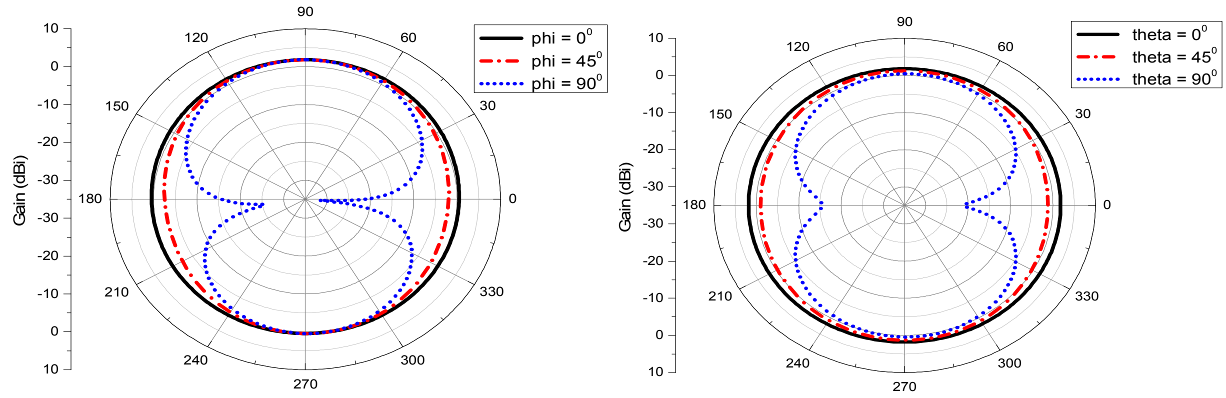


Fig. 3: Simulated and measured return loss of the antenna element

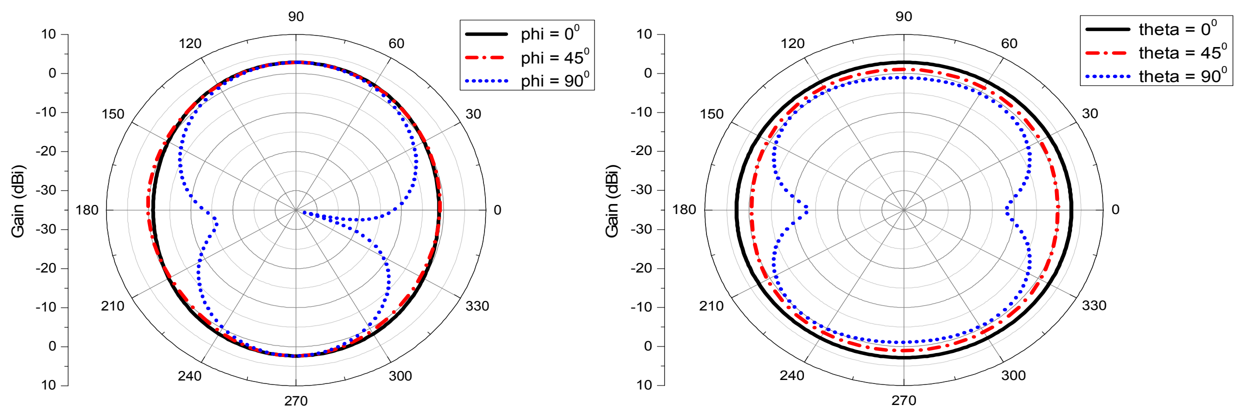
The return loss of the fabricated antenna is measured using a calibrated Rhode and Schwarz® ZVL vector network analyzer. The simulated and measured return loss curve has been depicted in Fig. 3. This figure reveals that the return loss of the antenna is more than 10 dB over a bandwidth range of 2.9 to 12.0 GHz. A reasonable agreement is achieved between simulation and measurement results. The slight differences between the two graphs can be attributed to the effect of SMA connector and fabrication tolerance. The normalized radiation patterns of the radiator in the *E*-plane (*y*-*z* plane) and *H*-plane (*x*-*z* plane) at various frequencies are plotted in Fig. 4. The results clearly show a stable omnidirectional pattern in the *H*-plane and a quasi-omni directional pattern in the *E*-plane.

MIMO CONFIGURATION

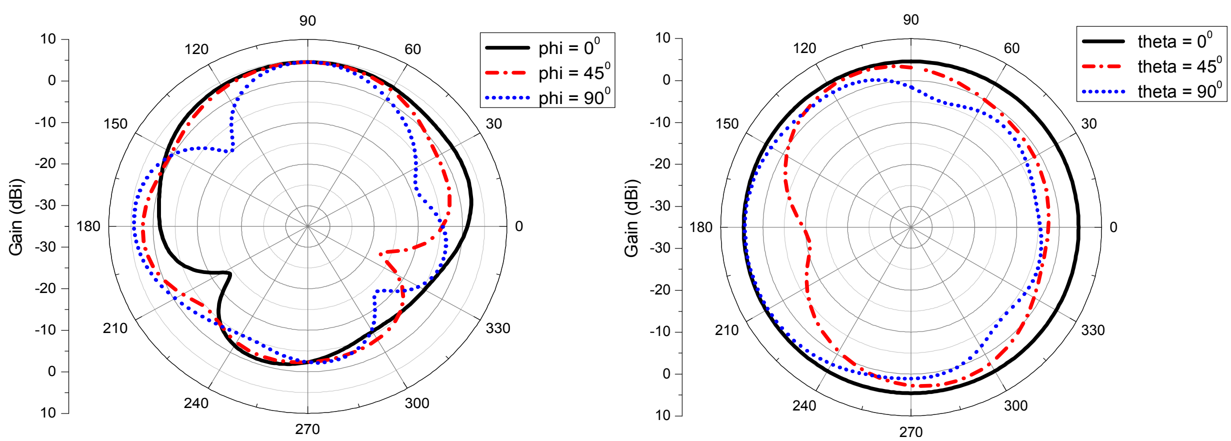
The antenna element described in pervious section exhibit all the desirable frequency domain characteristics demanded by the present UWB radio systems. Thus it is used to develop the proposed UWB-MIMO antenna. Figure 5 shows the geometry of the MIMO array composed by two identical radiating elements. To minimize mutual coupling effect, the distance between antenna elements feeds should be optimized. For this reason, in the present design, a distance between radiating element ports of 0.45λ (45 mm) at 3 GHz is considered for the MIMO array. The overall dimensions for the UWB-MIMO case are 32 mm×70 mm. The photograph of the fabricated UWB-MIMO array is shown in Fig. 6.



E–plane (a) H–plane



E–plane (b) *H*–plane



E–plane (c) H–plane

Fig. 4: Simulated *E*- plane and *H*- plane radiation patterns of the antenna element at (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz

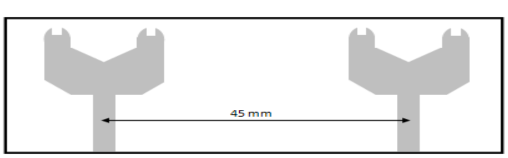


Fig. 5: Proposed MIMO array configuration

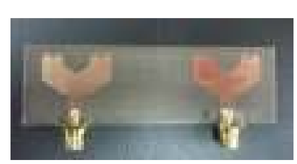


Fig. 6: Fabricated antenna array

RESULTS AND DISCUSSION

Figure 7 shows the simulated as well as the measured reflection coefficient plots of the proposed UWB-MIMO antenna structure. It is noticed that the measured-10 dB return loss bandwidths are from 2 to 11 GHz, which cover the UWB frequency range. The measured results agree with the simulated results well. The little difference between them is probably due to the manufacturing defects.

As reported in Zhou *et al*. (2010) and Najam *et al*. (2010), the mutual coupling performance of a MIMO antenna can be examined using both the forward transmission coefficient, S_{12} and the reverse transmission coefficient, S_{21}. The measured mutual coupling between the ports is less than -15 dB across the frequency band of interest, as shown in Fig. 8.

Figure 9 plots the normalized radiation patterns of the proposed antenna at 3, 6 and 9 GHz at *E*- and *H*-plane, respectively. The results indicate that antenna behaves nearly omni-directional in *H*-plane. A quasi-omnidirectional pattern is observed in *E*- plane due to uneven and complex current distributions. Figure 10 shows the measured gain at bore sight ($\theta = 0^0$, $\phi = 0^0$) for the MIMO antenna. It is seen that the antenna gain varies from 3.25 to 6.25 dBi across the UWB frequency region.

It is well known that correlation coefficient and diversity gain are closely interrelated in MIMO systems. Low correlation value concludes to better diversity gain. The mathematical relationship between diversity gain G_{app} and correlation ρ_e can be described as (Rosengren and Kildal, 2006):

$$G_{app} = 10\sqrt{1-|\rho|} \tag{1}$$

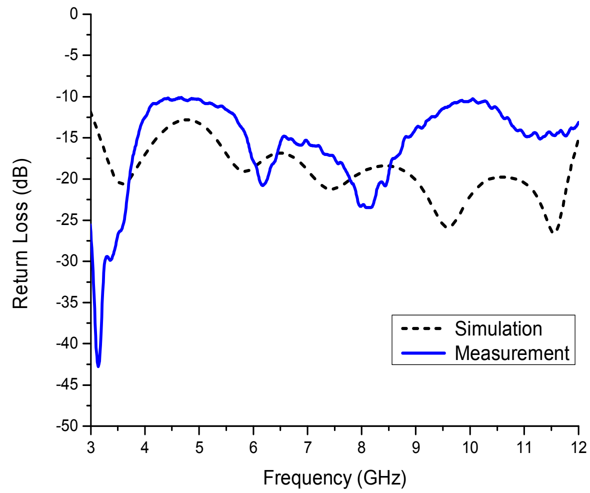


Fig. 7: Return loss of the MIMO array

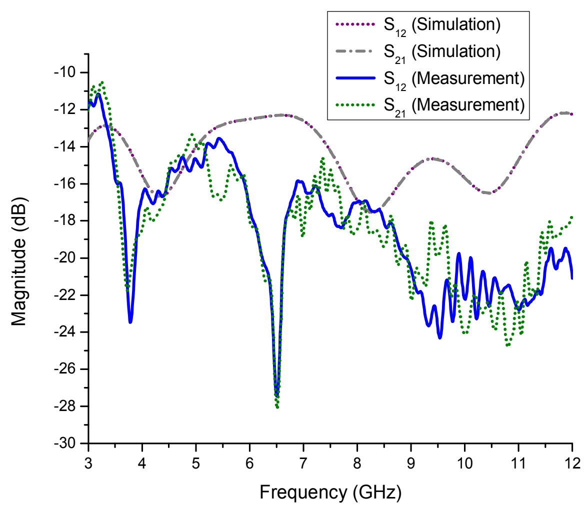
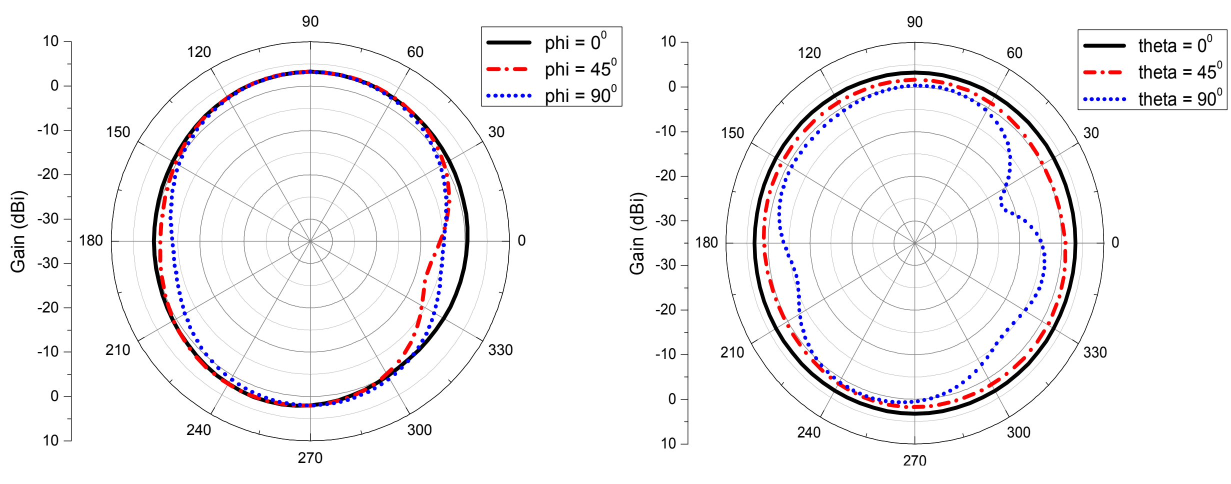
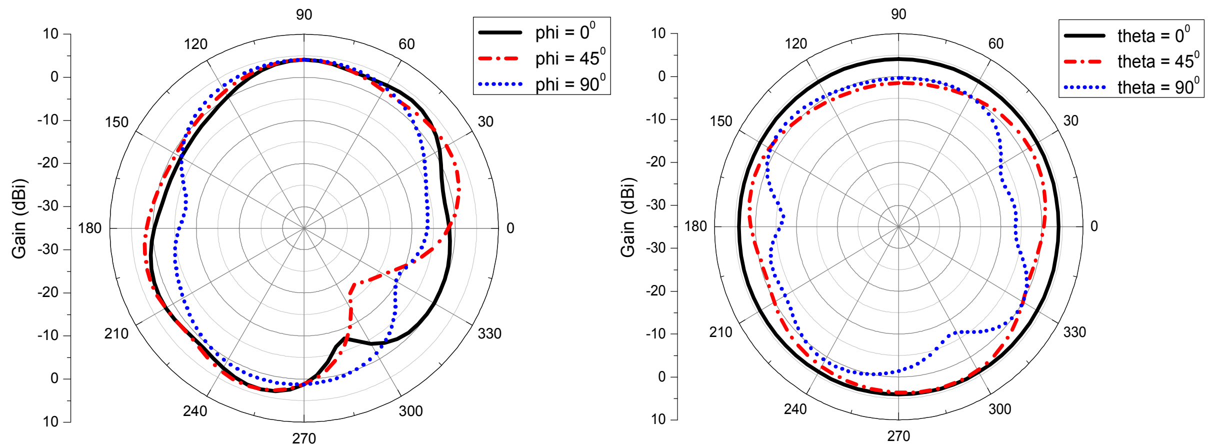


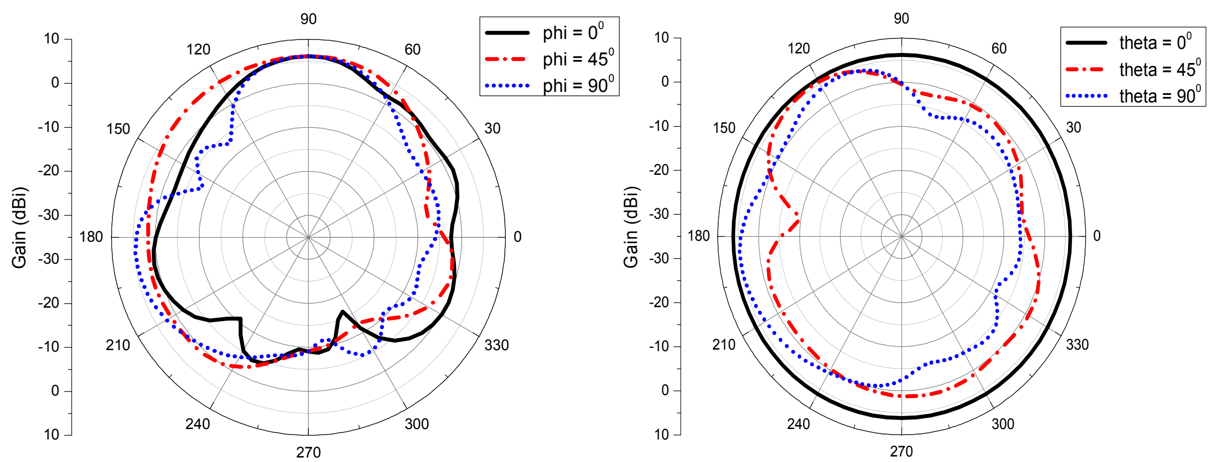
Fig. 8: Transfer parameters of the MIMO array



E-plane (a) H-plane



E-plane (b) H-plane



E-plane (c) H-plane

Fig. 9: Simulated E – plane and H – plane radiation patterns of the MIMO array at (a) 3 GHz, (b) 6 GHz, and (c) 9 GHz

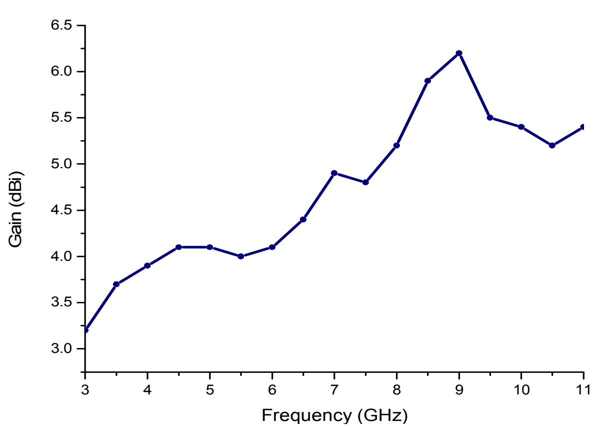


Fig. 10: Measured gains of the MIMO array at boresight

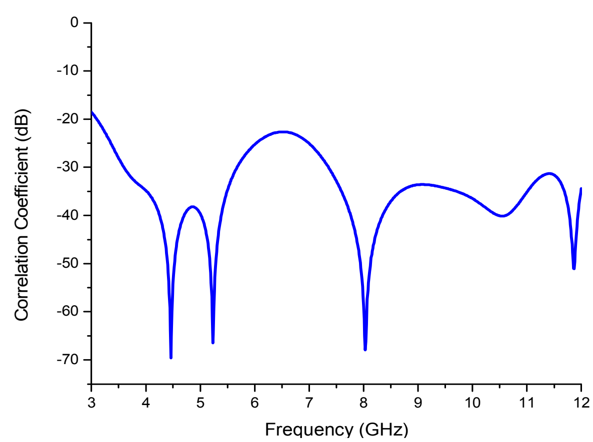


Fig. 11: Correlation coefficient of the UWB-MIMO array

According to Salonen and Vainikainen (2002), the envelope correlation ρ_e between the two radiators for the designed MIMO array can be obtained from the simulated S-parameters and is given by:

$$p_e = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^2}{\left[1-\left(\left|S_{11}\right|^2+\left|S_{21}\right|^2\right)\right]\left[1-\left(\left|S_{22}\right|^2+\left|S_{12}\right|^2\right)\right]} \quad (2)$$

The envelope correlation of the proposed MIMO system is presented in Fig. 11. From the result, it can be seen that the correlation for the designed antenna is less than -20 dB conforming its suitability for handheld MIMO devices.

CONCLUSION

This study proposes a compact two element MIMO array with a size of 32×70 mm^2 for portable UWB devices. The impedance bandwidth of the designed antenna ranges from 3 to 12 GHz. The broadband MIMO array features stable radiation pattern and high gain in a wide frequency band. Measurements show that proposed antenna has mutual coupling less than -15 dB within the UWB spectrum. From the antenna diversity results, it has been shown that the correlation coefficient value is less than 20 dB across the UWB band. It is anticipated that the presented antenna can be utilized for applications that incorporate UWB-MIMO technology.

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