UWB MIMO Antenna for High Speed Wireless Applications

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Abstract **─** The paper proposes a MIMO antenna composed of two elements in the form of UWB monopole antennas. Polarization diversity of the proposed antenna is obtained locating the two elements perpendicularly on a common substrate. Also the isolation between elements is accomplished without using any extra decoupling structures. The two monopoles antennas with half elliptical shape are fed with asymmetric coplanar strip (ACS). The presented antenna is located on substrate 48 × 28 mm^2 in total size. The distance between the two elements is 15 mm that is 0.15λ_0 at 3GHz. The antenna was designed to work effectively from 3 to 11.5 GHz with reflection coefficient better than -10 dB and isolation lower than 18 dB. In addition, antenna with elements located in parallel was designed to show the advantage of the original design. Envelope correlation coefficient, diversity gain and channel capacity loss document the antennas behavior. The antenna was fabricated and measured. Measurement validated the simulation and showed that the designed antenna can be well applied in UWB MIMO systems.

Index Terms **─** MIMO antenna, omni-directional radiation pattern, polarization diversity, UWB antenna.

I. INTRODUCTION

Ultra wideband (UWB) communication systems are a hot topic in wireless communication systems. There are clear advantages of these systems as high data rates, and low power consumption [1]. The unlicensed band of UWB technology operating at frequency band from 3.1 to 10.6 GHz is realized by the Federal Communication Commission (FCC) [2]. Many efforts have been employed to design UWB antennas due to their advantages such as low profile, compact size, larger impedance bandwidth and stable radiation characteristics [3-5]. In order to enhance the channel capacity, to decrease multipath fading, and to raise the quality of the received signals, antennas with polarization diversity are used more often than antennas known as MIMO systems [6-10]. The integration of the UWB antenna and diversity technology is used in wireless systems to achieve the good performance of the MIMO systems. Many UWB diversity antennas have been presented, e.g., in [11-13]. In the MIMO system, multiple and uncorrelated antenna elements are used to transmit and receive signals. The reliability of the system can be enhanced by selecting the received signal from different antenna elements. The design of compact size MIMO antennas of low signal correlation is important for portable devices. The problem is that antenna elements must be located very closely to save space, and at the same time high isolation between their elements must be kept. A number of ways how to increase the isolation between antenna elements has been proposed. These are: application of electromagnetic band gap (EBG) structures [14], and application of defected ground structures (DGSs) [15]. However, these structures are of a very complex configuration and occupy large areas. The asymmetric coplanar strip (ACS) feeding structure is used in the design to reduce the size of the UWB MIMO antenna. The ACS feeding structure introduces size reduction about one half of the CPW-fed antennas [16]. This paper proposes an original compact MIMO antenna with polarization diversity suitable for ultra wideband applications. The UWB antenna has bandwidth allocated for UWB applications from 3.1 to 10.6 GHz. More than -18 dB transmission coefficient through the entire UWB frequency range is achieved by without using any extra structure. The proposed UWB MIMO antenna has size of 48 × 28 mm^2. The two antenna elements are separated by 15 mm that is 0.15λ_0 at 3 GHz. For a verification

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purpose, the antenna was fabricated and its impedance and radiation characteristics were measured. The performance of simulated and measured results confirms that the proposed MIMO UWB antenna is suitable for UWB applications. All simulations are performed by the CST microwave studio (CST MwS). Correctness of the design is verified by measurements.

II. UWB MIMO ANTENNA CONFIGURATION

In this section two different UWB MIMO arrangements are presented as illustrated in Fig. 1 together with corresponding dimensions. Figure 1 (a) shows side by side configuration (antenna 1) and Fig. 1 (b) illustrates the perpendicular configuration (antenna 2).

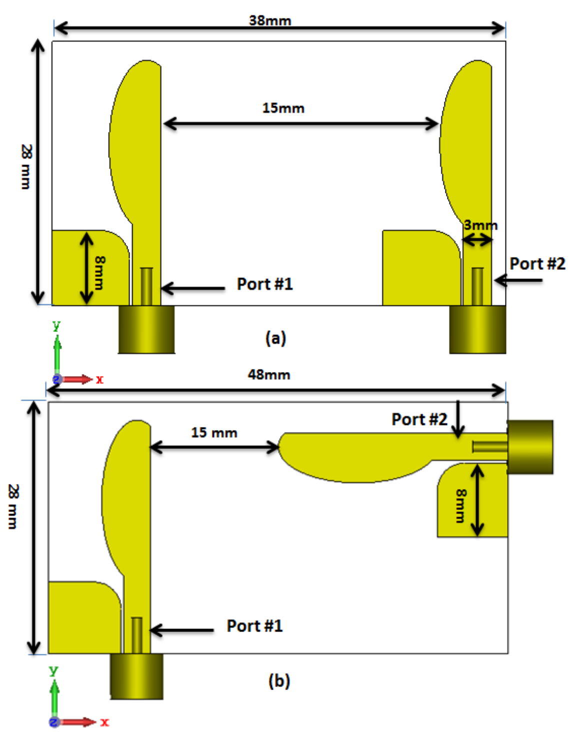

Fig. 1. Layout of the UWB MIMO antenna: (a) Antenna 1 (side by side arrangement), and (b) Antenna 2 (orthogonal arrangement).

The antennas are designed on FR4 substrate of permittivity 4.4 and 1.6 mm in thickness. The two antennas are fed by ACS with strip 3 mm in width and gap distance 0.3 mm to achieve 50 Ω characteristic impedance. The particular radiators are monopole antennas with semi elliptical shape. In order to improve the bandwidth of the UWB antenna, the ACS ground has a small curvature. ACS-fed is used to decrease the over size of the antennas. The distance between the two antenna edges in the two configurations has been succeeded to become 15 mm which equals $0.15\lambda_0$ at 3 GHz.

III. RESULTS AND DISCUSSION

A. Simulation

Figure 2 presents calculated scattering parameters of the two antenna versions. The antenna fed at port 2 shows similar values. The simulation results illustrate that the two antenna configurations have wide impedance bandwidth from 3 to 11.5 GHz with reflection coefficient lower than -10 dB. On the other hand, the mutual coupling in the antenna 2 (orthogonal arrangement) is better than the mutual coupling in the antenna 1 (side by side arrangement) as shown in Fig. 2 (b). There is more than -5 dB difference between the two antenna arrangements at different frequencies.

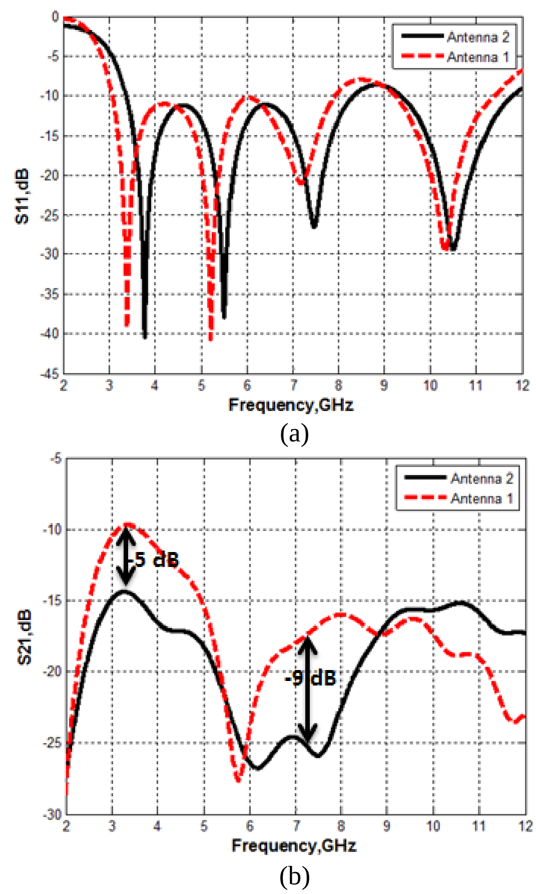

Fig. 2. Simulated S-parameters of the UWB MIMO antenna: (a) reflection coefficient, (b) transmission coefficient.

This presents the advantage the original configuration of antenna 2. The isolation coupling of antenna 2 is better than -18 dB at frequency bands from 4.5 to 9 GHz and around -15 dB from 3 to 4 GHz and from 9 to 11 GHz.

The simulated radiation patterns (3D) of the antenna 2 when one port 1 is excited and port 2 is matched with 50 Ω load and vice versa at 4 GHz, 6 GHz, and 10 GHz are presented in Fig. 3. Radiation patterns of the antenna excited by ports 1 and 2 are mutually orthogonal. Good polarization and pattern diversity between the two antenna elements follow from that. Peak gain and efficiency of antenna 2 calculated by the CST MwS supposing that port 1 is excited and port 2 is terminated by 50 Ω load are plotted in Fig. 4. The antenna has average gain around 3.5 dBi, and the efficiency has average value around 85% within the operating frequency band.

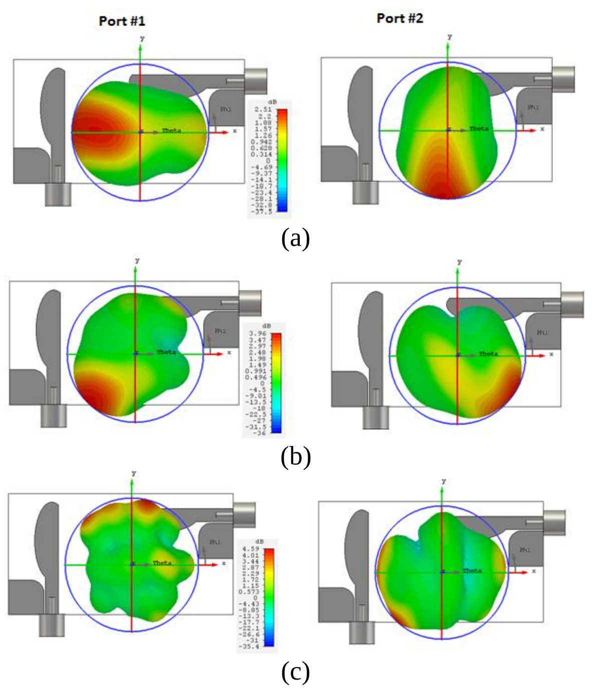

Fig. 3. Simulated 3D radiation patterns of the antenna 2: (a) at 4 GHz, (b) at 6 GHz, and (c) at 10 GHz.

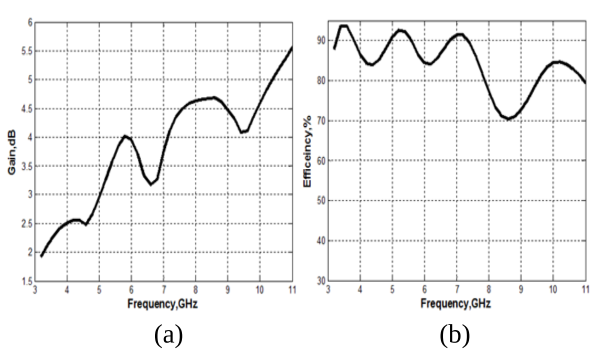

Fig. 4. Simulated results of UWB MIMO Antenna 2 (orthogonal arrangement): (a) peak gain and (b) total efficiency.

B. Measurement

The FR4 substrate with relative permittivity 4.4, 1.6 mm in thickness, and loss tangent equal to 0.025 was used in the fabrication of the proposed UWB MIMO antenna, see photograph in Fig. 5. Measured and simulated reflection and transmission coefficients are plotted in Fig. 6. Figure 6 (a) shows that the antenna operates at frequency band from 3 to 11.5 GHz with reflection coefficient lower than -10 dB. Mutual coupling is better than -18 dB within the frequency band from 4.5 to 11 GHz and from 4 to 4.5 GHz it reaches value better than -15 dB. A good consistency can also be noticed between the measured and simulated results. However, measured and calculated resonance frequencies are shifted. This is due to the mismatch of the feeding setup and the accuracy of fabrication process.

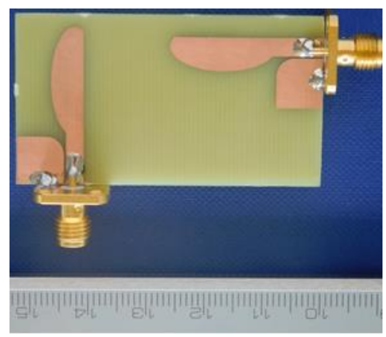

Fig. 5. Photograph of the fabricated UWB MIMO antenna.

Antenna radiation patterns were measured inside anechoic chamber using the NSI 800F-30 system at 4 GHz and 10 GHz for the three main planes, x-z plane, x-y plane, and y-z plane. They are plotted in Fig. 7 and Fig. 8. The measurement was done assuming the excitation at port 1 while port 2 was matched with 50 Ω load and vice versa. Radiation patterns in x-y and y-z planes of port 1 and port 2 are rotated by 90 degrees, and the radiation pattern in x-z plane of port 1 is almost similar to the radiation pattern in x-z plane of port 2. This is due to the fact that the two antenna elements are positioned on the substrate perpendicularly. The radiation patterns in x-z plane of port 1 and port 2 are omnidirectional, and are bidirectional in the x-y and y-z planes of port 1 and port 2. However, there are small differences between the measured and calculated radiation patterns. This is due to the asymmetric ground plane of the presented design fed through ACS and because the measured setup such as there is some radiated power doesn't take into account in the measurements due to the small size of the proposed antenna. Finally, it can be observed that there is reasonable agreement between the simulated and measured radiation patterns in all planes.

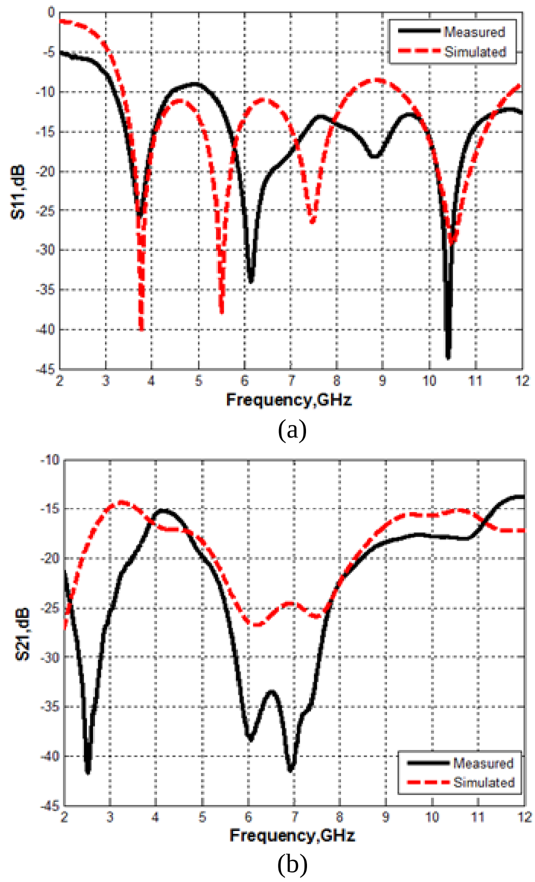

Fig. 6. Measured and simulated S-parameters of the UWB MIMO antenna: (a) reflection coefficient, and (b) transmission coefficient.

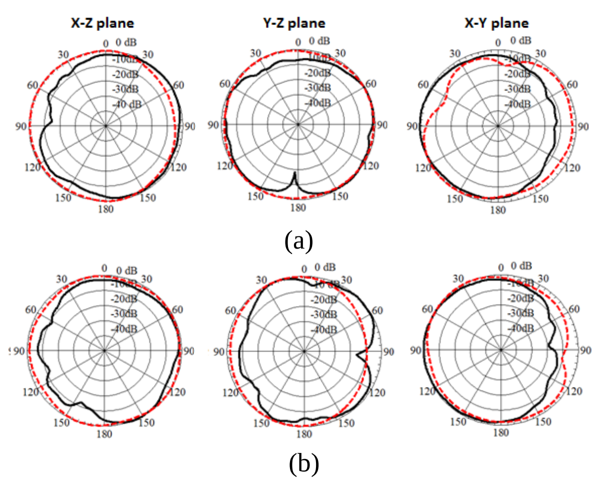

Fig. 7. Measured black (solid) and simulated red (dashed) results of the directive gain at 4 GHz: (a) port 1 and (b) port 2.

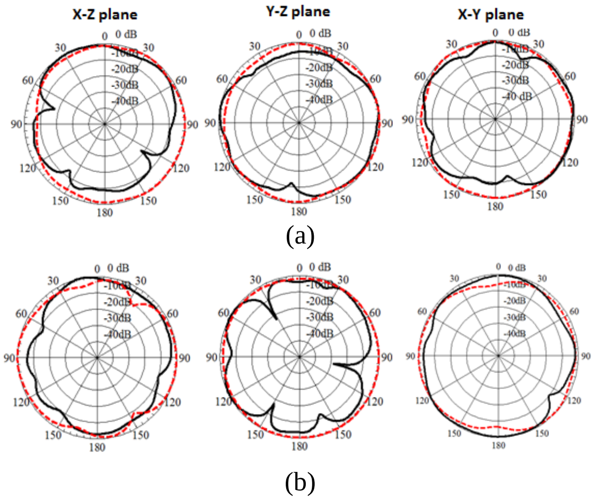

Fig. 8. Measured black (solid) and simulated red (dashed) results of the directive gain at 10 GHz: (a) port 1 and (b) port 2.

IV. MIMO PERFORMANCE

The diversity behaviour of the MIMO antenna can be confirmed by one of the three parameters: envelope correlation coefficient (ECC), by diversity gain, and/or by channel capacity loss (CCL).

A. Envelope correlation coefficient and diversity gain

ECC defines the correlation of antenna elements. The correlation coefficient between the antenna elements should to be with lower values for achieving a higher diversity between the MIMO antenna elements [17]:

$$ECC = \rho_e = |\rho_{ij}| = \frac{\left|S_{ii}^{*}S_{ij} + S_{ji}^{*}S_{jj}\right|^2}{\left(1-\left(|S_{ii}|^2+|S_{ji}|^2\right)\right)\left(1-\left(|S_{jj}|^2+|S_{ij}|^2\right)\right)}. \quad (1)$$

ECC of both antenna 1 and antenna 2 is plotted in Fig. 9. ECC of the proposed antenna 2 has value lower than -50 dB within the operating frequency band. However, ECC of the antenna 1 shows the same values except at the frequency band from 3.5 to 4.8 GHz where it increases to -40 dB. This means that the correlation between the elements of the proposed antenna 2 is better than the correlation of the antenna 1. Diversity gain (DG) relates to ECC [18]:

$$DG = 10 * \sqrt{1-|ECC|}. \quad (2)$$

The diversity gain of proposed antenna is plotted in Fig. 10. It is 10 dB within the operating frequency band. However, at frequency from 3.5 to 4.8 GHz it decreases to 9.8 dB in the case of the antenna 1.

B. Channel capacity loss (CCL)

CCL is an important parameter evaluating the MIMO performance. In any conventional system, CCL increases linearly with the number of used antenna elements without increasing the bandwidth or transmitted power and this occurred under a specified assumption [19]. The correlation between elements in MIMO channel systems produces capacity loss calculated by using [20]:

$$CCL = -\log_2 \det(\psi^R), \quad (3)$$

$$\psi^R = \begin{bmatrix} \rho 11 & \rho 12 \\ \rho 21 & \rho 22 \end{bmatrix}$$

$$\text{where} \quad \rho_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2 \right) \quad . \quad (4)$$

$$\rho_{ij} = -\left(S_{ii}^* S_{ij} + S_{ji}^* S_{ij} \right) \quad for \quad i, j = 1 \, or \, 2$$

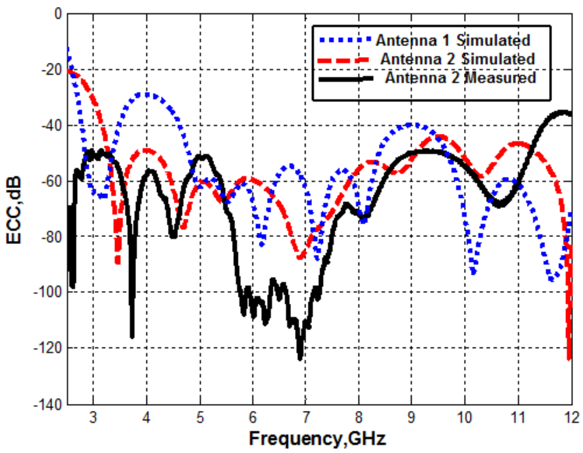

Fig. 9. Simulated and measured results of the envelope correlation coefficient of UWB MIMO antenna.

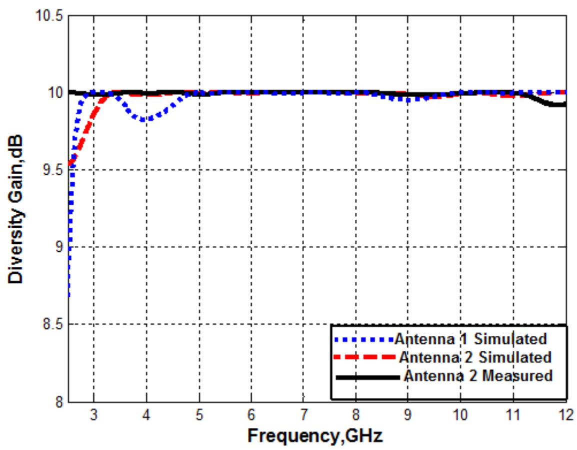

Fig. 10. Simulated and measured results of diversity gain of UWB MIMO antenna.

The simulated and measured CCL is plotted in Fig. 11. CCL value is lower than 0.4 bits/s/Hz within the operating frequency band. CCL of antenna 1 is higher than 0.4 bits/s/Hz as shown in Fig. 11. Finally, it follows from Fig. 9, Fig. 10, and Fig. 11, that the proposed MIMO UWB antenna achieves good MIMO performance, better than antenna 1. This confirms that the proposed antenna can be considered as a good choice to operate in UWB MIMO applications.

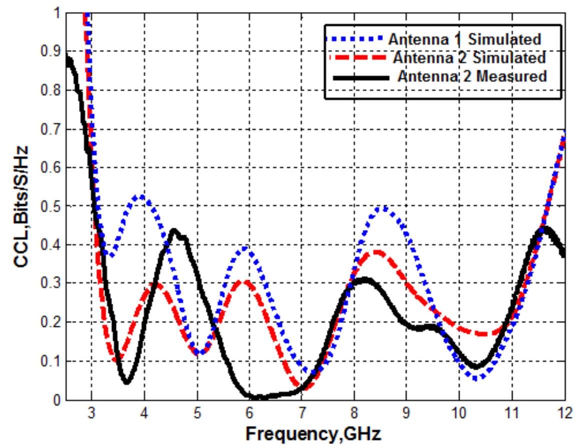

Fig. 11. Simulated and measured channel capacity loss of the UWB MIMO antenna.

V. CONCLUSION

A compact UWB MIMO antenna with polarization diversity has been presented. It consists of two elements in the form of monopoles of half elliptical shape. The elements are fed through asymmetric coplanar strip. The proposed antenna operates at frequency band from 3 to 11.5 GHz with reflection coefficient lower than -10 dB and isolation lower than 18 dB. Both simulations and measurements showed that the proposed configuration has polarization diversity features, low ECC through the operating frequency band, and has good MIMO performance. Due to this the designed antenna is a good candidate for UWB MIMO and polarization diversity applications. Theoretical design has been verified by experiments.

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