Optically Transparent 4-port UWB Antenna for MIMO Applications

Rabia Yahya
Department of Physics
Faculty of Science and Technology
Nouakchott University
Nouakchott, Mauritania
rabia.yahya@univ-nkc.mr

Haosen Yin
Department of Electrical and Computer Engineering
Cornell University
Ithaca, NY, United States
hy584@cornell.edu

David Bertuch
Department of Electrical and Computer Engineering
Cornell University
Ithaca, NY, United States
dcb277@cornell.edu

Amal El-Ghazaly
Department of Electrical and Computer Engineering
Cornell University
Ithaca, NY, United States
ase63@cornell.edu

***Abstract*— Herein, we present a novel transparent antenna with ultra-wideband (UWB) performance along with polarization diversity through 4 ports allowing MIMO operation. The antenna design can be of a great interest for a vehicular applications and Internet of Things (IOT) where the dual polarization and multiple ports allows as well as medical glasses and vehicular windows where transparency is needed for visibility. The proposed antenna provides compact size with dimensions of 50 mm×50 mm, through the employment of CPW, dual orthogonal-polarization, isolation level of 20 dB, and envelope correlation coefficient (ECC) of 0.0016 as well as MIMO performance.**

Keywords—Transparent antennas, UWB technology, Dual-polarization, MIMO systems.

I. Introduction

Antennas are indispensable elements in any electronic system, especially today as wireless communication technology has overrun almost every integrated system and electronics applications. Hence, comes the necessity of providing new approaches to reduce antenna crowding, both spatially and spectrally. The introduction of transparency into the antenna design is not only for aesthetic reasons but also for better integration into environments necessitating visibility through surfaces, such as in smart buildings, solar cells and even medical lenses and glasses. Furthermore, transparent antennas are promising for Internet of Things (IOT) applications, where a huge number of antennas are needed to ensure communications between all components of the network. Intelligent Transportation Systems (ITS) also arise as a competitive application for transparent antennas with the major advantage that the antennas can be easily integrated into the large area windows in the automotive vehicle surface. All of the aforementioned applications require high data rate, robustness to multipath fading, and interference mitigation between the large number of antennas needed for MIMO. These features can be provided by ultra-wideband (UWB) technology due to its extremely large bandwidth allocated by the Federal Communications Commission (FCC) in 2002 [1]. Additionally, diversity techniques are also utilized to compensate for the need for more than one antenna by providing independent propagation paths, maximizing the channel capacity, improving the transmission quality, and increasing the reliability of the system [2].

Recently, various UWB MIMO antennas have been reported to serve multiple applications. In [3], Suresh et al. design a spike shaped 4-port MIMO antenna, with small size (40 mm×40 mm), good isolation level of 26 dB, and remarkable diversity performance with envelope correlation coefficient (ECC) of 0.0016 for UWB wireless networks. Govindan et al. present a flexible MIMO antenna with ultra-wideband (UWB) performance for smart clothing applications, with size of 50 mm×50 mm, isolation level of 17 dB, and ECC of 0.045 [4]. Furthermore, in [5], Alfakhri et al. place four radiators orthogonal to each other to achieve the dual polarization operation; additionally, a cross-shaped Defected Ground Structure (DGS) is inserted in the ground plane to improve decoupling between the antenna elements resulting in an isolation level of 20 dB, ECC below 0.1, and occupying area of 48 mm×44 mm. Although these antennas all provide compact size, good performance, and orthogonal polarization, they all lack transparency. A novel optically transparent MIMO antenna for automotive applications is presented in [6]. However, this antenna has only two ports and does not provide orthogonal polarization. In [7], a transparent UWB MIMO antenna based on a wired metal mesh (MM) structure was fabricated with 77% transparency and size of 70 mm×70 mm. More recently, four identical elements have been strategically positioned in a sequential rotational arrangement to effectively realize MIMO diversity performance [8]. In this paper, we propose an antenna with all the aforementioned features: transparency, 4-port operation, orthogonal dual polarization, and good performance over the entire UWB frequency range from 3.1 to 10.6 GHz. The proposed antenna improves upon the previously mentioned antennas in terms of size, transparency, diversity features and structural symmetry (which provides similar radiation patterns for each of the two orthogonal polarizations), and combines these features all in the same structure.

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Section II explains the design of the proposed antenna, then Section III presents the performance of the antenna along with the fabrication process.

II. STRUCTURE OF THE PROPOSED ANTENNA

The structure of the proposed antenna was developed through a series of progressive steps as shown in Fig. 1. First, in Fig. 1a, a circular slot fed by two coplanar waveguide (CPW) lines through two semi-circular patches placed in a perpendicular arrangement to achieve orthogonal polarization. Two strips are inserted between the semi-circular patches to enhance the isolation between the ports. To maximize the polarization purity of the antenna, an additional two diagonal strips are added as indicated in Fig. 1b. Furthermore, to enhance MIMO diversity characteristics, two orthogonal CPW lines ending with semi-circular patches are inserted as in Fig. 1c. The four patches have the same dimensions and the CPW lines have a signal line width of 1.05 mm and a gap between the signal line and the coplanar ground plane of 0.3 mm, giving a 50 Ω characteristic impedance.

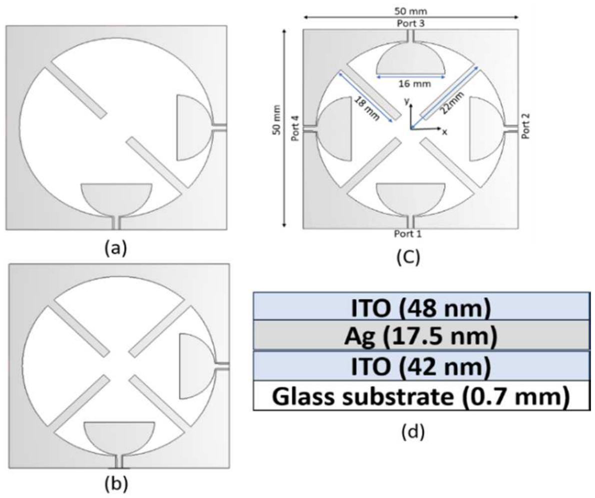

Fig. 1. Design steps of the structure of the proposed antenna.

a) Perspective view of two ports structure with isolation strips, b) perspective view of two ports structure with isolation strips and polarization strips, c) perspective view of the proposed antenna, and d) side view of the antenna structure.

The conductive layer of the antenna is composed of a thin film of Silver (Ag) inserted between two layers of Indium Tin Oxide (ITO). The conductor stack was deposited onto a glass substrate with approximate structure of ITO (48 nm)/Ag (17.5 nm)/ITO (42 nm)/Glass (0.7 mm) as reported in [9], where a transparency of 88% and sheet resistance of 3.1 Ω/sq are achieved. A Corning Eagle XG glass substrate is used, having a relative permittivity of 5.27, loss tangent of 0.001, and thickness of 0.7 mm. The proposed structure has been fabricated in the Cornell NanoScale Science and Technology Facility (CNF) and a picture of the fabricated antenna is included in Fig. 2. The fabrication process began by first, cleaning the glass substrate with acetone and isopropyl alcohol, then prebaking it before coating it with LOR-3A and S1813 photoresists. The antenna design was then exposed onto the substrate using a contact aligner and the pattern was developed. ITO was then sputtered onto the glass substrate on one side using an Indium-Tin target in a Kurt J. Lesker PVD 75 sputtering tool with a partial pressure of oxygen and a substrate temperature of 100°C. The composition of the ceramic sputtering target used is 90% Indium/10% Tin. After sputtering the ITO, a layer of Ag with thickness of 17.5 nm was e-beam evaporated using a CHA evaporator. Later, the process of ITO deposition was repeated. Subsequently, the substrate was soaked in Microposit Remover 1165 and sonicated to lift-off the photoresist and achieve the desired pattern. The substrate was then diced in a Disco wafer saw to extract the precise square antenna piece. As a final step, 50 Ω SMA ports were connected to the antenna CPW feed lines using a conductive epoxy to prepare the antenna for measurement.

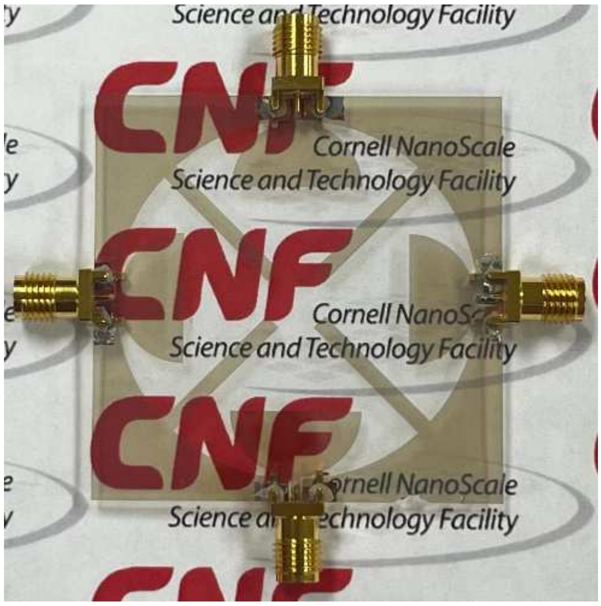

Fig. 2. Image of the fabricated transparent antenna prototype.

III. RESULTS AND DISSCUTION

The proposed antenna was simulated using CST (Computer Simulation Technology) and the fabricated prototype was measured using a Vector Network Analyzer working up to 8.5 GHz. Fig. 3 shows the simulated and measured reflection and transmission characteristics of the antenna. As a benefit of the symmetry of the antenna structure, the reflection coefficients of all four ports are similar, and the agreement between the simulated and measured results is noteworthy. Therefore, we can conclude that the antenna operates over the entire UWB band, with a good isolation level of 20 dB between adjacent ports (port 1 and port 2) as well as opposite ports (port 1 and port 3). The radiation patterns simulated throughout the operating band are shown in Fig. 4 where the radiation patterns in the E-plane (xz-plane) and in H-plane (yz-plane) at specifically 3 GHz, 7 GHz, and 10 GHz are depicted. For brevity, only the radiation patterns of port 1 are shown since the radiation patterns for port 3 are similar, and those for the ports 2 and 4 simply exhibit a rotation of 90 degrees due to their orthogonal polarization. Additionally, the cross-polarized radiation patterns are shown in H-plane to visualize the purity of polarization obtained. For all radiation patterns, we notice a clear similarity over the operating band.

To evaluate the diversity performance of the proposed antenna and to ensure its MIMO functionality, the simulated envelope correlation coefficient (ECC) and diversity gain (DG) are indicated in Fig. 5. The value of the ECC is less than 0.0016 over the entire UWB band signifying high isolation and uncorrelated radiation patterns between any two ports of the antenna. The DG of the antenna also shows a great diversity performance with a value of 10 dB over the entire UWB band.

The performance of the proposed antenna is compared with relevant state of the art designs in Table I, indicating the favorable performance of this antenna based on its size, high isolation, small ECC, transparency, and number of ports.

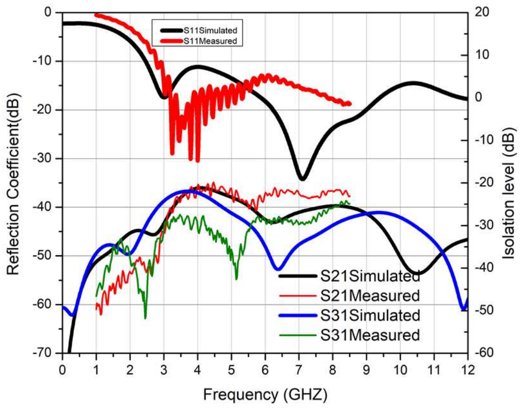

Fig. 3. Measured and simulated S-parameters of the proposed antenna.

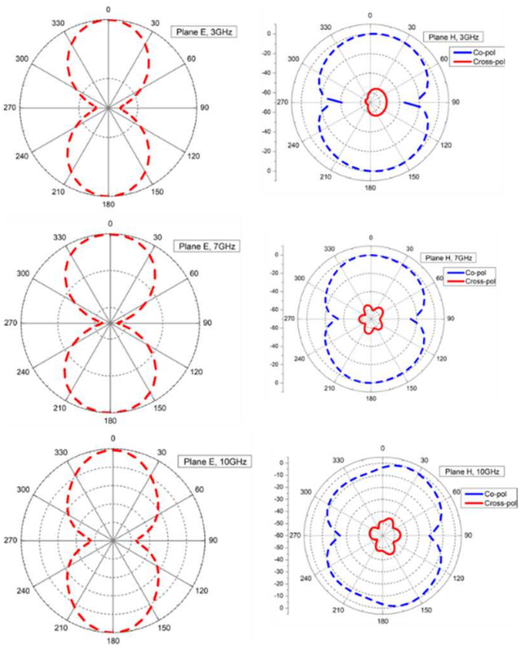

Fig. 4. Simulated radiation patterns of the proposed antennas in E-plane and H-plane at 3 GHz, 7 GHz and 10 GHz.

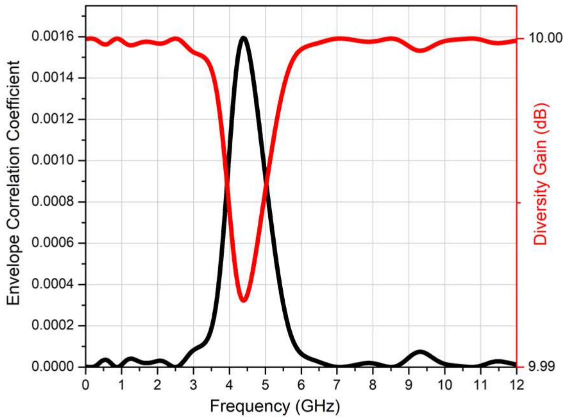

Fig. 5. Simulated ECC and DG for the proposed antenna.

TABLE I. COMPARAISON OF THE PROPOSED ANTENNA WITH RELEVANT STATE OF THE ART

Reference	Size mm×mm	Isolation	ECC	Transparent	ports
[3]	40×40	26 dB	0.0016	No	4
[4]	50 ×50	17 dB	0.045	No	4
[5]	48 ×44	20 dB	<0.1	No	4
[6]	29×50	20 dB	<0.04	Yes	2
[7]	70×70	20 dB	<0.04	Yes	4
This work	50×50	20 dB	0.0016	Yes	4

CONCLUSION

An ultra-wide band transparent antenna with features suitable for MIMO is proposed for various applications across automotive, IOT, and medical industries, among others. The performance of the antenna has been proven through simulation as well as primarily measurement results with return loss below -10 dB and an isolation level of 20 dB. The proposed antenna provides high transparency, a symmetric and compact structure, dual orthogonal polarization with similar radiation patterns, and diversity characteristics with ECC less than 0.0016 and DG on the order of 10 dB over the entire UWB. Such multiport UWB antennas can significantly reduce the area consumption of antennas in wireless electronic systems and be used even on glass surfaces to enable high data rate communications without obstructing visibility.

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