UWB-MIMO Quadruple with FSS-Inspired Decoupling Structures and Defected Grounds

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Abstract **─** In this paper, a quad element Ultra Wideband Multiple-Input Multiple-Output (UWB-MIMO) antenna system is presented. The proposed design is compact as it has four semi-elliptical shaped antennas along with the decoupling structures, fabricated on a compact substrate. The substrate employed is a low cost FR-4 laminate. The antenna elements are decoupled by employing Defected Ground Structures (DGS) and structures inspired from Frequency Selective Surfaces. An enhanced impedance match over lower to medium band is achieved by introducing dipole-like parasitic stubs on rear sides of the antennas. Measured results show that the isolation achieved by the proposed design is more than 20 dB over desired frequency band.

Index Terms **─** Frequency Selective Surface (FSS), Multiple Input Multiple Output (MIMO), Ultra Wideband (UWB).

I. INTRODUCTION

A radio system that has a bandwidth more than 25 percent of its center frequency or a bandwidth more than 500 MHz may be defined as UWB. The UWB technology has drawn significant research attention due to low cost, high data rates and low power requirements [1]. The Federal Communication Commission (FCC) has allocated a frequency band of 3.1-10.6 GHz for the UWB technology [2].

A MIMO system needs a number of transmitters and receivers which operate concurrently to achieve system diversity gain [3-5]. However, placing multiple antennas in the limited space of a transceiver poses a significant challenge in the incorporation of MIMO technique. The individual antennas not only have to be impedance matched but also effectively isolated/decoupled from the neighboring MIMO antennas. The more the antennas in the MIMO transceiver, greater is the design challenge. As far as decoupling is concerned, one of the methods is to place antennas far apart. However, this method is not efficient as it is wasteful of space. Therefore, an efficiently designed decoupling/ isolation structure isolates all the antenna elements while not compromising space [6]. Compact MIMO systems for two elements has been proposed in [4,5] to cover the UWB frequency spectra with maximum isolation of 20 dB. The MIMO systems reported in [7,8] are designed to cover the lower and upper band of LTE with isolation of 15 dB and 20 dB, respectively. In [9], four element MIMO array with isolation of 15 dB was designed for the WLAN application. A four element MIMO system is reported in [3] to cover a band of 1.63 to 2.05 GHz.

Here in this work, a UWB-MIMO antenna quadruple is presented. Finite Element Method (FEM) based simulations in Ansys High Frequency Structure Simulator (HFSS) are employed for the proposed design. The fabricated UWB-MIMO quadruple is shown in Figs. 1 (a)

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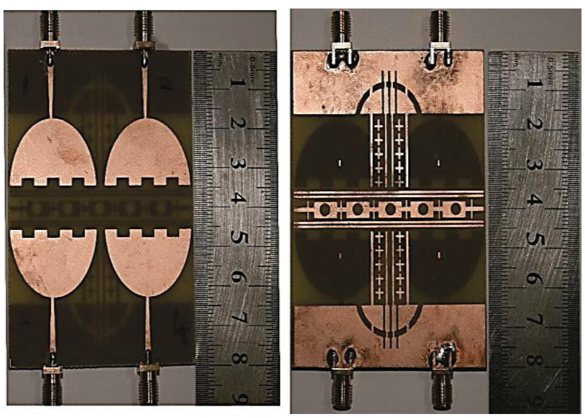
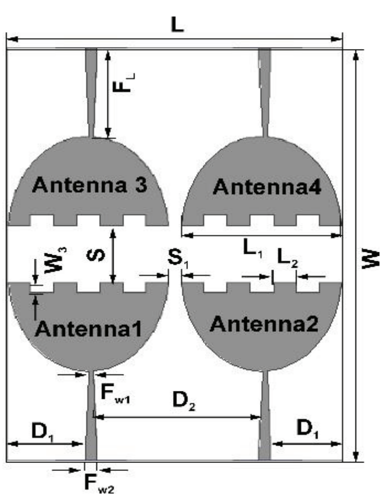
and 1(b).

As shown in Figs. 1 (a) and 2 (a), the quad antenna elements are semi-elliptical in shape. Each antenna has four rectangular structures placed on the top edge. These rectangular structures act as parasitic patches and provide better resonances, and in turn, an overall enhanced impedance match. Defected Ground Structures (DGS) are present on the rear side of antenna along with semi-circular arcs and vertical stub sections. The DGS provides enhanced impedance match, especially on the middle operating frequencies. Moreover, to further improve impedance match on the middle frequencies, miniature dipole-like parasitic structures [10] are placed on middle of the rear sides of antenna.

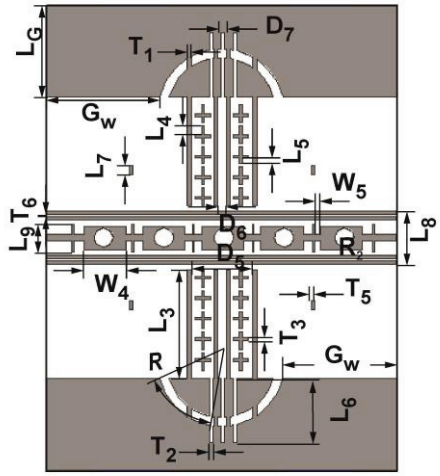


(a) Front view (b) Back view

Fig. 1. Fabricated antenna.



(a) Front view



(b) Back view

Fig. 2. UWB-MIMO simulated design.

The decoupled UWB-MIMO quadruple is presented with novel isolation/decoupling structures. As the quadruple is designed for MIMO communication, there are two main challenges in the design. First challenge, is to keep the impedance match of the individual antennas while maintaining a considerable level of decoupling among all of the antenna elements [8]. Second challenge, is to manage overall compactness of the UWB-MIMO array while adjusting four antenna elements and the decoupling structures on the substrate. The antennas placed side-by-side are decoupled by cross-shaped structures placed between pairs of narrow vertical strips attached to the DGS. The cross-shaped structures are similar to those employed in the design of FSSs [11]. Over most of the frequency band, an isolation of 20 dB between the antennas placed side-by-side is achieved by this linear arrangement of cross-shaped structures. The antenna pairs placed across each other are again decoupled by an FSS-inspired structure. This chain-like structure is an alternating combination of crosses and rectangular patches which have miniature circular slots. In general, in most of the frequency band, an isolation of 20 dB is achieved between antennas placed across or diagonally across each other.

The layout of the rest of this paper is as follows: in Section II a discussion of the antenna elements is given, the FSS-inspired decoupling structures are discussed in Section III, simulated and measured results are discussed in Section IV, and finally in Section V the paper is concluded.

II. ANTENNA ELEMENT DESIGN

The geometry and design of proposed UWB-MIMO system is shown in Figs. 1 and 2. The system is fabricated on an FR-4 substrate of thickness of 1 mm. The proposed MIMO system is compact with dimensions of L=58 mm × W=79 mm. The top layer comprises of quadruple antenna elements; whereas, the ground planes are etched on substrate flip side. The proposed design consists of quadruple semi-elliptical radiating elements. The radiators are independently impedance matched to a 50-Ω tapered feed line of length F_L=17 mm. The taper of this feed line is created by straight lines. The feed line has width of F_{W2}=2 mm at the SMA pcb-type connector and gradually reduces to F_{W1}=0.67 mm at the antenna. The feed lines are separated by a distance D_2=28 mm and located at a distance D_1=13 mm from substrate edges. The antennas are semi-elliptical in order to provide an enhanced impedance bandwidth. The semi-elliptical elements have major axis radii of 18 mm and axial ratios of 0.77. The antenna top end width is kept at L_1=27 mm. The antenna placed side-by-side are separated by a distance of S_1=4 mm at the top ends. However, the antennas placed across each other are separated by a distance of only S=11 mm, so an overall compact size is maintained. Each radiating element has four parasitic structures placed on the top edge. These parasitic structures provide more resonances, or in other words, an enhanced impedance match. Each of these rectangles have dimensions of L_2=4 mm × W_3=2 mm. In the proposed design, a single DGS is shared by antennas placed beside each other. This DGS has dimensions of W=58 mm × L_G=16 mm.

III. DESIGN OF DECOUPLING STRUCTURES

The geometry and design of proposed decoupled UWB-MIMO quadruple is shown in Figs. 1 and 2. The proposed quadruple is mutually decoupled by employing a total of four different arrangements of decoupling structures etched on flip side of the substrate.

A. Decoupling structure for side-by-side antennas

The antennas placed side-by-side are decoupled by multiple structures. First of these multiple structures are cross-shaped. As may be observed, these crosses are placed between narrow vertical strips attached to the DGS. The outer vertical strips are separated by a distance of D_5=15 mm and have dimensions of L_3=10 mm × T_3=1 mm. The inner vertical strips are detached by a distance of D_6=5 mm and have dimensions of L_3=10 mm × T_2=0.5 mm. The crosses each have dimensions of L_4=2 mm × T_3=0.5 mm; L_5=2.5 mm × T_3=0.5 mm.

Second of these decoupling structures are the DGS. A semi-circular slot of radius R=10 mm and width 1 mm is etched in the shared ground plane. Moreover, four vertical stubs are introduced in the circular slot to provide impedance match over the middle frequency band [12]. These slots have dimensions of L_6=2.5 mm × T_2=0.5 mm and a separation of D_7=3 mm. Overall, the proposed circular shaped DGS serves dual purpose of a high order matching network as well as an effective decoupling structure by suppressing the undesired induced currents.

Third of these multiple decoupling structures are four miniature dipole stubs. These stubs are placed behind each radiation element. Dimensions of each stub are L_7=1.5 mm × T_5=0.5 mm. These stubs serve dual purpose of improving the isolation on the lower frequency band and enhancing the impedance bandwidth.

B. Decoupling structures for antennas placed across each other

The antenna pairs placed across each other are separated by a distance of only L_8=11 mm. Therefore, an effective decoupling/isolating structure has to be employed to provide isolation between antennas placed across and diagonally across each other. This decoupling is achieved by the fourth decoupling arrangement. As shown in Figs. 1 (b) and 2 (b), antennas placed across are decoupled by a chain-like arrangement of crosses and rectangular patches. This chain-like structure is enclosed by double strips on either side. The cross-shaped structures have dimensions of L_9=5 mm × T_5=1 mm; whereas, the rectangular patches have dimensions of W_4=10 mm × L_9=5 mm. The circular slots introduced in each rectangular patch have radii of R_2=2 mm.

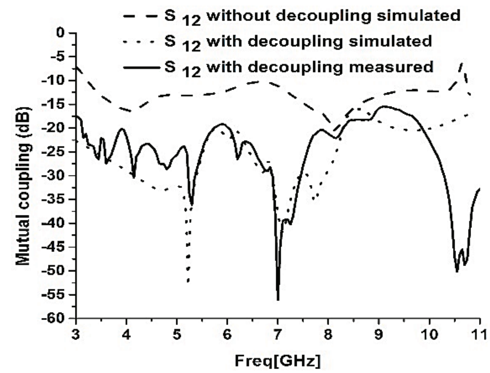
IV. SIMULATION AND MEARUREMENTS

A. Decoupling performance

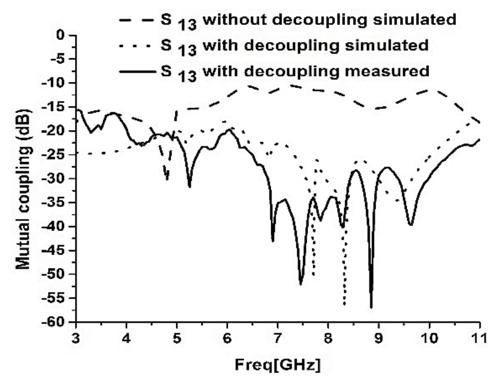
To demonstrate the isolation/decoupling performance, the proposed UWB-MIMO quadruple is simulated, with and without the decoupling arrangement. The simulated and measured insertion loss plots are shown in Fig. 3. As shown in Fig. 3 (a), the isolation between antennas placed side-by-side is not effective without a decoupling structure. However, introduction of the decoupling structure achieves an isolation of more than 20 dB over most of the frequency band. The simulation results for antennas placed across are presented in Fig. 3 (b). It may be observed that, for antennas placed across, without parallel strips enclosed chain structure, considerable isolation cannot be achieved. However, introduction of the chain-like structure achieves an isolation of more than 20 dB over most of the frequency band. The simulation results for antennas placed diagonally across are presented in Fig. 3 (c). For antennas placed diagonally across each other, the decoupling is better when the chain-like decoupling structure is introduced. With the decoupling structure, an isolation of over 25 dB is achieved. Simulated and measured results are shown in Table 1.

Table 1: Comparison of measured isolation; with and without decoupling structure

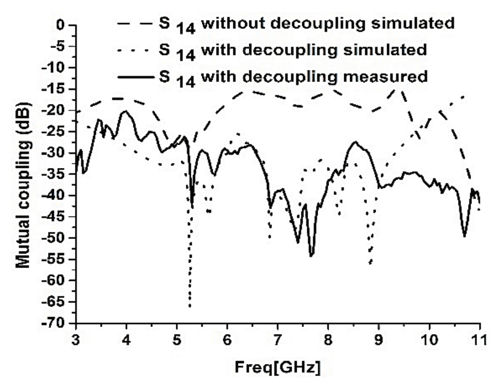
Frequency (GHz)	Side-by-Side with/without Decoupling Structure (dB)	Placed Across with/without Decoupling Structure (dB)	Diagonally Across with/without Decoupling Structure (dB)
3	-17.5/-8	-15/-18	-34/-20
7	-34/-11.5	-35/-11.3	-38/-16
9	-16/-13	-29/-15	-37/-20



(a) Side-by-side antennas: 1 and 2



(b) Antenna placed across: 1 and 3

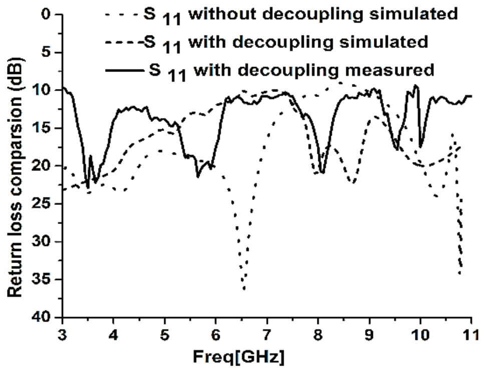


(c) Antenna placed diagonally across: 1 and 4

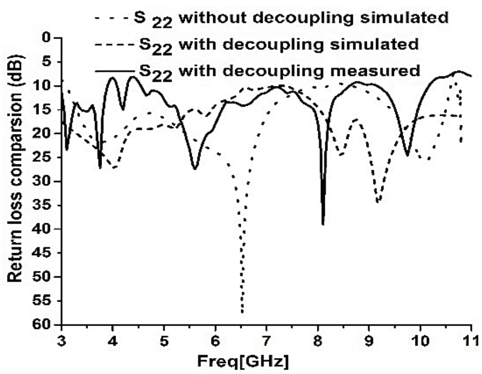
Fig. 3. Decoupling/isolation between antennas.

B. Higher band impedance enhancement

A comparison of return loss performance of the proposed UWB-MIMO quadruple is presented in this section. Simulated vs. measured results are plotted in Fig. 4. It may be observed that, in the absence of the decoupling structures, there is mismatch at the higher frequency band; i.e., 8-10 GHz. However, when the isolation/decoupling structures are placed, a match on this frequency band is achieved.



(a) Antenna 1



(b) Antenna 2

Fig. 4. Decoupling/isolation between antennas.

C. Total active reflection coefficient

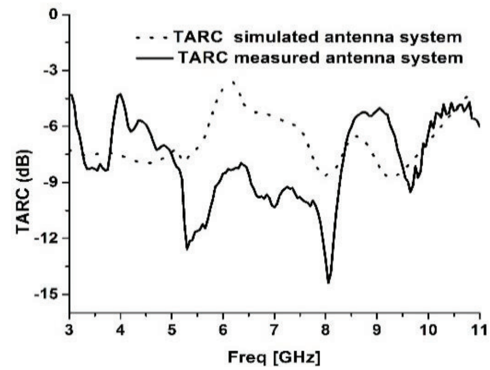
The Total Active Reflection Coefficient, TARC, is defined as the square root of the ratio of reflected power to the incident power. It may be viewed as return loss of the overall MIMO system [13]. The value of TARC for the proposed quadruple is plotted in Fig. 5 (a).

D. Channel capacity loss

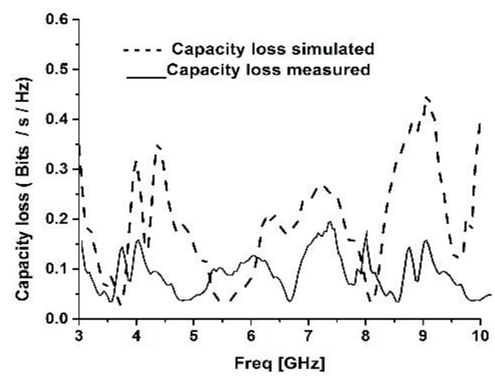
Channel capacity of a MIMO systems increases with increase in number of antennas. However, mutual coupling causes a capacity loss in MIMO systems. The acceptable value of channel capacity loss for MIMO system is reported as less than 0.4 bit/sec/Hz [7]. The measured and simulated channel capacity loss plots are shown in Fig. 5 (b). The plots indicate that proposed MIMO system has a capacity loss value below 0.4 bits/sec/Hz.

E. Radiation characteristics

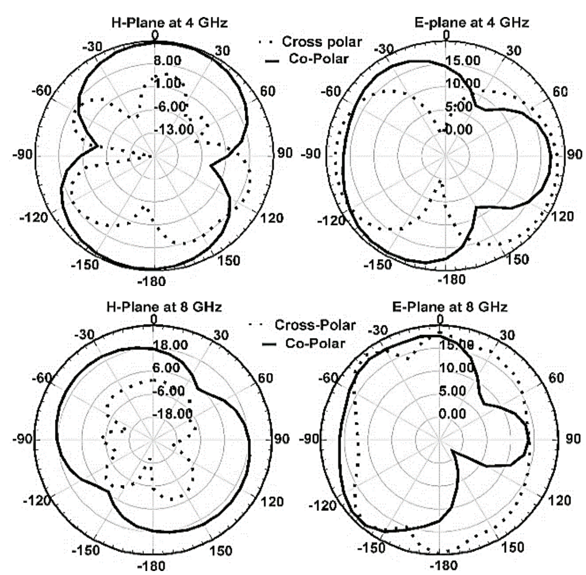
The radiation characteristics of the proposed antenna quadruple is investigated at frequencies 4 and 8 GHz. Simulated radiation patterns for E-field and H-field are shown in Fig. 5 (c). The radiation pattern is found to be nearly omni-directional at 4 GHz. The radiation pattern at 8 GHz depicts distortion within the tolerable limit.



(a) Total active reflection coefficient, TARC



(b) Channel capacity loss, CCL



(c) E- and H-plane radiation at 4 and 8 GHz

Fig. 5. TARC, CCL and radiation patterns.

V. CONCLUSION

This paper proposes a quad element UWB-MIMO antenna system. Four mutually decoupled antenna elements are fabricated on a 1 mm thick FR-4 substrate. To achieve enhanced isolation/ decoupling among the antenna elements, DGS and FSS-inspired decoupling structures are employed. The design exhibits impedance match as well as isolation over the entire UWB frequency band. The isolation among antennas, whether placed side-by-side, across or diagonally across is at least 20 dB. More importantly, the proposed design does not compromise compactness while achieving impedance match and isolation.

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