An Interdigital FSS based Dual Channel UWB-MIMO Antenna Array for System-in-Package Applications

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Abstract **─** In this paper, a miniaturized, dual channel Multiple Input Multiple Output (MIMO) antenna array is presented for Ultra Wideband applications. The array configuration is well suited for 3-D system-in-package applications. MIMO antennas are reported in two different configurations, i.e., back-to-back and orthogonal/corner. The array is designed on an FR-4 substrate of thickness 1 mm and compact dimensions of 40 mm × 35 mm. An Interdigital FSS based decoupling structure is analyzed and deployed to reduce mutual coupling between array ports. Simulated and measured results show that an isolation better than 20 dB is achieved over most of the band. More importantly, other performance criteria such as envelope correlation coefficient, total active reflection coefficient, channel capacity loss and gain also indicate that the proposed array is a potential candidate for UWB-MIMO applications.

Index Terms **─** Frequency Selective Surfaces (FSS), microstrip antennas, Multiple-Input Multiple-Output (MIMO), mutual coupling, Ultra Wideband (UWB) antennas.

I. INTRODUCTION

Any radio system that has a bandwidth more than 25 percent of its central frequency or a bandwidth larger than 500 MHz may be referred to as an Ultra Wideband (UWB) system. U.S. Federal Communications Commission (FCC) has allocated a bandwidth of 7.5 GHz, ranging from 3.1-10.6 GHz, for the UWB applications [1]. In general, UWB antennas are employed due to compact size and ease of integration in compact devices. In MIMO arrays, multiple antennas are deployed at both transmitter and receiver sides. MIMO antennas are important for increasing channel capacity and link reliability [2]. As compact antenna arrays are needed in modern smart miniaturized gadgets, MIMO elements have to be placed in close proximity to one another. However, mutual coupling increases when MIMO antenna elements are placed close to each other. For MIMO arrays, mutual coupling is undesirable as it distorts the radiation patterns of individual antenna elements and decreases overall diversity gain of the MIMO array. In general, to obtain full advantages of a MIMO array, mutual coupling has to be suppressed effectively. Various techniques have been proposed in the existing literature to achieve isolation among antenna ports in a MIMO array. These techniques include but are not limited to Defected Ground Structure (DGS) [3-4], neutralization technique [5], Electronic Band Gap (EBG) structures [6], Frequency Selective Surfaces (FSS) [10] and parasitic elements [7]. These decoupling techniques are reported for planar antennas.

MIMO designs can be broadly characterized as planar [8] and non-planar arrangements [9-10]. In planar arrangements, multiple antennas are placed in a single plane. Generally, for planar arrangements, ground plane is shared by the MIMO elements. Planar MIMO configurations may be suitable when there is no limitation on horizontal size. Non-planar MIMO configurations are well-suited when there are constraints on placing antennas horizontally. More importantly, non-planar arrangements are well suited for around-corner mounting or 3-D system-in-package applications [1]. However, it may not be possible to provide a shared ground plane to corner-mounted or 3-D MIMO antenna arrangements, especially when multiple configurations are required.

As shown in Fig. 1, in this work, a dual port/channel, UWB-MIMO antenna is reported for orthogonal and back-to-back configurations. The antennas are fabricated on 40 mm × 35 mm FR-4 substrate. A 20 mm thick polystyrene block with relative permittivity of 2.6 and dielectric loss tangent, $tan\delta$ of 3×10^{-4} supports the antennas for both configurations.

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(a) (b)

Fig. 1. Fabricated MIMO configurations: (a) back-to-back, and (b) orthogonal.

Rest of this paper is organized as follows: Section II details the antenna element and MIMO array configurations. In Section III, simulated and measured performance parameters are discussed, and finally Section IV concludes the paper.

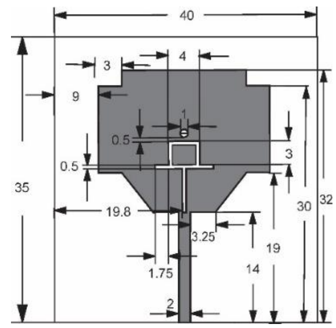
II. DESIGN LAYOUT

The simulated design layout is shown in Figs. 2 (a) and 2 (b). The design has radiating element on one side of the substrate while ground plane and decoupling structure are placed on flip side of the substrate. A T-shaped slot is etched at center of radiating element for enhanced impedance match on higher frequencies. The radiating element is beveled near the feed for an overall impedance match. Moreover, the proposed MIMO design has a defected ground structure (DGS) for improved impedance match and isolation characteristics, especially at higher frequencies. The isolation structure is a grid-like Interdigital FSS, formed by an arrangement of strips.

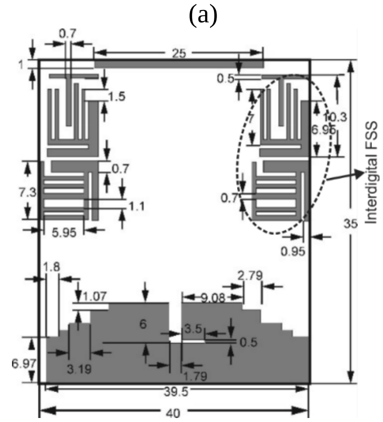
The proposed antenna geometry is shown in Fig. 2 (a). The antenna is fabricated on an FR-4 substrate with thickness of 1 mm and compact dimensions of 40 mm × 35 mm. The design is matched to a 50-Ω feed line with a length of 14 mm and width 2 mm. The radiating element employs beveling and slot etching for bandwidth enhancement. Moreover, chamfering small squares in top of radiating patch gives impedance match on middle frequency band.

The decoupling structure along with defected ground plane is shown in Fig. 2 (b). The ground plane has an L-type slot etched in the top edge for enhanced impedance match and improved isolation among antenna ports, especially on higher band frequencies. The stepped profile of ground plane helps improve the overall impedance match.

A pair of Interdigital FSSs are placed as decoupling structures above the ground plane, on either side of the radiation element. This Interdigital FSS is an arrangement of horizontal and vertical strips. In the existing literature, different metamaterial and FSS based structures are reported [1, 8, 10] as decoupling structures. This Interdigital FSS arrangement prevents propagation of surface waves, which otherwise cause coupling in both antennas. In the proposed design, position, thickness and gaps of Interdigital FSSs are optimized for better isolation and impedance match characteristics.



(a)



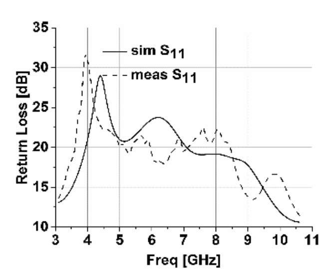
(b)

Fig. 2. UWB-MIMO array - all dimensions are in mm: (a) front view and (b) back view.

III. SIMULATED AND MEASURED PERFORMANCE CRITERIA

A. Return loss

To investigate return loss performance, the proposed MIMO antenna is simulated in the proposed dual configurations, both with and without the decoupling structure. The return loss of single antenna element and the proposed MIMO system in both configurations are presented in Fig. 3. As illustrated in Fig. 3, this MIMO antenna system exhibits good impedance match, with and without the decoupling structure in both configurations.



(a)

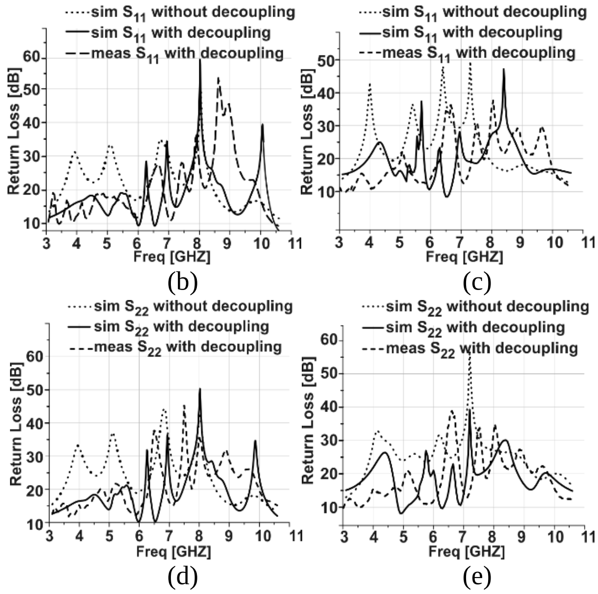
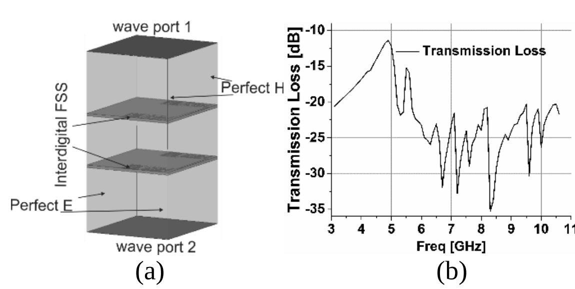


Fig. 3. Return loss: (a) single antenna element, (b), (d) back-to-back, and (d), (e) orthogonal.

B. Isolation characteristics

Interdigital FSS are etched on rear side of each antenna element to not only suppress the undesired coupling but also improve the impedance match. The analysis and optimization of these structures is performed by using a full-wave Finite Element Method (FEM) based electromagnetic solver (Ansys HFSS®). To analyze and optimize transmission loss of the proposed FSS structures, FEM based wave guide excitation method is employed as shown in Fig. 4 (a). A pair of perfect E and perfect H boundaries are assigned to confine analysis to area that contains FSS. Moreover, two wave ports are modelled at distances of $\lambda/4$ from the surface to evaluate the transmittance in the confined region [10]. The proposed FSSs are optimized to achieve overall transmission loss over UWB band, in particular, at higher frequencies as shown in Fig. 4 (b). The simulated and measured results are shown in Fig. 4 (c) and Fig. 4 (d) for both configurations. In general, the decoupling is more than 20 dB over most of the frequency band. In particular, the decoupling is more than 30 dB over higher band frequencies.



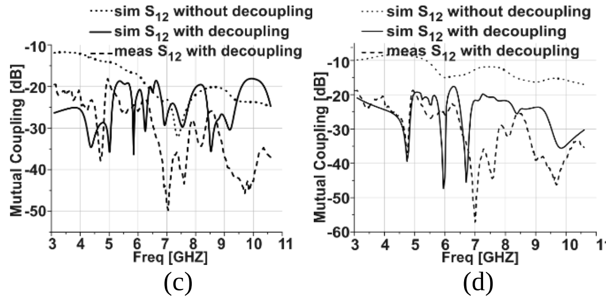


Fig. 4. Transmission loss and isolation: (a) FSS simulation setup, (b) transmission loss, (c) back-to-back, and (d) orthogonal.

C. Induced current suppression

Surface current density plots are shown in Fig. 5. In obtaining the surface current density plot, one antenna is excited and the other is matched terminated. When the proposed MIMO design is simulated without the decoupling structure, undesired surface currents are induced on antenna feedline and radiating element causing significant mutual coupling. However, these surface currents are suppressed effectively by employing the Interdigital FSS

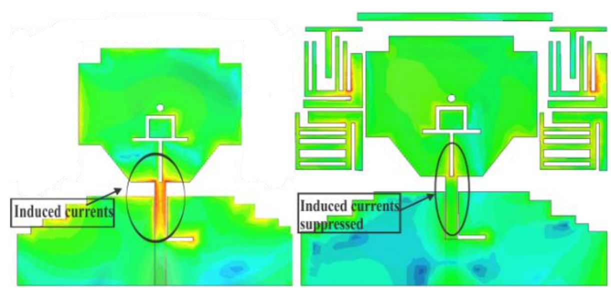


Fig. 5. Surface current distribution at 5 GHz.

D. MIMO performance criteria

TARC (Total Active Reflection Coefficient), ECC (Envelope Correlation Coefficient), CCL (Channel Capacity Loss) and overall gain of the proposed MIMO system are computed to analyze the diversity performance of the proposed design. For acceptable MIMO performance, it is desirable to have TARC < 0 dB, ECC < -3 dB and CCL < 0.5 bits/sec/Hz. The proposed design exhibits TARC < -8 dB, ECC < -40 dB and CCL < 0.45 in both configurations as shown in Fig. 6 [1, 10]. Moreover, both the configurations achieve at least 3 dB gain enhancement in most of the UWB band. However, the Interdigital FSS slightly reduces the gain in the middle frequency band. This loss may be attributed to transmission loss.

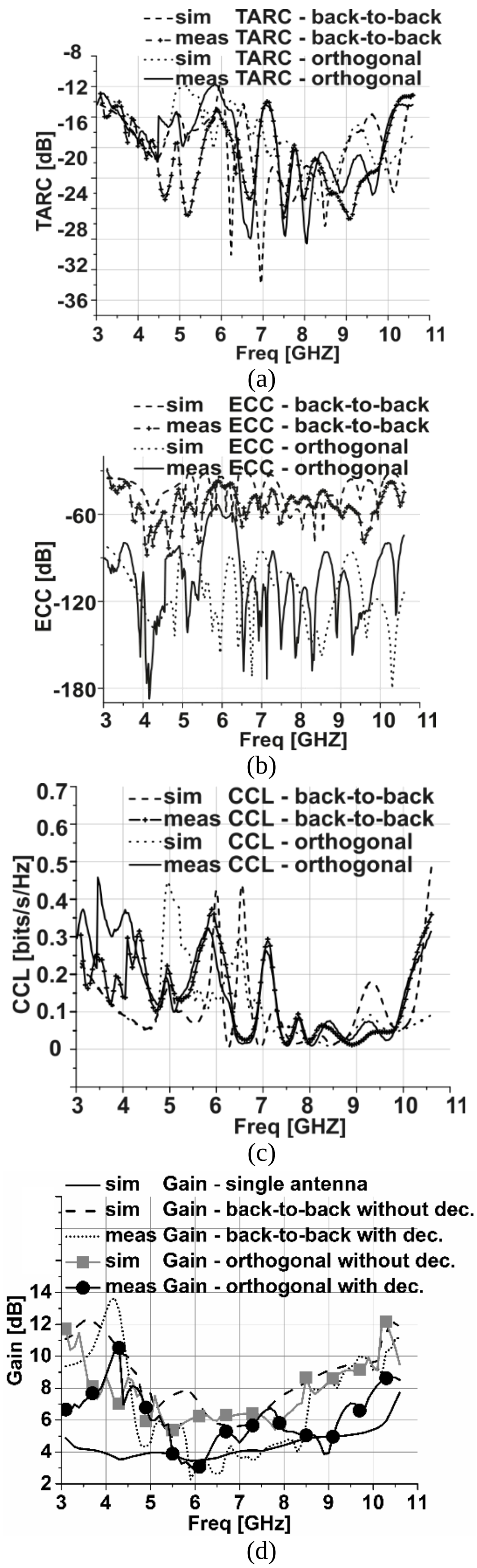
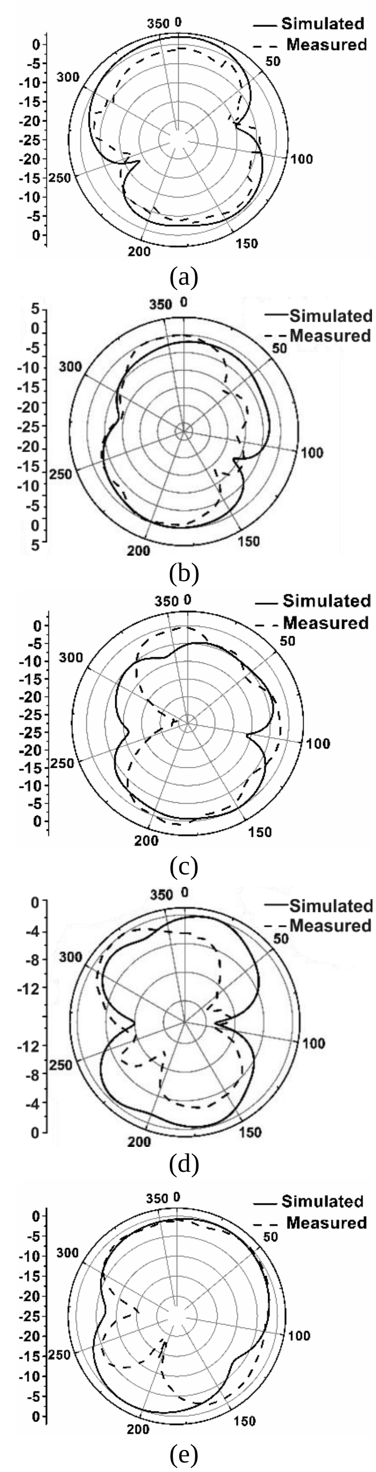
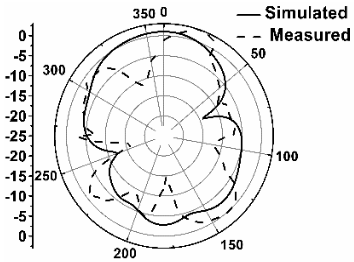


Fig. 6. MIMO performance criteria: (a) TARC, (b) ECC, (c) CCL, and (d) Gain.

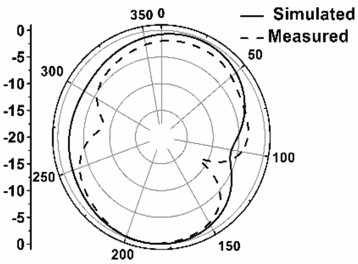
E. Radiation patterns

The simulated E-plane radiation patterns at 3 GHz and 10 GHz, for both orthogonal and back-to-back configurations, are shown in Fig. 7. The results indicate some degree of pattern distortion which is not uncommon for non-planar antenna configurations, as also reported in the existing literature [4, 10].

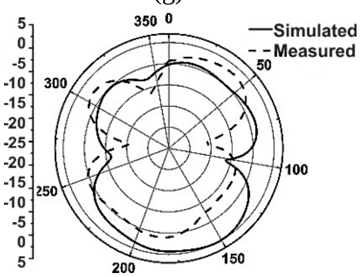




(f)



(g)



(h)

Fig. 7. Radiation patterns: (a) E-field at 3 GHz back-to-back, (b) H-field at 3 GHz back-to-back, (c) E-field at 3 GHz orthogonal, (d) H-field at 3 GHz orthogonal, (e) E-field at 10 GHz back-to-back, (f) H-field at 10 GHz back-to-back, (g) E-field at 10 GHz orthogonal, and (h) H-field at 10 GHz orthogonal.

IV. CONCLUSION

In this paper, a dual element MIMO antenna array is proposed for UWB communication. Two different configurations, i.e., back-to-back and orthogonal provide employability in 3-D system-in-package application. The proposed design achieves significant isolation among MIMO ports while also maintaining ECC, TARC, channel capacity loss and gain within the acceptable limits. For the proposed design, simulated and measured results are in good agreement. More importantly, miniaturized dimensions, performance parameters and ease of integration suggest suitability of the proposed array for 3-D system-in-package UWB-MIMO applications.

REFERENCES

[1] R. Saleem, M. Bilal, K. B. Bajwa, and M. F. Shafique, "Eight-element UWB-MIMO array with three distinct isolation mechanisms," *Electronics Lett.*, vol. 51, no. 4, pp. 311-313, 2015.

[2] Y. L. Q. Chu, J. F. Li, and Y. T. Wu, "A planar H-shaped directive antenna and its application in compact MIMO antenna," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 9, pp. 4810-4814, 2013.

[3] H. Peng, R. Tao, W. Y. Yin, and J. F. Mao, "A novel compact dual-band antenna array with high isolations realized using the neutralization technique," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 4, pp. 1956-1962, 2013.

[4] M. T. Islam and M. S. Alam, "Compact EBG structure for alleviating mutual coupling between patch antenna array elements," *Progress In Electromagnetics Research*, vol. 137, pp. 425-438, 2013.

[5] B. K. Lau and J. B. Andersen, "Simple and efficient decoupling of compact arrays with parasitic scatterers," *IEEE Trans. Antennas Propagat.*, vol. 60, no. 2, pp. 464-472, 2012.

[6] W. Xie, T. Yang, X. Zhu, F. Yang, and Q. Bi, "Measurement-based evaluation of vertical separation MIMO antennas for base station," *IEEE Antennas and Wireless Propagat. Lett.*, vol. 11, pp. 415-418, 2012.

[7] M. S. Sharawi, M. U. Khan, A. B. Numan, and D. N. Aloi, "A CSRR loaded MIMO antenna system for ISM band operation," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 8, pp. 4265-4274, 2013.

[8] A. Elsherbini and K. Sarabandi, "Dual-polarized coupled sectorial loop antennas for UWB applications," *IEEE Antennas and Wireless Propagat. Lett.*, vol. 10, pp. 75-78, 2011.

[9] G. Adamiuk, T. Zwick, and W. Wiesbeck, "Compact, dual-polarized UWB-antenna, embedded in a dielectric," *IEEE Trans. Antennas Propagat.*, vol. 58, no. 2, pp. 279-286, 2010.

[10] M. Bilal, R. Saleem, H. H. Abbasi, M. F. Shafique, and A. K. Brown, "An FSS based non-planar quad element UWB-MIMO antenna system," *IEEE Antennas and Wireless Propagat. Lett.*, vol. PP, no. 99, pp. 1-1, 2016.

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