Dielectric Resonator Antenna Based Dual Port Multiple Input Multiple Output Antenna

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Abstract **─** This paper presents a Dielectric Resonator based dual frequency band Multiple Input and Multiple Output (MIMO) antenna for wireless communication. This antenna is designed for WLAN (5.5–5.8 GHz) and X–band (8–8.1 GHz) applications. A pair of DRAs is placed on a FR-4 substrate and is excited through microstrip feed lines placed on rear side of substrate. A via-less EBG structure is introduced to suppress the mutual coupling among DRAs. The measured isolation among the two antenna ports is 25 dB and 41 dB for 5.6 GHz and 8.05 GHz respectively. The overall dimension of the antenna is 0.72 $\lambda_o \times 0.52\ \lambda_o$ at lower resonant frequency. Simulated and measured results are in good agreement, which supports the potential application of the proposed antenna for high gain WLAN and X–band applications.

Index Terms **─** Dielectric Resonator Antenna (DRA), decoupling structure, Electromagnetic Band Gap (EBG), Multiple Input Multiple Output (MIMO).

I. INTRODUCTION

MIMO system is the technology of choice in wireless communication to meet the high data rate and high diversity gain requirements [1]. Microstrip patch antennas are extensively reported for MIMO applications. However, these antennas are prone to high metallic losses and lesser radiation efficiency, especially at higher frequencies. Dielectric Resonator Antennas (DRAs) do not have these disadvantages. They have several distinct benefits as compared to microstrip patch antennas, such as high radiation efficiency, higher gain and low losses [2]. MIMO system performance is affected by undesired mutual coupling among the radiating elements which is developed due to miniaturization of the antenna design. Different techniques such as the Defected Ground Structures (DGSs), Electromagnetic Band Gap (EBG) structures and Frequency Selective Surfaces (FSSs) [3, 4] are reported in the literature to enhance isolation between antenna elements for different MIMO systems. A split ground plane is another commonly reported solution to accomplish high isolation in MIM DRAs [5, 6]. Aperture-coupled and probe feedings in hybrid feeding mechanism can also be used to achieve high isolation [7]. However, the techniques presented in [5, 6, 7] make fabrication more complex and compromise the design compactness.

In this work, a compact dual band MIMO DRA is proposed for WLAN and X–band applications. DRAs are placed on a 38.8 mm × 28 mm × 1.6 mm FR-4 substrate. A via-less EBG structure has been used to enhance the isolation among the DRAs.

The rest of this paper is organized as follows: in Section II a discussion of proposed antenna design configuration is given, DRA resonant frequency and modal analysis are given in Section III, simulated and measured results are presented in Section IV, and finally Section V concludes the paper.

II. ANTENNA DESIGN

The proposed design geometry is shown in Figs. 1 (a) and 1 (b) along with the dimensions. The proposed antenna is simulated and optimized in Ansys HFSS®. The realized MIMO design is shown in Figs. 2 (a) and 2 (b). The dimensions of the substrate are l_1 = 28 mm × w_1 = 38.8 mm × h_2 = 1.6 mm, as shown in Fig. 1 (a). The

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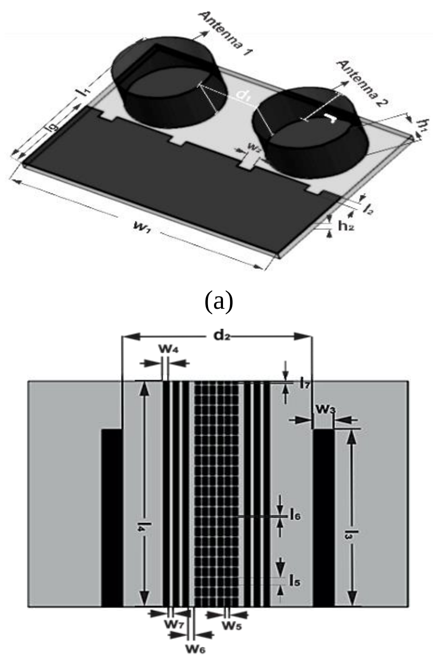
cylindrical DRAs are mounted on the top side of FR-4 substrate. These DRAs are made of Alumina with: dielectric constant, ε_r, of 9.8; dielectric loss tangent, tan δ of 0.002; radius, r of 6.35 mm and height, h_1 of 9 mm. The spacing between the DRAs is d_1 = 8.72 mm. DRAs are proximity/couple-fed through two microstrip feed lines etched at the rear side of substrate, each of length l_3 = 22 mm and width w_3 = 2.05 mm. Feed lines are separated by a distance d_2 = 19 mm.



(a)

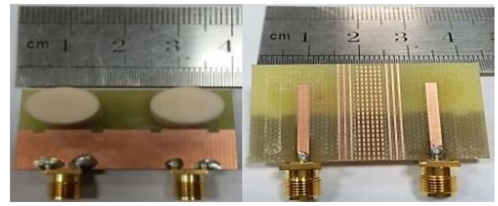
(b)

Fig. 1. MIMO DRA design: (a) front side and (b) back side.

A common ground plane arrangement is employed on the front side of substrate in the suggested MIMO design, as shown in Fig. 1 (a). The ground plane dimensions are l_g = 13.4 mm × w_1 = 38.8 mm. Rectangular shaped slits are imprinted in the top edge of the ground plane to improve impedance matching for the desired resonant frequencies. These rectangular slits have dimensions of l_2 = 1.1 mm × w_2 = 2 mm.

A via-less EBG structure is employed in this design to enhance isolation. This structure is imprinted on the back side of the substrate as shown in Fig. 1 (b).

The dimensions of each single rectangular block in via-less EBG structure are l_5 = 1 mm × w_5 = 0.5 mm. The spacing l_6 between adjacent rectangular blocks is 0.25 mm. Furthermore, a pair of three vertical strips is placed on both sides of the via-less EBG structure. The dimensions of each strip are l_4 = 28 mm × w_4 = 0.5 mm. The spacing between adjacent strips is w_7 = 0.5 mm and first strip is placed at a distance of w_6 = 0.75 mm from the EBG structure.



(a) (b)

Fig. 2. Fabricated MIMO DRA: (a) front side and (b) back side.

III. RESONANT FREQUENCY AND MODAL ANALYSIS OF DRA

The proposed DRA design has two resonant modes, $HEM_{11\delta}$ and $TM_{01\delta}$. The first resonant mode is $HEM_{11\delta}$ and it produces broadside radiation pattern, as shown in Fig. 3 and it can be theoretically verified with the following relation [9]:

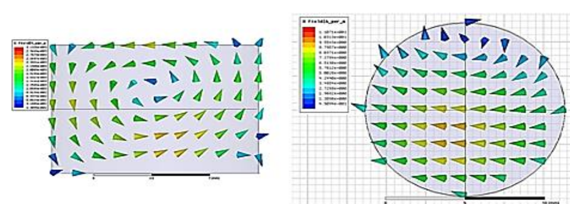
$$f_{o(HEM_{11\delta})} = \frac{c\times 6.324}{2\pi a\sqrt{\varepsilon_r+2}}\left(0.27+0.36\frac{a}{2h}+0.02\left(\frac{a}{2h}\right)^2\right). \quad (1)$$

Where "a" is the radius of DR and "h" is the height of DR. The above equation is valid for $0 \le a/h \le 6$. The theoretical calculation of the resonant frequency from the above equation gives 5.53 GHz.

The second resonant mode is $TM_{01\delta}$ and it offers end-fire radiation pattern, as shown in Fig. 4 and it can be theoretically calculated [9] as:

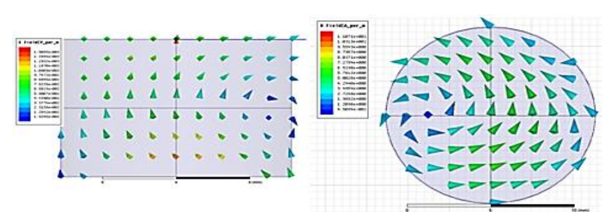
$$f_{o(TM_{01\delta})} = \frac{c\sqrt{3.83^2+\left(\frac{\pi a}{2h}\right)^2}}{2\pi a\sqrt{\varepsilon_r+2}}. \quad (2)$$

The above equation is valid for $0.33 \le a/h \le 5$. The theoretical calculation of the resonant frequency from the above equation gives 8.73 GHz.



(a) (b)

Fig. 3. First resonant mode $HEM_{11\delta}$ of the DRA: (a) E-field pattern and (b) H-field pattern.



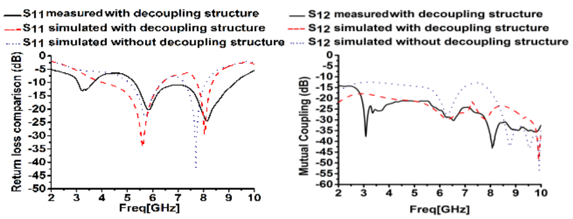
(a) (b)

Fig. 4. Second resonant mode $TM_{01\delta}$ of the DRA: (a) E-field pattern and (b) H-field pattern.

IV. SIMULATED AND MEASURED RESULTS

A. S-parameters

Measured and simulated S_{11} and S_{12} results with and without decoupling structure are shown in Fig. 5. The S_{11} result shows that the suggested MIMO antenna design is well matched on 5.6 GHz and 8.05 GHz. The S_{12} result shows that more than 20 dB isolation is achieved between antennas, when the via-less EBG structure is introduced.

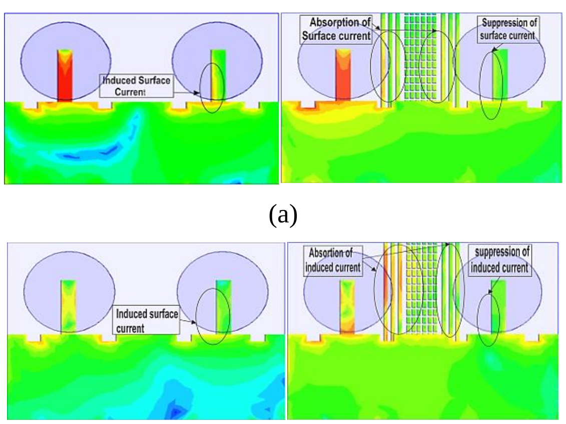


(a) (b)

Fig. 5. Simulated and measured S-parameters of MIMO design: (a) S_{11} and (b) S_{12}.

B. Induction current suppression

The surface current density is plotted at 5.6 GHz and 8.05 GHz, as shown in Figs. 6 (a) and 6 (b). The *Jsurf* plots show the undesired induced surface currents on ground plane and the feeding line of antenna, when the MIMO design is simulated without the decoupling structure. However, decoupling structure effectively suppresses the undesired surface currents, resulting in significant isolation between the antenna ports.



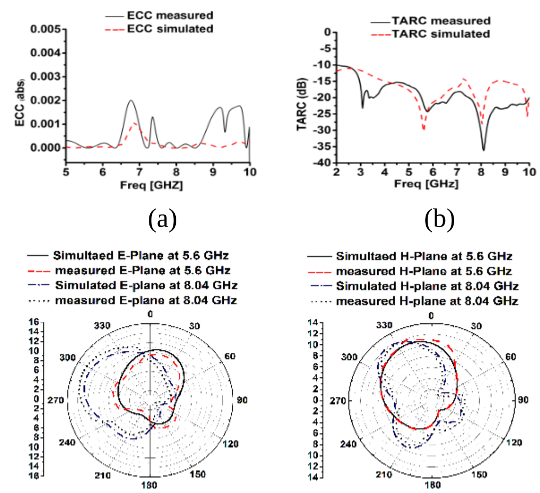
(a)

(b)

Fig. 6. *Jsurf* current distribution plots at: (a) 5.6 GHz and (b) 8.05 GHz.

C. MIMO performance parameters

The diversity performance of a MIMO system is judged by its performance parameters. In this regard, the envelope correlation coefficient (ECC) and total active reflection coefficient (TARC) have been measured for the proposed MIMO DRA system. A maximum threshold of ECC < 0.5, TARC < 0 dB is allowed for an acceptable MIMO system [8]. The proposed design has ECC < 0.001 and TARC < -20 dB, in both bands, as shown in Fig. 7 which assures the optimum performance of the suggested MIMO antenna. Simulated and measured radiation patterns for *E*-planes and *H*-planes are shown in Fig. 7 (c). The fabrication and measurements imperfections cause slight distortion in radiation patterns. The comparison of the proposed work with the reviewed literature is given in Table 1.



(a) (b)

(c)

Fig. 7. MIMO performance parameters: (a) ECC, (b) TARC, and (c) radiation patterns.

Table 1: Comparison of the proposed work with the reviewed literature

Ref.	Freq. MHz/GHz	Isolation	Antenna Size [mm^3]
[1]	803–823 MHZ 2.44–2.9 GHz	20 dB 14 dB	50×100×1.56
[2]	3.4–3.7 GHz 5.1–5.35 GHz	13 dB 16 dB	50 ×50×1.6
[3]	2.4 GHz 5.2 GHz	20 dB 18 dB	40×80×1
[7]	5.15–5.35 GHz	35 dB	60×60×1
This work	5.5–5.8 GHz 8 –8.1 GHz	28 dB 41 dB	28×38×1.6

V. CONCLUSION

A dual-port dual-band MIMO DRA for high gain WLAN and X–band application is proposed. The design is fabricated on a 1.6 mm thick FR-4 substrate. A via-less EBG structure is employed to achieve effective isolation between antenna elements. The measured results demonstrate the isolation better than 20 dB in both bands. MIMO performance criteria such as ECC, TARC and radiation patterns also exhibit excellent performance. The proposed design exhibits excellent impedance match and isolation, without compromising the compactness. The total antenna is $0.72\ \lambda_o \times 0.52\ \lambda_o$ in size at the lower frequency band.

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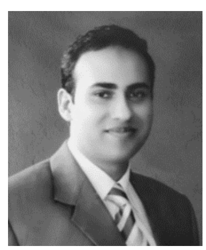

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