Mutual Coupling Reduction in Dielectric Resonator Antennas Using Metasurface Shield for 60 GHz MIMO Systems

Abdolmehdi Dadgarpour, Behnam Zarghooni, Bal S.Virdee, and Tayeb A. Denidni

***Abstract*—This paper presents an effective technique for reducing the near-field mutual coupling in Dielectric Resonator Antennas (DRA) operating at 60 GHz. This is achieved by incorporating a metasurface in the DRA that acts like an effective electromagnetic shield. The metasurface comprises an array of unique split-ring resonator (SRR) unit-cells that are integrated between the Dielectric Resonators in the H-plane. The SRR configuration is designed to provide band-stop functionality in the region of operation centered at 60 GHz. By loading the DRA with 1×7 array of SRR unit-cells is shown to yield substantial reduction in coupling by 28 dB without compromising the antenna performance. The measured isolation of the prototype antenna varies from -30 to -45 dB over 59.3–64.8 GHz. The corresponding reflection-coefficient of the DRA is better than -10 dB over 56.6–64.8 GHz.**

***Index Terms*—Dielectric resonator antenna, MIMO, millimeter-wave antenna, split-ring resonator, mutual coupling**

I. Introduction

MULTIGIGABIT wireless networks are on the cusp of economic viability with the worldwide availability of the unlicensed spectrum at 60 GHz coupled with the recent advances in low-cost millimeter-wave RF integrated circuits and devices. This is evident by the significant industry interest of this technology for various indoor applications such as wireless personal area networks [1], wireless local area networks [2], and wireless uncompressed HDTV [3]. The use of the 60 GHz band is also becoming very attractive for outdoor mesh networks with relatively short links of 100–200 m, in particular for the emerging 5G wireless cellular networks and Internet-of-Things (IoT). However, oxygen absorption in the 60 GHz band produces propagation losses of 10–16 dB/km, which adds about 3 dB to the link budget for a 200 m link. Such multigigabit outdoor mesh networks will provide an easily deployable broadband infrastructure that can have a multitude of applications, including wireless backhaul for picocellular networks and as an alternative to fiber to the home.

With the availability of several gigahertz of unlicensed spectrum this millimeter-wave technology should enable the substantial growth of data traffic with the advent of IoT. In order to accommodate the ever growing high capacity demands expected in the near future will require the use of Multiple-input Multiple-output (MIMO) antennas that can provide spatial multiplexing gain, diversity gain, and interference reduction capability. To improve the spectral efficiency of wireless systems using MIMO requires low correlation and high isolation between antennas.

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In this effort a great deal of work has been reported to date on reducing the mutual coupling between antennas including application of (i) parasitic elements [4][5], (ii) EBG structures [6]-[9], and (iii) metamaterial-based resonators [10]-[13].

In this paper an effective technique is demonstrated to substantially increase the isolation between adjacent Dielectric Resonators in DRAs designed to operate at 60 GHz for MIMO application. This is achieved by using a metasurface shield constructed of a unique split-ring resonator that is designed to provide band-stop functionality over the operating frequency range centered at 60 GHz. By integrating the array of SRR unit-cell structure between the DRs in the H-plane results in the substantial reduction in the mutual coupling between adjacent radiators. Using the proposed technique the isolation between the antennas is measured to be -48 dB at 60 GHz.

II. Split-Ring Resonator Unit-cell

This section presents the characteristic properties of a metasurface shield employed in the proposed DRA. The metasurface comprises a unique metamaterial unit-cell, shown in Fig. 1, which is constructed from a split-ring resonator where the conductive elements create the inductance and the gap in the ring the capacitance. Loaded within the split-ring structure is smaller semi-circular parasitic ring whose purpose is to enhance the bandwidth of the resonator over desired frequency range (57–64 GHz). The parasitic semi-circular ring is designed to generate an additional resonance mode at 63.5 GHz to shift the resonator's lower 3 dB frequency from 59.2 to 58.2 GHz, as shown in Fig. 2. Analysis and characterization of the metamaterial unit-cell is described in [14]. The SRR structure was fabricated on the top and bottom of RT5880 substrate with relative permittivity of 2.2 and thickness of 0.254 mm. To compute the S-parameters of proposed unit-cell, PEC and PMC boundary conditions were assigned in the *xz* and *xy*-planes, respectively. Two wave-ports were located in the *y*-direction to excite the planar TEM wave [14].

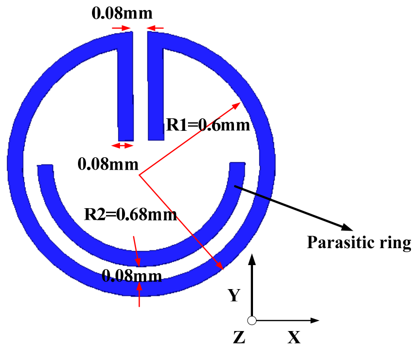


Fig. 1. The configuration of proposed split-ring resonator.

The proposed structures S-parameter response, shown in Fig. 2, exhibits a band-stop characteristic over the frequency range of 57–64 GHz, and the magnitude of the isolation is greater than 20 dB over 58.5–63.7 GHz.

III. Mimo Antenna

The DRA MIMO antenna design is based on reference [15]. The configuration of the proposed DRA structure is shown in

Fig. 3. The antenna is constructed on a multi-layer substrate where the lower substrate is RT6010 with relative dielectric constant 10.2 and thickness of 0.254 mm. The feed-lines are constructed on this substrate which is necessary to excite the DRAs through a rectangular slot cut out of the upper substrate. The ground-plane is located on the bottom side of the lower substrate. The upper substrate is RT5880 with relative permittivity 2.2 and thickness of 0.254 mm. The DRs are mounted on top of this substrate immediately above the rectangular slot cut out in the substrate, as shown in Fig. 3.

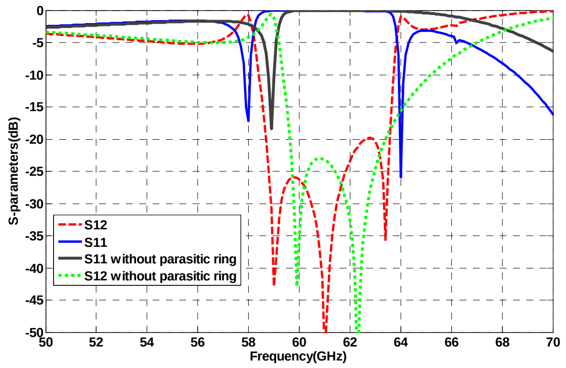


Fig. 2. The S-parameters of the modified shape of split-ring resonator and the effect of parasitic ring on the transmission-coefficient response.

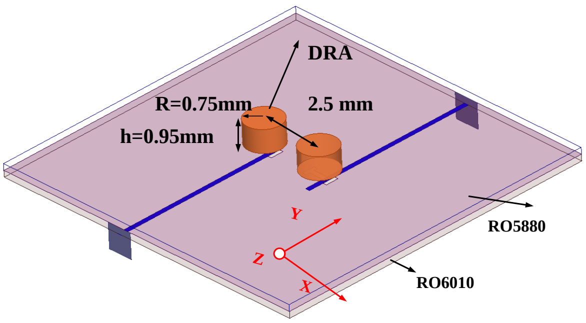


Fig. 3. Configuration of 1×2 DRAs arranged in the H-plane.

The array of 1×2 DRAs are arranged in the H-plane (*xz*) with a center-to-center distance of 2.5 mm corresponding to $\lambda_o/2$ at 60 GHz. The S-parameter response of DRA is shown in Fig. 4. The results indicate that the reflection-coefficient of the antenna is better than -10 dB and the isolation is -18 dB over 57–64 GHz.

In order to reduce the electromagnetic interaction between the DRAs, a 1×7 array of the proposed SRR unit-cell is implanted between the two Dielectric Resonators in the H-plane, as shown in Fig. 5. The S-parameter response of this structure in Fig. 4 shows considerably reduction in the mutual coupling. Isolation of -43 dB is obtained at 60 GHz which corresponds to a reduction of 28 dB with the shield. The effect on the H-field with and without the metasurface is shown in Fig. 6. It is evident the near-field interaction is effectively curtailed with the location of the metasurface between the DRs in the *xz*-plane. The results confirm the proposed array of SRR unit-cells has an effective band-stop property in the band 57–64 GHz.

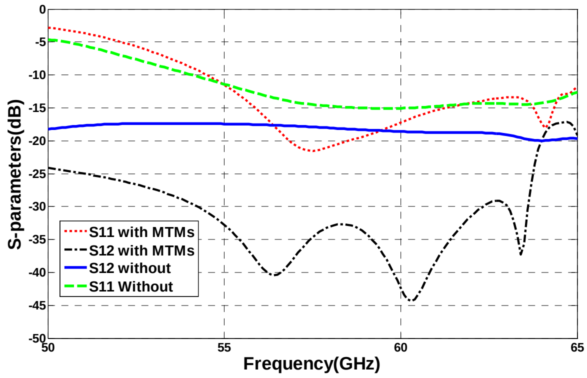


Fig. 4. The S11 and S12 response of the 1×2 DRAs antenna with and without metamaterial (MTM) unit-cells.

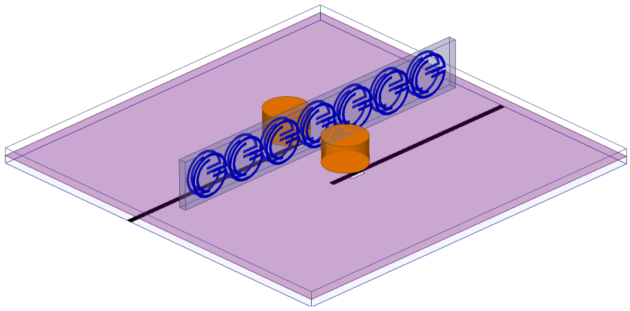


Fig. 5. Configuration of 1×2 DRA with 1×7 metamaterial based SRR in the H-plane.

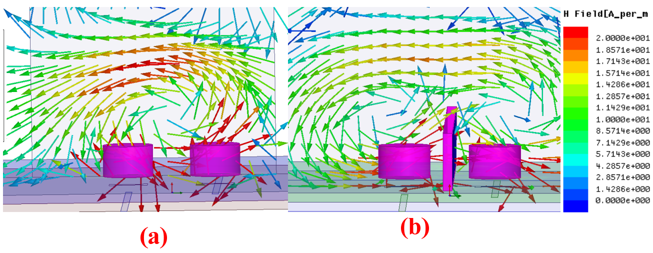
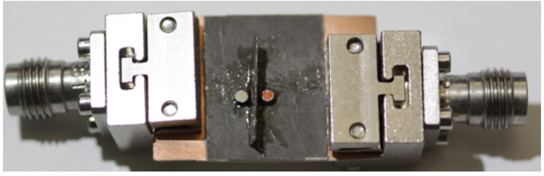


Fig. 6. The H-field vector distribution in the H-plane, (a) without shielding, and (b) with 1×7 array of metamaterial unit-cells.

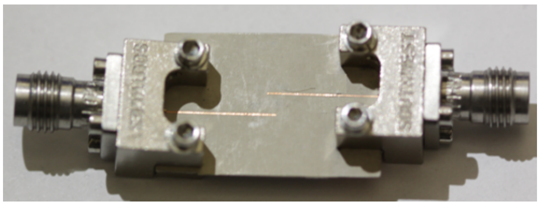
IV. Experimental Results

The proposed 1×2 DRA which is integrated with 1×7 array of SRR unit-cells was fabricated and its performance measured. The photograph of the prototype antenna is shown in Fig. 7. The measured reflection-coefficient of the antenna is better than -10 dB over 57–64 GHz. The measured isolation is -47 dB at 60.5 GHz and better than -30 dB over 59.3–64.8 GHz. A 1.85 mm end-launch connector (model no.1893-03A-5) was used for the measurement.

In order to validate the simulation results the radiation pattern of proposed structure was measured when antenna port-1 is excited and antenna port-2 is connected to the 50 ohm load. The measured E-plane and H-plane radiation pattern at 60 GHz with 1×7 and array are shown in Fig. 9 & 10, respectively. As can be observed the radiation pattern in the H-plane has tilted by 60 degrees with respect to broadside radiation which is attributed to the presence of the metasurface between the DRAs. In the E-plane (*yz*) the antenna radiates in the broadside direction.



(a)



(b)

Fig. 7. (a) Photograph of 1×2 Dielectric Resonator Antenna with SRR arrays, (a) top view, and (b) feed-line section.

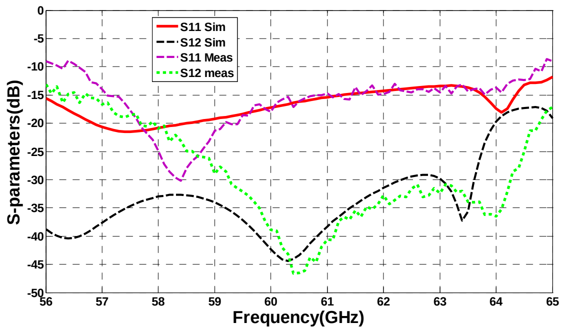


Fig. 8. The measured and simulation S-parameters of the 1×2 array of DRA with 1×7 array of SRR resonators.

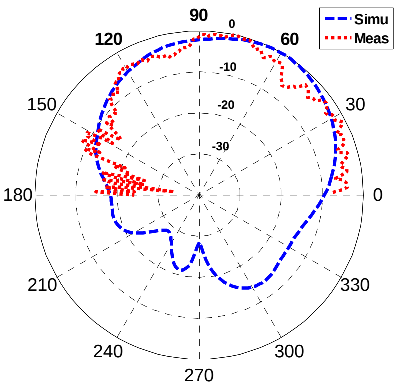


Fig. 9. The normalized radiation pattern of DRA antenna with a 1×7 array of SRR unit-cells at 60 GHz in the H-plane (*xz*).

V. Conclusion

An effective technique is proposed to substantially reduce the mutual coupling between Dielectric Resonator Antennas at millimeter-waves for MIMO applications. This is achieved by incorporating a metasurface consisting of an array of split-ring resonator unit-cells in the H-plane between the individual antennas. Measurements show isolation between antennas varies between -30 to -47 dB over 59.3–64.8 GHz, which constitutes an improvement of 28 dB at 60 GHz.

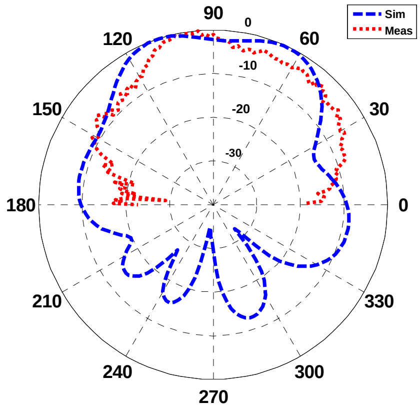


Fig. 10.The normalized radiation pattern of DRA antenna with a 1×7 array of SRR unit-cells at 60 GHz in the E-plane (*xz*).

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