New Design Approach for Mutual Coupling Reduction in Two-Port Compact Antenna Array for W-LAN MIMO Applications

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Abstract

A compact antenna array comprised of two half-split cylindrical dielectric resonator antennas (CDRAs) is presented to achieve low mutual coupling. These CDRA elements are formed by partitioning a cylindrical dielectric block into two identical semicircular segments and are separated by a vertical metallic plate with an air gap. A pair of L-shaped microstrip feed lines is used to excite the half-split CDRA elements. A defected ground structure (DGS) with engineered slots and a vertical metallic plate are used to reduce the mutual coupling between the array elements significantly. With an inter-element spacing of $0.036\lambda_0$, the mutual coupling decreased to -22.66 dB at 5.2 GHz, which represents an improvement of 14 dB over a reference array. Realized peak gain of the proposed antenna array is approximately 4.77 dBi estimated at 5.2 GHz.

1 Introduction

Multiple-input-multiple-output (MIMO) communication system fulfills the demand for higher data rate and better quality of service in modern communication systems. MIMO communication systems use multiple antennas at the transmitter (T_X) and receiver (R_X) sides, and its data transfer rate increases linearly with the number of the antenna elements [1]. Mutual coupling (MC) between two antennas is considered to be highly undesirable in the performance of a MIMO communication system [2, 3, 4, 5]. Compactness is one of the most important requirements to design a modern MIMO system. Arrays with a small inter-element spacing typically have high mutual coupling since antenna interaction is inversely proportional to the distance between the radiators. A challenge is therefore to minimize the mutual coupling between antennas and to obtain wideband characteristics with a small inter-element spacing ($< 0.1\lambda_0$ at the lowermost operating frequency).

The dielectric resonator antenna (DRA) is popular for its low loss characteristics, thus offering higher radiation efficiency and gain [6]. They may be integrated easily with other electronics modules that use the same substrate. A

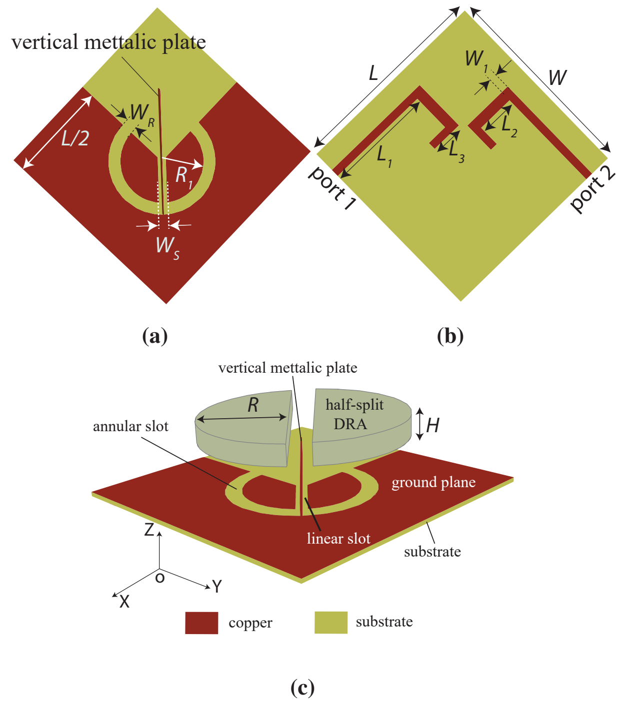


Figure 1. Proposed antenna configuration: (a) top view, (b) bottom view, and (c) 3-D isometric view. Parameters: $D = 2R = 18.5$, $H = 4$, $L = W = 55$, $L_1 = 32.5$, $L_2 = 10.6$, $L_3 = 10$, $W_1 = 2.2$, $W_R = 3.1$, $W_S = 2.1$, $R_1 = 10.9$, $h = 0.8$. All dimensions are in mm.

DRA array with low mutual coupling is therefore of great interest to MIMO antenna researchers, particularly when using a smaller footprint for more efficient use of space. Several methods were proposed to reduce the mutual coupling between DRA elements [7, 8, 9, 10, 11, 12, 13, 14]. A ring-shaped defected ground structure (DGS) was demonstrated to suppress mutual coupling between two CDRAs [7]. In [8], a wideband operation was achieved by using a mushroom-shaped DRA that is excited by employing a conformal trapezoidal patch. Radiators are arranged orthogonally to reduce the mutual coupling between them. A

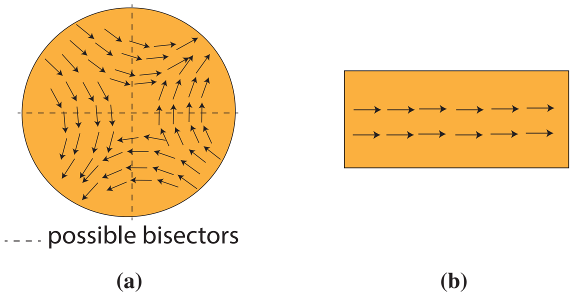


Figure 2. Electric field portrays of $HEM_{21\delta}$ mode in CDRA: (a) top view and (b) side view.

triple-port, two-element CDRA with excitation of orthogonal modes was presented in [9] for MIMO applications. Conformal strips were used to excite two A-shaped DRAs that offers wide impedance bandwidth [10]. Three decoupled modes of a single rectangular DRA are excited by using three separate ports [11]. The defected ground structure was used to suppress the interaction between the tree-shaped fractal DRAs and the wide bandwidth is achieved by employing the fractal geometry [12]. Vertical metal plates were used to reduce the mutual coupling of DRA array with four ports [13]. A decoupling structure consist of a single-negative meta-grid line was integrated with the ground plane to improve the isolation between two CDRAs [14]. But, for both the MIMO antenna configurations [13, 14], inter-element spacing between the DRA elements is more than $0.081\lambda_0$.

This paper proposes a novel design of a two-element antenna array that uses two half-split cylindrical dielectric resonator antennas (CDRAs). A CDRA is split symmetrically into two halves to obtain these half-split elements. There is a vertical metallic plate separating them with an air gap. A defected ground structure is also used along with this vertical plate to reduce the mutual coupling significantly. The mutual coupling performance of the antenna is improved by about 14 dB compared with that of the reference antenna. All antenna parameters are optimized by using a commercial simulator and only a few representative results are provided here. The performance of the proposed antenna is compared with some contemporary designs. It demonstrates superior performance in terms of antenna volume and inter-element spacing. Fabrication of the antenna is underway. Experimental results are expected shortly.

2 Antenna Geometry and Design

Fig. 1 shows the configuration of the proposed antenna array. A square-shaped FR-4 substrate measuring 55mm in both length (L) and width (W) and 0.8mm in height (h) is used for the proposed design. Two half-split CDRA blocks of $\varepsilon_r = 16$, radius R and height H are symmetrically placed above the ground plane. An air gap is maintained between the DRA blocks. Two L-shaped microstrip feed lines are used to excite the CDRA elements through a C-shaped annular slot (radius=R_1, width=W_R) on the ground plane. This C-shaped slot together with a square-shaped etched segment ($L/2 \times L/2$) functions like a DGS. A thin metal wall is placed vertically between the CDRAs along with a linear slot (width=W_s) on ground plane.

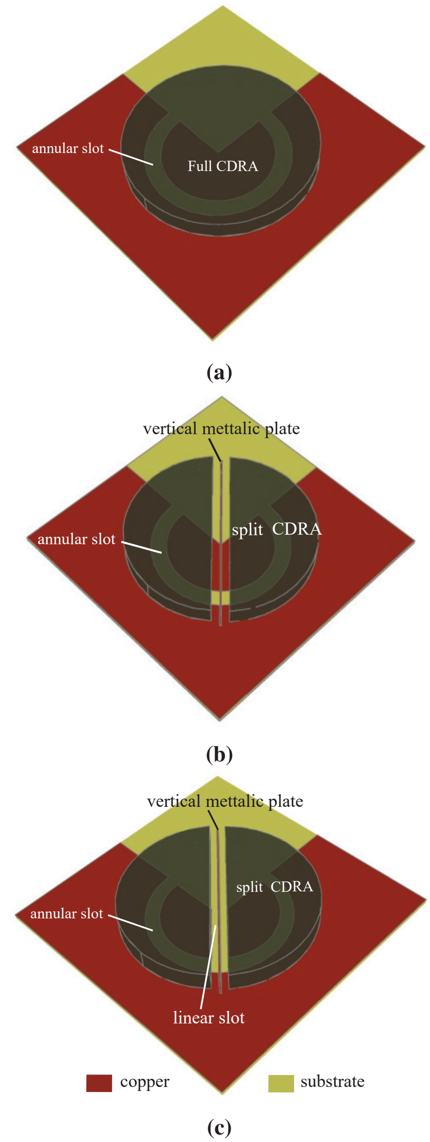


Figure 3. Antenna design evolution stages: (a) stage-1 (reference antenna): full CDRA with annular slot, (b) stage-2: half-split CDRA with metal wall and annular slot, (c) stage-3 (proposed design): half-split CDRA with metal wall, annular and linear slot

3 Working Mechanism and Results

The proposed MIMO antenna is developed with an intention to reduce the mutual coupling between closely spaced array elements. In order to excite the $HEM_{21\delta}$ mode of CDRA, two half-split blocks have been created by bifurcating a full cylindrical DRA vertically [15]. This

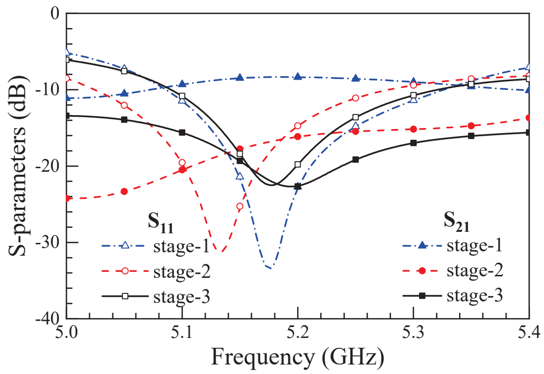
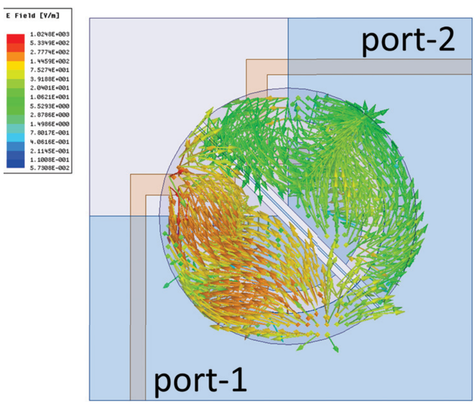
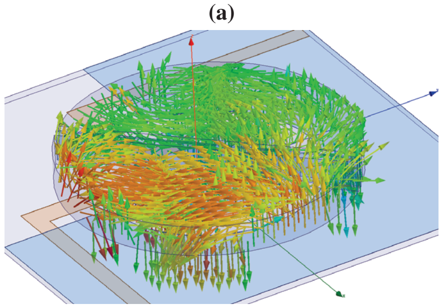


Figure 4. Simulated S-parameters of the proposed antenna compared with its various design stages.



(a)

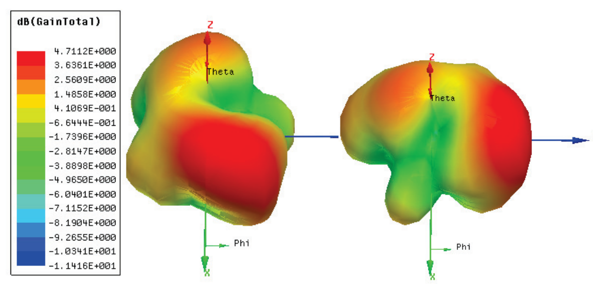


(b)

Figure 5. Simulated Electric field portrays in half-split CDRA at 5.2 GHz when only port-1 is excited: (a) top view and (b) isometric view.

should maintain the boundary condition corresponding to $HEM_{21\delta}$ mode of CDRA as demonstrated in Fig. 2. The $HEM_{21\delta}$ mode of these half-split CDRAs can be excited independently by using a suitable feeding mechanism. This has been implemented successfully by employing two L-shaped microstrip feed lines and a DGS with a C-shaped annular slot. To realize the role of the vertical wall and the linear slot, three evolutionary stages of the antenna (stage-1, stage-2 and stage-3) are developed as illustrated in Fig. 3. Fig. 4 compares the scattering parameters of all antenna variants. Stage-1 consists of a full CDRA designed to resonate around the W-LAN band (5.2 GHz) and is excited by using a C-shaped annular slot (Fig. 3(a)). Mutual coupling between the two ports appears to be very high, about -8.35dB. Stage-2 have been realized by following [15] where a full cylindrical DRA was reduced to half by employing a conducting plate to impose a perfect electric boundary. Stage-2 is therefore realized by using two half-split CDRAs separated by a vertical metallic wall with an air gap. The mutual coupling of stage-2 is -16.15 dB at 5.2 GHz, which is about 8 dB lower than the stage-1 antenna. The stage-2 antenna, however, resonates at a slightly lower frequency.

A linear slot (slot width=Ws) is added to the antenna configuration of stage-2 to realize stage-3 (the proposed antenna array). Consequently, the mutual coupling is further reduced to -22.66 dB, which is 6 dB better than the stage-2 antenna. Compared to a reference antenna (stage-1), the proposed antenna (stage-3) shows an overall improvement of 14 dB in mutual coupling. Fig. 5 shows a simulated electric field at 5.2 GHz when only port-1 is excited. As shown in Fig. 2, the simulated electric fields closely resemble the



(a) **(b)**

Figure 6. 3-D radiation patterns of the proposed antenna at 5.2 GHz: (a) only port-1 excited, (b) only port-2 excited.

Table 1. Comparison of the proposed work with the state of the art

References	Bandwidth (GHz)	Antenna size (λ_0^3)	Isolation (dB)	No. of ports	Inter-element spacing (λ_0)	Gain (dBi)
[8]	5.08-9.5	0.88×0.44×0.27	20	2	13 mm or 0.22λ_0	2.34-7.9
[9]	5.25-5.92	1.05×0.7×0.15	20	3	17 mm or 0.298λ_0	5
[10]	3.24-6	1.07×1.07×0.31	20	2	21.4 mm or 0.23λ_0	5.29-7
[11]	9.04-9.92	1.7×1.7×0.424	20	3	Not applicable	7.4-8.1
This work	5.1-5.32	0.95×0.95×0.083	15	2	2.1 mm or 0.036λ_0	4.77

$HEM_{21\delta}$ mode of CDRA. Fig. 6 shows a 3D radiation pattern for the proposed antenna when two ports are exited separately. As expected, the antenna shows a quasi end-fire pattern resulting from the $HEM_{21\delta}$ mode of the CDRA [16]. The performance of the proposed antenna is compared with few recent state of the art developments as listed in Table 1. With respect to antenna volume and inter-element spacing, it proves superior to other antenna arrays.

4 Conclusions

An array of two half-split cylinder dielectric resonator antennas (CDRAs) has been developed and analysed. A vertical metallic plate with a defected ground structure has been successfully implemented for significant improvement in mutual coupling. The envelope correlation coefficient is below 0.008, thus satisfying the low correlation criteria of MIMO. The proposed compact antenna array may thus be considered as a suitable candidate for MIMO antenna systems. The antenna design may be further improved by exploring various dielectric resonator antenna shapes and defected ground structures with novel feeding techniques.

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