Mutual-coupling Reduction of Four-element Cavity-backed Slot Antenna System Using Mushroom Walls

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***Abstract*— In this paper, double-layer mushroom walls are applied in between the substrate integrated waveguide (SIW) cavity-backed slot (CBS) antennas for reducing inter-element mutual coupling of a four-element antenna system. The mushroom wall comprises two printed circuit boards (PCB), two arrays of metallic patches printed onto the both surfaces of the PCBs, a shared ground sandwiched in between the PCBs and an array of vias connecting the patches to the ground. A compact mushroom wall loaded four-element SIW CBS antenna array, wherein the center-to-center distance of the antenna elements is 0.42 λ (λ is the wavelength in free space at 2.4 GHz), achieves extremely high inter-element isolation of 43 dB throughout the -10 dB reflection coefficient bandwidth of 2.395– 2.433 GHz.**

***Index Terms*— Mutual coupling, mushroom, antenna array, substrate integrated waveguide (SIW), cavity-backed slot (CBS) antenna.**

I. Introduction

Multiple-input multiple-output (MIMO) communication system is able to improve the efficiency and channel capacity of the wireless commutation system. Meanwhile, high order MIMO systems are introduced to meet the requirements of higher efficiency and larger channel capacity [1]. Thus, a 2×2 MIMO system will have higher data transfer rate as well as reliability than a conventional 1×2 MIMO system.

In an MIMO antenna system, the strong mutual coupling between the antenna elements will lead to stronger interference, lower radiation efficiency, and significant reduction of the channel capacity [1]. Therefore, the reduction of mutual coupling between the antenna elements is one of the key issues for the design of a MIMO system.

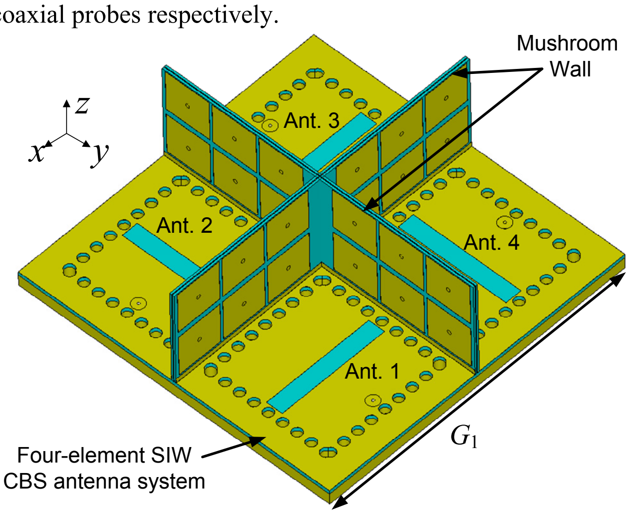
Many methods have been studied to reduce the mutual coupling. For example, cutting slots on the shared ground plane of two antennas [2]; utilizing EBG structure, split-ring resonators [4, 5] as well as mushroom structure [6] and applying parasitic elements [7] or neutralization technique [8]

The methods mentioned above address the mutual coupling problem between two antenna elements only. So far, there are few articles that deal with the mutual coupling issue of a compact array with more than two elements. Decoupled networks [9] and broadside coupled split ring resonant (SRR) wall [10] are presented to a four-element antenna system to reduce the mutual coupling while the achieved mutual coupling is undesired.

This paper investigates a compact four-element substrate integrated waveguide (SIW) cavity-backed slot (CBS) antenna system with mushroom walls. The resonant mushroom structure concentrates the field in itself so that the significant suppression of mutual coupling between the antenna elements can be realized. The antenna system is designed and optimized using CST Microwave Studio [11].

II. Antenna and Mushroom Wall Configuration

The configuration of the four-element SIW CBS antenna system with mushroom walls is shown in Fig. 1, wherein the two pieces of mushroom walls are symmetrically crossed in between the four CBS antenna elements. The adjacent SIW CBS elements are orthogonally positioned and fed by four coaxial probes respectively.



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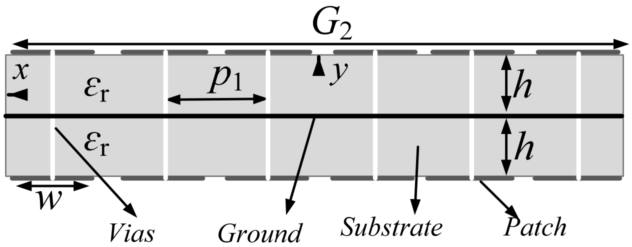

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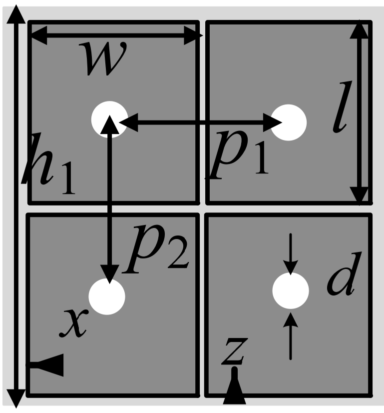

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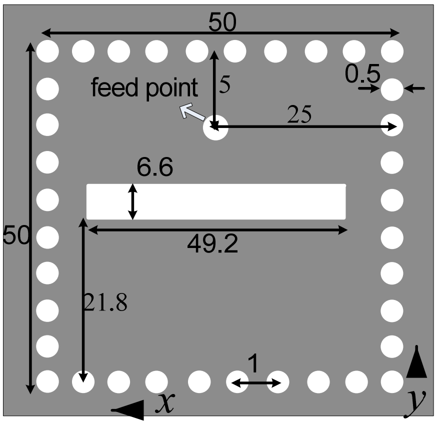

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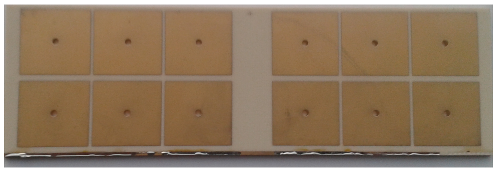
Fig.1. Configuration of the four-element SIW CBS antenna system with mushroom walls; (a) overall view, (b) cross-sectional view of the mushroom wall, (c) top view of mushroom structure and (d) SIW CBS antenna element. (Unit: mm)

III. PABRICATION AND RESULTS

The photos of the four-element SIW CBS antenna system prototype are exhibited in Fig. 2, where each mushroom wall has 2 × 6 mushroom cells. The dimensions of the mushroom wall are listed in Table I. The mushroom wall is fabricated on a double-layer Rogers 4003C with a thickness of 0.813 mm, ε_r =3.55, tanδ = 0.027, patch size of 18.38 mm× 17.23 mm, the vertical periodic and horizontal periodic of 19.58 mm. The patches are grounded through a via with a radius of 0.8 mm. The height of the mushroom wall is 42 mm. The edge-to-edge distances between each adjacent element are kept as 3 mm. The overall size of the antenna system is 150 × 150 × 43.5 mm^3.

TABLE I
DIMENSIONS OF THE FOUR-ELEMENT SIW CBS ANTENNA WITH MUSHROOM WALL (MM)

w	18.38	l	17.23	d	0.8
p_1	19.58	h_1	42	h	0.813
p_2	19.58	G_1	150	G_2	150



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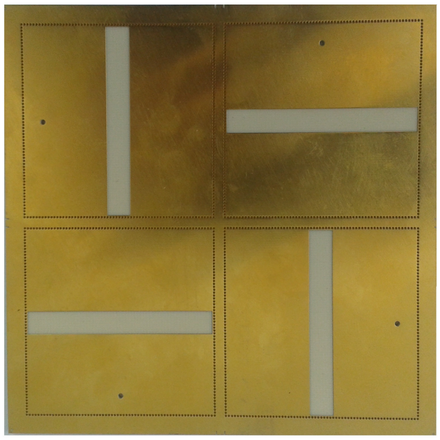

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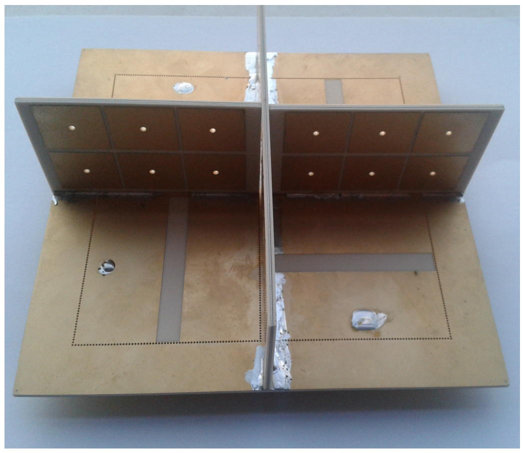

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Fig.2. Photos of the four-element SIW CBS antenna system with mushroom wall, (a) mushroom wall, (b) four SIW CBS antenna elements and (c) four-element SIW CBS antenna system with mushroom walls.

The simulated and measured *S*-parameters of the four-element SIW CBS antenna system with/without mushroom walls is shown in Fig. 3. Because all the four identical SIW CBS antenna elements are symmetrically distributed, the reflection coefficient of each element is identical. Thus, only the reflection coefficient of the Antenna Element 1 is presented. It can be seen that the frequency band for the -10-dB reflection coefficient is 2.395–2.433 GHz.

The mutual coupling between the adjacent elements along vertical and horizontal directions is the same, namely $S_{12}=S_{23}=S_{34}=S_{41}$. In addition, the mutual coupling between the adjacent elements along the diagonal line is the same as well, namely, $S_{13}=S_{24}$. For brevity, only the $|S_{21}|$, $|S_{31}|$ and $|S_{11}|$ are presented. As shown in Fig. 3, the simulated $|S_{21}|$ and $|S_{31}|$ of the antenna system without mushroom wall are less than -40 dB and -25 dB, respectively. Loaded with mushroom, the simulated mutual coupling between the adjacent antenna elements along the vertical and horizontal lines is less than -45 dB; the simulated mutual coupling between the antenna elements along parallel lines is less than -55 dB. In addition, the measured mutual coupling between all the adjacent antenna elements is less than -43 dB over the impedance bandwidth.

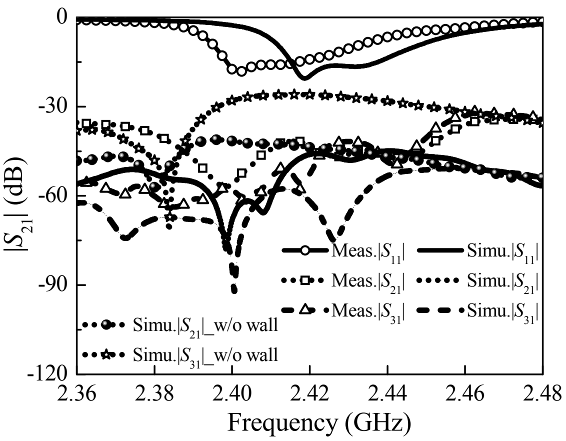


Fig.3. Measured and simulated S-parameters

The measured far-field patterns of the Antenna Element 1 at 2.4GHz, 2.42 GHz and 2.44 GHz, including the co- and cross polarizations, are shown in Figs. 5 and 6, respectively. The maximum measured realized gain of 3.4 dBi is achieved at 2.42 GHz. The maximum radiation efficiency of the antenna system of 77% is also observed at 2.42 GHz. The beam squinting is caused by the reflection from the mushroom walls. A beam squinting of 20° from the bore-sight in *E*- and *H*-planes is observed. It can be seen that within the impedance bandwidth of 2.395–2.433 GHz, the front-to-back ratio is larger than 15 dB, and the cross-polarization level is less than -15 dB.

The three-dimensional *E*-field distribution at 2.42 GHz is shown in Fig. 4. It is observed that when Antenna 1 is excited, the electromagnetic energy is almost trapped in the closest space (x>0 and y>0) of the mushroom wall, and the coupled wave to other antenna elements is negligible. The results validates that the mushroom wall is an effective to improve the isolation between antenna elements.

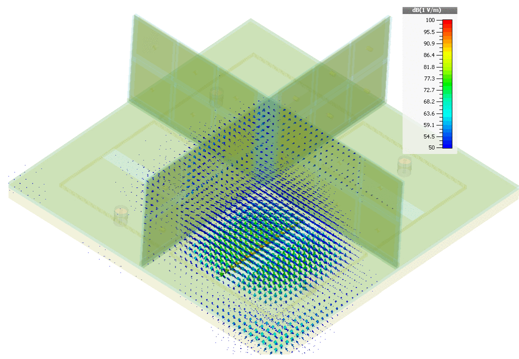
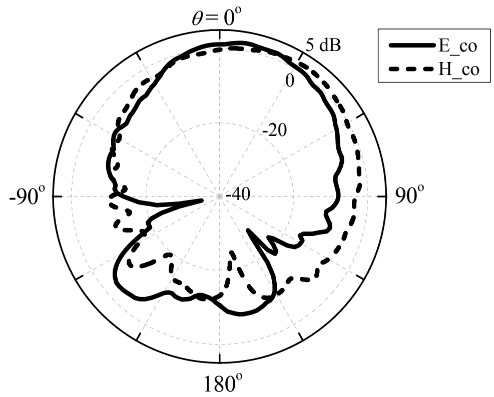


Fig.4. The simulated E-field distribution (excited by Antenna 1 at 2.42 GHz)

IV. Conclusion

The proposed mushroom wall has been proposed for mutual coupling suppression, it is able to block the space wave propagation from the antenna elements and absorb part of fields at the operating frequency band as well. This technology is promising for antenna design for higher order MIMO system.



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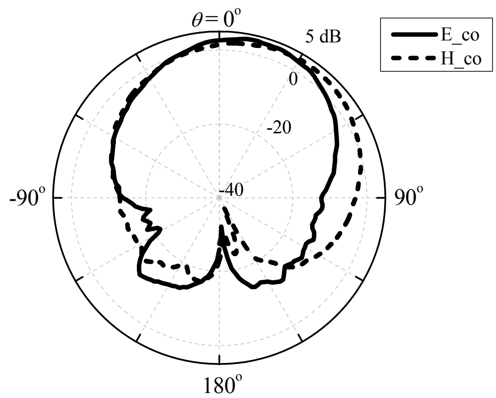

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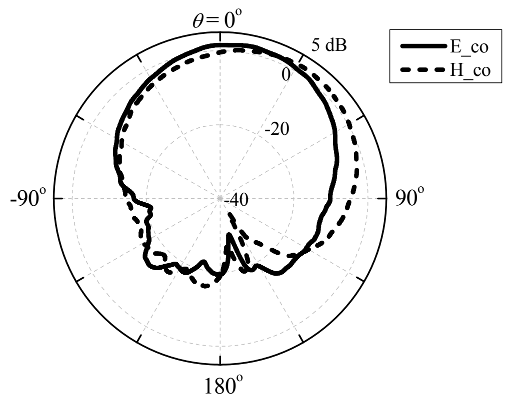

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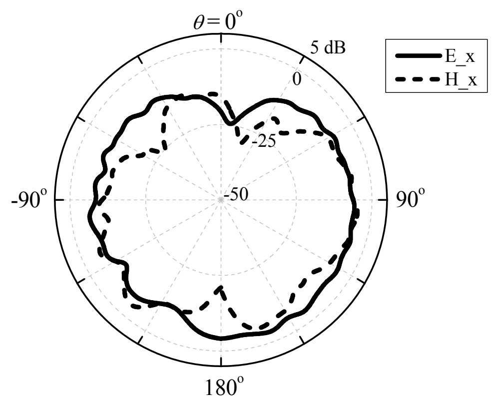
Fig.5. Measured far-field patterns of the Antenna Element 1 (co-polarization), (a) 2.4 GHz, (b) 2.42 GHz and (c) 2.44 GHz.



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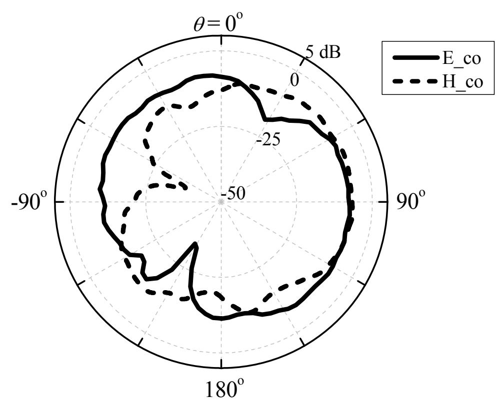

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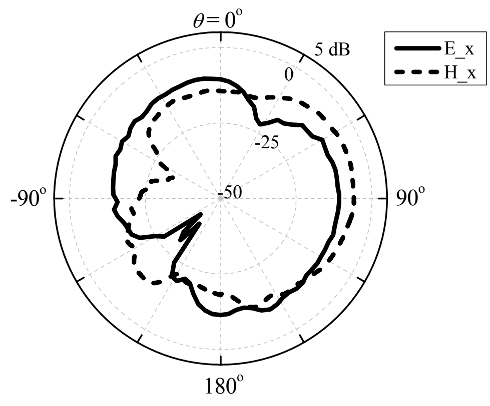

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Fig.6. Measured far-field patterns of the Antenna Element 1 (cross-polarization), (a) 2.4 GHz, (b) 2.42 GHz and (c) 2.44 GHz.

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