Isolation Enhancement Between Two Closely Spaced Substrate Integrated Cavity-backed Slot Antennas Using Mushroom

Guohua Zhai[1], Zhi Ning Chen[1,2], Xianming Qing[1]
[1]Institute for Infocomm Research, A*star, Singapore
{zhaigh, chenzn, qingxm@i2r.a-star.edu.sg}
[2]National University of Singapore, Singapore
{eleczn@nus.edu.sg}

***Abstract*-This paper presented a single mushroom-liking loading to enhance the isolation between two closely packed substrate integrated waveguide cavity-backed slot (SICBS) antennas. The mushroom inserted between two SICBS antennas blocks and concentrates part of the spaced-fields radiation from one antenna element, so that an inter-between isolation enhancement is achieved. The two-element parallel directed SICBS antennas (side-to-side) with the mushroom structure, wherein the height of mushroom is 0.04 λ_0 (λ_0 is the free-space wavelength at the central operating frequency), enhances the inter-between isolation by 8 dB over the operating band ($|S_{11}|$<-10 dB) of 2.375 GHz–2.415 GHz.**

I. INTRODUCTION

Within complex multipath environment, the performance of the wireless communication system, in terms of channel capacity and data transfer rate, can be greatly improved by the multiple-input-multiple-output (MIMO) technology [1]. However, within limited size, the closely placed multiple antenna elements lead to a reducing inter-element isolation, which deteriorates the performance of the MIMO system [2]. Therefore, it is a challenge to enhance the isolation for a compact MIMO system.

Numerous isolation-enhanced methods of multiple antenna elements have been reported. They can be summarized as the adoption of decoupling matching networks (DMNs) [3], the usage of current cancelling branches [4], as well as the utilization of the metamaterials, such as DGS [5], EBG [6], SRRs [7], and mushroom structure [8].

Substrate integrated cavity-backed slot (SICBS) antenna is suitable for the modern wireless MIMO system because of the advantages of stable far-filed patterns, low profile, and easy integration [9], [10]. In particularly, the surface-wave coupling of the SICBS antenna system is reduced due to the adoption of the metallic vias array.

Owing to the ban-gap characteristics (associated with a stopband for surface-wave propagation), the mushroom structures can be applied to improve the performance of the MIMO system by suppressing the surface-wave coupling between multiple elements [8]. However, it isn't suitable to increase the inter-between isolation of the MIMO antenna system when the spaced-field coupling is the dominant over the surface-wave one. Especially, the planer mushroom structures inserted between two antennas increase the design complexity and the size of the antenna system [8]. Therefore, it is necessary to develop a simple structure to reduce the spaced-field coupling between closely-spaced SICBS antenna elements for enhancing MIMO system performances.

In this paper, a single mushroom structure is loaded between two closely-spaced MIMO SICBS antennas to enhance the inter-element isolation. A metallic patch is connected through by a post, which is then downward extends to the ground plane of the two-element SICBS antennas. Part of spaced fields are blocked and concentrated around the mushroom loading, so that the inter-between isolation of the two-element MIMO antennas can be increased.

II. TWO-ELEMENT SICBS ANTENNA SYSTEM LOADED WITH A SINGLE MUSHROOM STRUCTURE

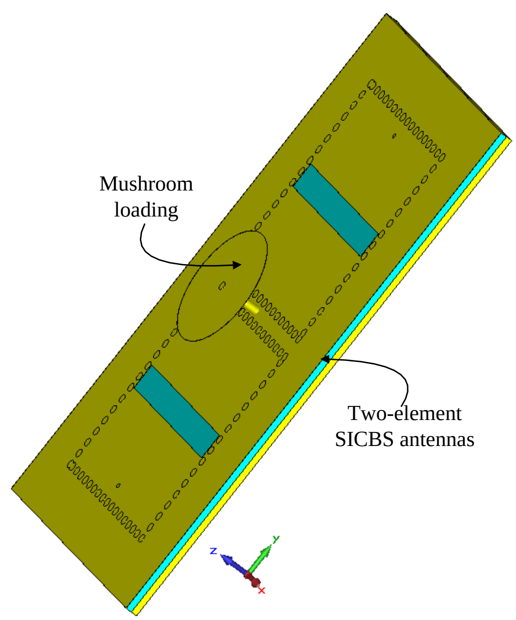
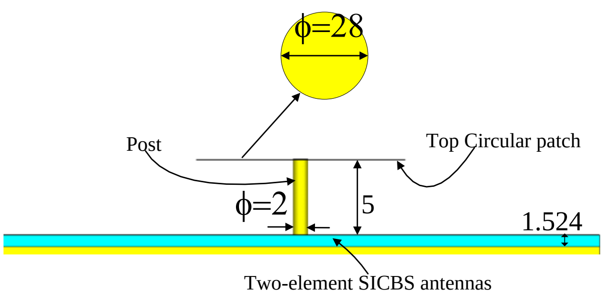


Figure 1. The perspective view of the SICBS antenna pair loaded with mushroom structure.

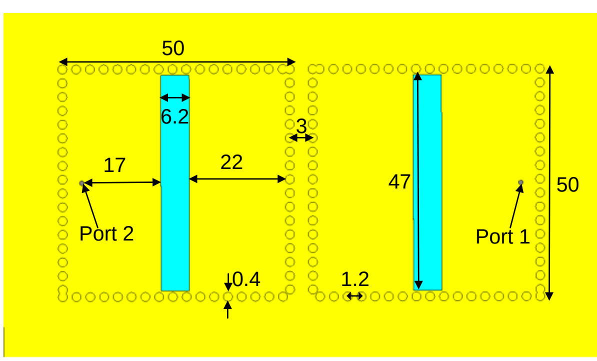
The geometry of the parallel directed SICBS antenna pair (side-to-side) with a simple single-mushroom loading is shown in Fig. 1, wherein the mushroom structure comprises a metallic patch and a grounded post. The post connects the patch and extends to the ground plane of the two-element SICBS antennas, which are separately fed by the coaxial probes, respectively. The mushroom is inserted inter-between the two antennas.

The two-element SICBS antennas are implemented on a substrate of Rogers RO4003C with ε_r of 3.38, tanδ of 0.0027, and a thickness of 1.524 mm in this paper. The dimension of the two-element SICBS antennas loaded with a single-mushroom structure is illustrated in Fig. 2.

It can be seen that the mushroom comprises a metallic circular patch with a radius of 28 mm ($0.23\lambda_0$, λ_0 is the free-space wavelength at the central operating frequency) and a post with a radius of 1 mm and a height of 5 mm ($0.04\lambda_0$). Two identical SICBS antennas with a size of 50 mm × 50 mm are parallel directed (side-to-side) with an edge-to-edge distance of 3 mm ($0.024\lambda_0$). The overall size of the two SICBS antennas loaded with a single mushroom is 130 mm × 80 mm × 6.5 mm.



(a) Cross view



(b) Top view

Figure 2. The dimension of the proposed two-element SICBS antennas loaded with mushroom structure. (Unit: mm)

When Ant.1 is excited, the *E*-field distribution along *xy*-plane is exhibited in Fig. 3. Because of the adoption of the mushroom loading, the majority of spaced-fields are blocked, and part of the fields is trapped around the mushroom, and thus very little field is coupled to other one. Therefore, the mushroom loading changes the distribution of the near field, which leads to an isolation enhancement of two closely spaced SICBS antennas. The two-element SICBS antennas with mushroom loading are optimized and simulated using the software CST [11].

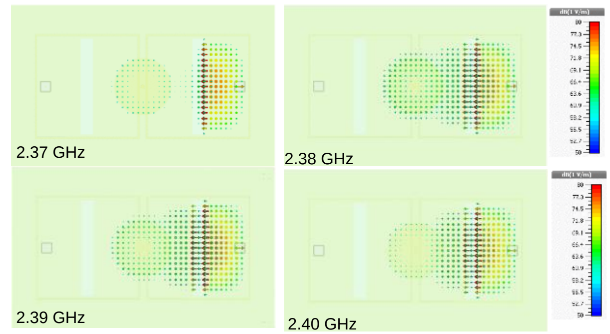


Figure 3. The simulated *E*-filed magnitude distribution along *xy*-plane at 2.37GHz, 2.38GHz, 2.39GHz, and 2.4GHz (excited by Ant. 1, *z*=1.525 mm).

III. Results

Figure 4. The photo of the fabricated two-element SICBS antennas with mushroom loading

The photo of the two-element SICBS antennas with mushroom loading is illustrated in Fig. 4. The simulated and measured $|S_{11}|$ of the two-element SICBS antennas with/without mushroom are sketched in Fig. 5.

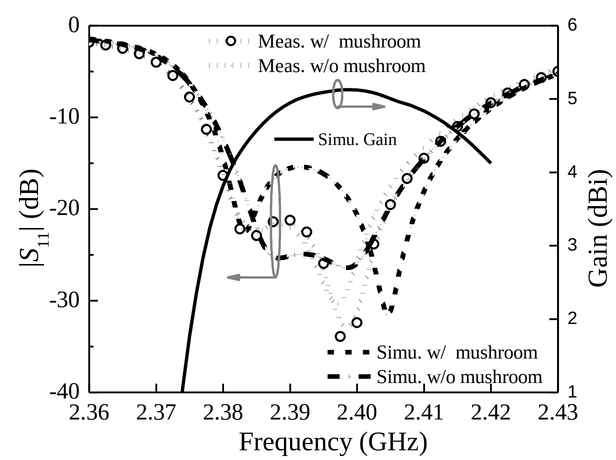


Figure 5. The simulated and measured $|S_{11}|$ of the two-element SICBS antennas with/without mushroom as well as the simulated realized gain of that with mushroom.

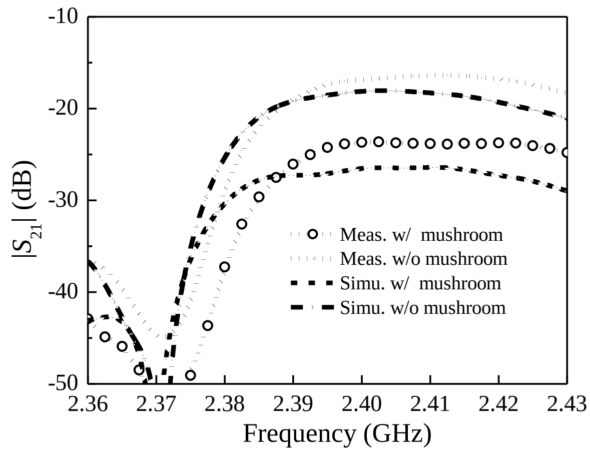


Figure 6. The simulated and measured $|S_{21}|$ of the two-element SICBS antennas with/without mushroom.

The measured $|S_{11}|$ is less than -10 dB from 2.375 GHz to 2.415 GHz. The measured maximum $|S_{21}|$s of the two antennas with/without mushroom-liking loading are -16 dB and -24 dB within the operating band ($|S_{11}|$ <-10 dB), respectively. Therefore, keeping the reflection coefficient unchanged, the isolation between the two antennas is increased by 8 dB, which validates the mushroom loading can enhance the isolation of the antennas. Additionally, the maximum gain of 5.2 dBi can be achieved within the operating band.

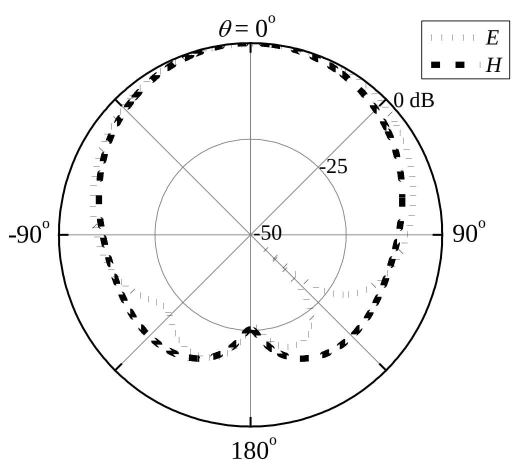


Fig. 7. Simulated radiation patterns (2.4 GHz).

The simulated far-field radiation pattern of Ant. 1 with the mushroom structure at 2.4 GHz is shown in Fig. 7. In both *E*- and *H*-planes, the front-to-back ratio is larger than 18 dB ranging from 2.375 to 2.415 GHz. It can be seen there is a small beam squint of 15^{o} in the *E*-plane patter due to the blocking by the mushroom loading along the *E* plane.

IV. CONCLUSION

A single mushroom has been loaded to increase the isolation of two-element SICBS antennas for MIMO applications. The spaced-field radiation from one antenna is blocked, and its distribution is changed by the mushroom loading. Thus, an inter-element isolation enhancement of 8dB has been achieved. Due to the simple design and easy optimization, this isolation-enhanced method can be developed and implemented to the MIMO system required more antenna elements.

REFERENCES

[1] A. J. Paulraj, D. A. Gore, R. U. Nabar, and H. Bolcskei, “An overview of MIMO communications—A key to gigabit wireless,” *IEEE Proc*., vol. 92, no. 2, pp. 198–218, Feb. 2004.

[2] M. A. Jensen and J. W. Wallace, “Review of antennas and propagation for MIMO,” *IEEE Trans. Antennas Propag*., vol. 52, no. 11, pp. 2810–2824, Nov. 2004.

[3] T.-I. Lee and Y. Wang, “Mode-based information channels in closely coupled dipole pairs,” *IEEE Trans. Antennas Propag*., vol. 56, no. 12, pp. 3804-3811, Dec. 2008.

[4] S. Farsi, H. Aliakbarian, D. Schreurs and B. Nauwelaers, “Mutual Coupling Reduction Between Planar Antennas by Using a Simple Microstrip U-Section,” *IEEE Antennas Wireless Propag. Lett*., vol. 11, pp. 1501-1503, 2012.

[5] C.Y Chiu, C. H. Cheng, R. D. Murch and C. R. Rowell, “Reduction of mutual coupling between closely packed antenna elements,” *IEEE Trans. Antenna Propag*., vol. 55, no. 6, pp. 1732–1738, Jun. 2008.

[6] M. M. B-Suwailam, M.S. Boybay, and O. M. Ramahi, “Electromagnetic coupling reduction in high-profile monopole antennas using single-negative magnetic metamaterials for MIMO applications,” *IEEE Trans. Antennas Propag*., vol. 58, no. 9, pp. 2894–2902, Sep. 2010.

[7] L. Y. Zhao and K. L. Wu, “A decoupling technique for four-element symmetric arrays with reactively loaded dummy elements,” *IEEE Trans. Antennas Propag*., Jun. 2014

[8] F. Yang and Y. R Samii, “Micro T-shaped monopole antennas integrated with electromagnetic band-gap (EBG) structures: a low mutual coupling design for array applications,” *IEEE Trans. Antennas Propag*., vol. 10, no. 2, pp. 2936–2946, Feb. 2003

[9] G. Q. Luo, Z. F. Hu, W. J. Li, X. H. Zhang, L. L. Sun and J. F. Zheng, “Bandwidth enhanced low profile cavity backed slot antenna by using hybrid SIW cavity modes,” *IEEE Trans. Antennas Propag*., vol.60, no.4, pp.1698–1704, Apr. 2012.

[10] G. H. Zhai, Z. N. Chen, and X. M. Qing, “Enhanced isolation of a closely-spaced four-element MIMO antenna system using metamaterial mushroom,” *IEEE Trans. Antennas Propag*., vol.63, no.8, Aug. 2015.

[11] CST Microwave Studio, Computer Simulation Technology [Online]. Available: https://www.cst.com/Products/CSTMWS