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Isolation Enhancement in Patch Antenna Array with Fractal UC-EBG Structure and Cross Slot

Xu Yang, Ying Liu, *Senior Member, IEEE*, Yun-xue Xu, and Shu-xi Gong, *Member, IEEE*

***Abstract*—A compact patch antenna array with high isolation by using two decoupling structures including a row of fractal uniplanar compact electromagnetic band-gap (UC-EBG) structure and three cross slots is proposed. Simulated results show that significant improvement in interelement isolation of 13dB is obtained by placing the proposed fractal UC-EBG structure between the two radiating patches. Moreover, three cross slots etched on the ground plane are introduced to further suppress the mutual coupling. The design is easy to be manufactured without the implementation of metal vias and a more compact array with the edge-to-edge distance of 0.22λ_0 can be facilitated by a row of fractal UC-EBG, which can be well applied in the patch antenna array.**

***Index Terms*—uniplanar compact electromagnetic band-gap (UC-EBG), fractal, cross slot, mutual coupling.**

I. Introduction

With the rapid development of multi-antenna systems, electromagnetic interference between antenna elements is one of the most concerned problems. Moreover, mutual coupling caused by surface waves has a serious effect on antenna array performances, such as radiation pattern, gain, operating bandwidth and so on [1]. In MIMO systems, multiple antennas are placed in a small space, which would generate strong mutual coupling leading to degradation in radiation efficiency and channel capacity [2]. It is essential to find a suitable method to reduce the mutual coupling and improve the performance of antenna array.

Several methods have been investigated to suppress mutual coupling. In [3] and [4], defected ground structures (DGS) were presented to reduce the mutual coupling effects between the antenna elements. A neutralization line has been chosen to suppress coupling by canceling out the original coupling [4], [5]. Another approach to reduce mutual coupling in patch antenna arrays is to use SC-CSRR as the metamaterial structures, but the decoupling structure increases the longitudinal height of the antenna array [6]. EBGs are periodic structures which have a frequency band-gap, in which no surface-wave propagations are allowed. Hence many proper configurations of EBG structures have been used to reduce mutual coupling in the antenna arrays [7-12]. In [7], a kind of UC-EBG structure presented is placed on top of radiating layer to enhance the isolation by 10dB. In reference [8], by taking advantage of a planar EBG structure and a multilayer dielectric substrate, the suppression of mutual coupling is significantly improved. Although these EBG configurations applied in antenna arrays have improved isolation, most of these configurations utilize multi-period EBG structures that occupy large area and cannot form a compact antenna array.

In this work, a row of fractal UC-EBG structure and cross slots as the decoupling structures applied in the antenna array are proposed to improve isolation of the antenna array significantly. Also the spacing between patch elements is obviously reduced. The UC-EBG unit cell inspired by [13] is based on the third iteration of Moore curve as a variant of Hilbert curve [14]. It adopts complementary structure of the UC-EBG which is only used to enhance impedance bandwidth in [13]. However the stop-band characteristic of the fractal UC-EBG in the proposed design is used to reduce the mutual coupling obviously. Three cross slots etched on the ground plane of the UC-EBG structure are employed to further enhance isolation. The cross slots can be regarded as a stop-band filter through disturbing surface currents to reduce mutual coupling. The patch antenna array works at 5GHz. Finally, when the array is combined with two decoupling structures, measured results show that the isolation is lower than -33dB within the operating bandwidth. Compared with reference [6] [7]，the proposed decoupling structures and antenna patches are in the same plane, which decrease the profile of the array. The antenna array(1×2) with $30\times50\text{mm}^2$ also has a small edge-to-edge spacing of 0.22λ_0 (where λ_0 is the free space wavelength).

This paper is arranged as follows. Section II describes the design and simulated results of the proposed UC-EBG structure. The implementation of UC-EBG and cross slots between radiating patches and their effects on isolation are investigated too. Section III presents and discusses measured results. A brief summary is presented in Section IV.

II. Design Process

The concrete shape of the proposed UC-EBG unit is shown in Fig. 1(a). The fractal UC-EBG structure is based on third iteration of the Moore curve. When the iterations and the total length of unit cell are ensured, the specific values like line width g and the spacing between lines s can be determined. The fractal UC-EBG has a stop-band where electromagnetic waves are not allowed to propagate. By simulating the dispersion diagram of the fractal UC-EBG, the stop-band characterization of the fractal UC-EBG structure can be reflected. Fig. 1(b) shows the band-gap which is around 5GHz. The antenna

This work is supported by the National Natural Science Foundation of China (No. 61372001 and 61401336).

The authors are with the National Key Laboratory of Antennas and Microwave Technology, Collaborative Innovation Center of Information Sensing and Understanding, Xidian University, Xi'an, Shaanxi, 710071, China (e-mail: liuying@mail.xidian.edu.cn).

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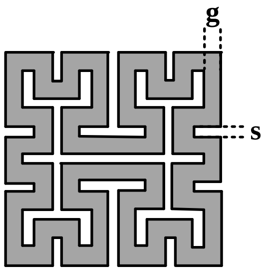
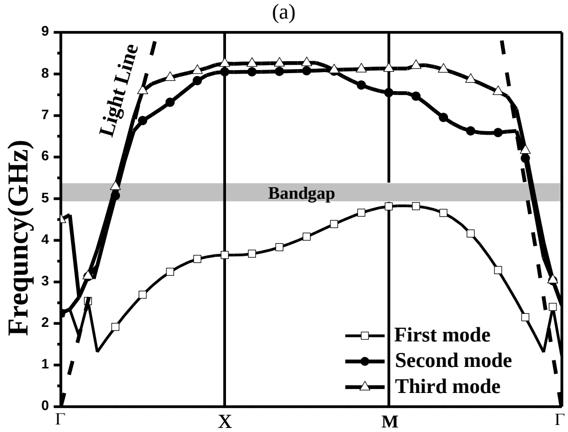
system is designed and optimized using the high frequency structure simulator (HFSS ver. 15).



(a)

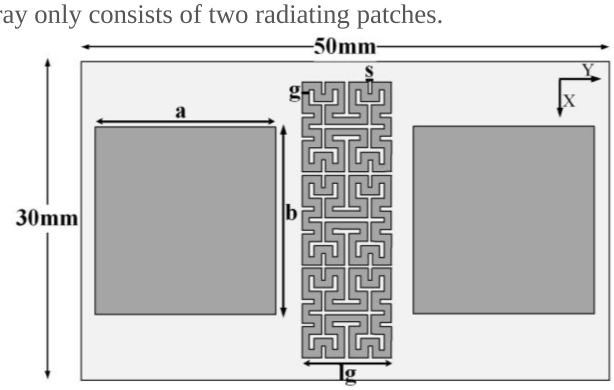


(b)

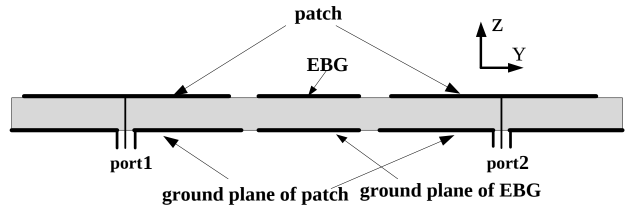
Fig. 1. (a) Geometry of the fractal UC-EBG unit cell, (b) dispersion diagram of the fractal UC-EBG structure.

A. fractal UC-EBG

To analyze the performance of the fractal UC-EBG, an antenna array (1×2) is presented. The substrate with a relative dielectric constant of 2.65, loss tangent of 0.001 is employed in the antenna array. The geometry of the antenna array with the fractal UC-EBG is shown in Fig. 2. Two rectangular metallic patch antennas directly excited by 50Ω SMA probes are placed on the top of 1mm-thick substrate. Meanwhile, the fractal UC-EBG structure placed in the middle of two patch elements consists of three unit cells. The antenna array has a compact size of 30×50mm^2. The separation between two patches is chosen as 0.5λ_0. The final design parameters optimized for the antenna array with the fractal UC-EBG are as follows: a=17.6mm, b=17mm s=0.4mm, g=0.7mm, lg=8.4mm. In contrast to the array with the fractal UC-EBG, the reference array only consists of two radiating patches.



(a)



(b)

Fig. 2. Structure of the antenna array with the fractal UC-EBG, (a) front view of the array, (b) side view of the array.

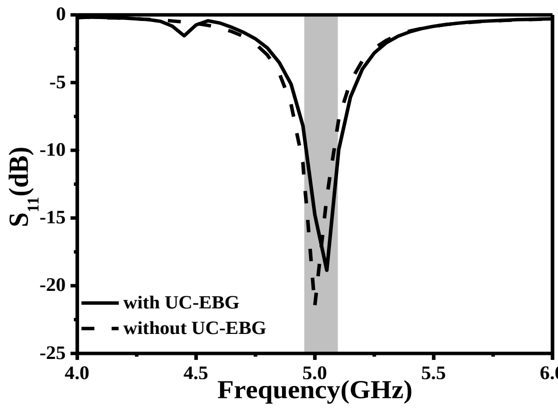


Fig. 3. Simulated S_{11} of the array with and without the fractal UC-EBG.

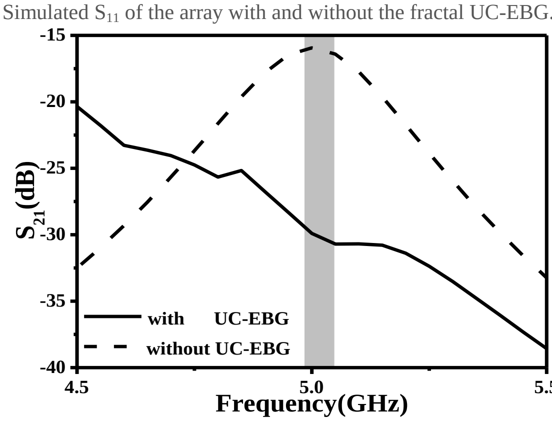


Fig. 4. Simulated S_{21} of the array with and without the fractal UC-EBG.

It can be observed from Fig. 3 and Fig. 4 that the array which has -10dB impedance bandwidth of 2.5% works at 5GHz. Compared with the reference array, mutual coupling of the array with the fractal UC-EBG is reduced by about 13dB over the operating bandwidth. Besides, owing to one row arrangement of fractal UC-EBG structure, the edge-to-edge spacing only is 0.22λ_0, which can be more beneficial to form a compact antenna patch array.

B. Cross Slot

In order to further enhance isolation in the array with fractal UC-EBG, three cross slots are utilized. The cross slot as DGS structure can effectively reduce mutual coupling. The main reason for this is that three cross slots as the band-gap structures can perturb surface currents of the ground plane. These slots are cut from the ground plane of the UC-EBG structure. The specific configuration is shown in Fig. 5. After optimizing the parameters of slots, the length of the cross slot has been determined: L1=4.5mm, L2=3.45mm. Width of the slot is 0.2mm.

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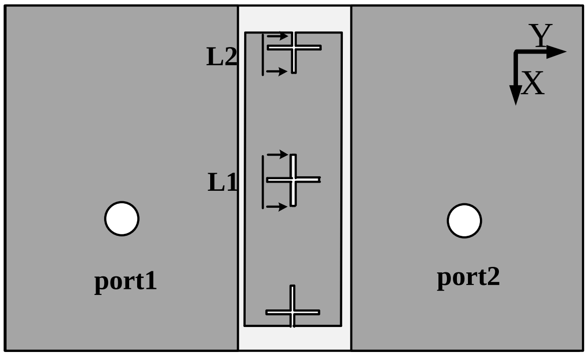


Fig. 5. Back view of the proposed antenna array.

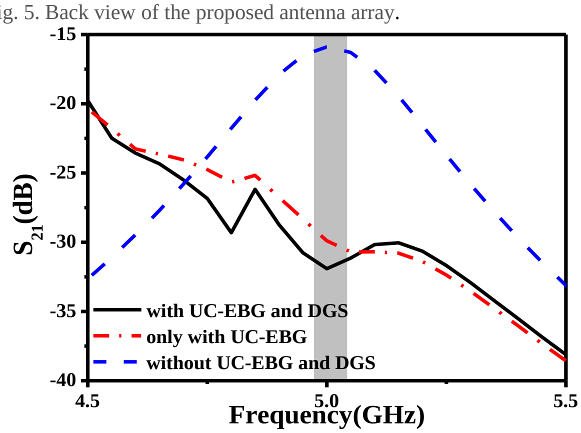


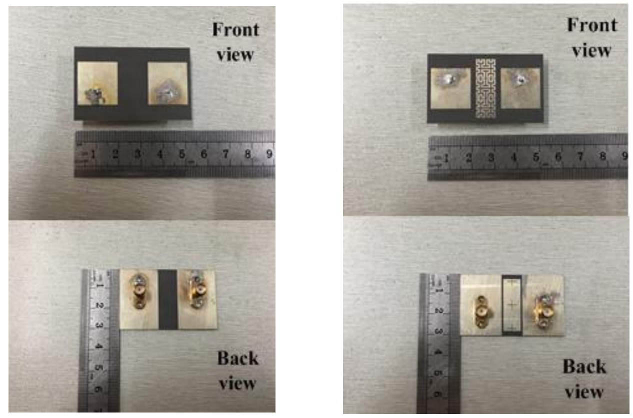
Fig. 6. Simulated S_{21} of the proposed antenna array and the array only with EBG.

Mutual coupling performances of the antenna array with and without two decoupling structures and only with EBG structures are indicated in Fig. 6. In comparison with the array only with EBG structure, the suppression of mutual coupling in the patch array consisting of two decoupling structures is improved by about 3dB. In other words, when two structures are both introduced in the patch array, the isolation can be significantly enhanced by about 16dB. Furthermore, the array compared with [7] has a more compact size and does not increase the profile of the antenna patch array. Also both of decoupling structures without vias are very easy to be fabricated.

III. Results and Discussion

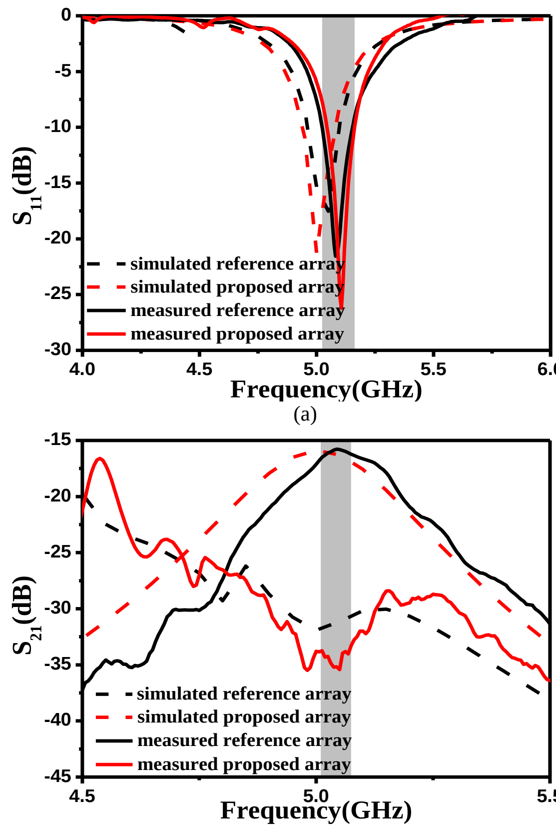
To further verify properties of the proposed antenna array, prototypes of the proposed and reference antenna arrays are fabricated and tested. Their photographs are shown in Fig. 7. The impedance bandwidth and transmission coefficients are measured with an Agilent 8719ES vector network analyzer and the radiation performances of the antenna array are measured in the Satimo SG 128 spherical near-field chamber.

Fig. 8（a）shows the measured and simulated S_{11} of proposed and reference antenna array. The measured resonant frequencies of proposed and reference arrays shift slightly to higher frequency band compared with the simulated resonant frequencies, which can be caused by fabrication tolerance and



(a) (b)

Fig. 7. Pictures of the manufactured reference and proposed antenna array, (a) reference antenna array, (b) proposed antenna array.



(a)

(b)

Fig. 8. Measured and simulated S_{11} (a) and S_{21} (b) of the fabricated proposed and reference antenna arrays.

measurement error. Fig.8 (b) shows comparison between the simulated and measured transmission coefficients. The measured and simulated results show a good agreement. The measured average coupling suppression is around 18dB.

Performances of several antenna arrays (1×2) with different EBG structures in isolation, array size, operating bandwidth and the center to center spacing are given in Table I. The antenna array with the proposed decoupling structures exhibits much better coupling suppression and the smaller center to center spacing.

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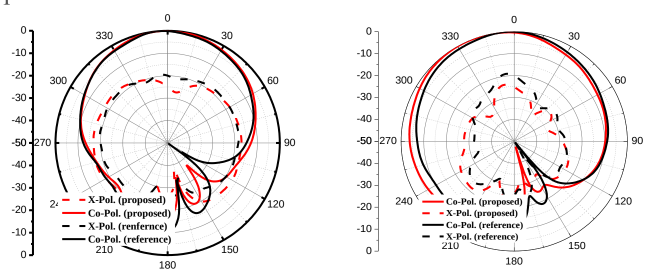
TABLE I
PERFORMANCES OF THE PROPOSED DECOUPLING STRUCTURES AND PREVIOUS WORKS

Ref.	Center frequency f_0(GHz)	Size (λ_0)	-10dB bandwidth (%)	Center to center spacing (λ_0)	Coupling suppression (dB)
[7]	5.75	1.5×1.5	1.74	0.63	10.0
[8]	3.00	1.3×1.3	7.67	0.75	10.0
[9]	5.80	NA	1.70	0.75	8.8
[10]	7.87	NA	15.63	0.60	5.0
[11]	60.00	NA	11.57	0.50	13.0
Proposed	5.05	0.5×0.8	2.50	0.50	16.0

Fig. 9 shows the measured radiation patterns of the one patch antenna in the array with and without decoupling structures, while another patch antenna is terminated with 50Ω load. Compared with the reference antenna array, the array with the fractal UC-EBG structure and cross slots almost has little impact on the radiation characteristics.



(a) 5.06GHz (b) 5.06GHz

Fig. 9. (a) Measured normalized XOZ plane radiation patterns. (b) Measured normalized YOZ plane radiation patterns

IV. CONCLUSION

To significantly improve the isolation, a fractal UC-EBG structure and cross slots are applied in the antenna array. Compared with the traditional mushroom-like EBG structure, the proposed UC-EBG structure without vias is much easier to be fabricated. The antenna array also achieves a compact size (edge-to-edge spacing of $0.22\lambda_0$) due to a row of the fractal UC-EBG. Moreover, three cross slots etched on the ground plane of the EBG structure are further utilized to improve the isolation. The proposed decoupling structures can be well employed in a compact antenna patch array for isolation enhancement.

REFERENCES

[1] A. Ludwig, "Mutual coupling, gain and directivity of an array of two identical antennas," *IEEE Trans. Antennas Propag*, vol. 24, no. 6, pp. 837–841, Nov. 1976.

[2] R. Janaswamy, "Effect of element mutual coupling on the capacity of fixed length linear arrays," *IEEE Antennas Wireless Propag. Lett.*, vol. 1, pp. 157–160, 2002.

[3] A. Habashi, J. Naurinia and C. Ghbadi, "A rectangular defected ground structure (DGS) for reduction of mutual coupling between closely-spaced microstrip antennas," *20th Iranian Conference on Electrical Engineering (ICEE2012)*, Tehran, pp. 1347–1350, 2012.

[4] C. M. Luo, J. S. Hong and L. L. Zhong, "Isolation enhancement of a Very compact UWB-MIMO slot antenna with two defected ground structures," *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 1766-1769, 2015.

[5] T. C. Tang and K. H. Lin, "An ultrawideband MIMO antenna with dual band-notched function," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 1076–1079, 2014.

[6] Z. Qamar, U. Naeem, S. A. Khan, M. Chongcheawchanman and M. F. Shafique, "mutual coupling reduction for high performance densely packed patch antenna arrays on finite substrate," *IEEE Trans. Antennas Propag*, vol. 64, no. 5, pp. 1653-1660, May 2016.

[7] H. S. Farahani, M. Veysi, M. Kamyab, and A. Tadjalli, "Mutual coupling reduction in patch antenna arrays using a UC-EBG superstrate," *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 57-59, 2010.

[8] E. Rajo-Iglesias, O. Quevedo-Teruel, L. Inclan-Sanchez, "Mutual coupling reduction in patch antenna arrays by using a planar EBG structure and a multilayer dielectric substrate," *IEEE Trans. Antennas Propag*, vol. 56, no. 6, pp. 1648-1655, June 2008.

[9] F. Yang, Y. Rahmat-Samii, "Microstrip antennas integrated with electromagnetic band-gap (EBG) structures: a low mutual coupling design for array applications," *IEEE Trans. Antennas Propag*, vol. 51, no. 10, pp. 2936-2946, Oct. 2003.

[10] G. Exposito-Dominguez, J. M. Fernandez-Gonzalez, P. Padilla and M. Sierra-Castaner, "New EBG solutions for mutual coupling reduction," *2012 6th European Conference on Antennas and Propagation (EUCAP)*, Prague, pp. 2841-2844. 2012.

[11] M. J. Al-Hasan, T. A. Denidni and A. R. Sebak, "Millimeter-wave compact EBG structure for mutual coupling reduction applications," *IEEE Trans. Antennas Propag*, vol. 63, no. 2, pp. 823-828, Feb. 2015.

[12] G. Exposito-Dominguez, J. M. Fernandez-Gonzalez, P. Padilla and M. Sierra-Castaner,"Mutual coupling reduction using EBG in steering antennas," *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 1265-1268, 2012.

[13] J. Zhang, G. Ci, Y. Cao, N. Wang and H. Tian, "A wide bandgap slot fractal UC-EBG based on moore space-filling geometry for microwave application," *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 33-37, 2016.

[14] J. Anguera, Jaume, E. Martinez, and E. Rozan, "The fractal Hilbert monopole: a two-dimensional wire." *Microw. Opt. Technol. Lett.*, vol. 36, no. 2, pp. 102-104, Jan. 2003.