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A Low Mutual Coupling Design for Array Microstrip Antennas Integrated with Electromagnetic Band-Gap Structures

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Abstract

Developing and employing methods to reduce the mutual coupling between elements of an antenna array has become a hot topic in the design of antenna arrays. The utilization of electromagnetic band-gap (EBG) structures is an attractive way to reduce surface wave excitation in printed antenna geometries so to mitigate the mutual coupling problem. This paper investigates the performance of a microstrip antenna phased array embedded in an EBG. A novel EBG array configuration is proposed, the band-gap feature of mushroom-like EBG has been studied, its band-gap feature of surface-wave suppression is demonstrated by plotting variations of the transmission coefficient S12 with frequency and dispersion diagram. The antenna design is verified by High Frequency Structural Simulator (HFSS), the simulating results show that the EBG design approach is a good candidate for a reduction in mutual coupling at certain frequencies between radiator elements, which in turn increases antenna directivity.

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Keywords: Electromagnetic band gap (EBG) structures; mutual coupling reduction; array antenna; dispersion diagram; reflection phase.

1. Introduction

Electromagnetic band gaps (EBGs) with their periodic-like structures has gained significant interest in academia and RF-microwave industries due to their extraordinary surface wave suppression property. The band –gap features of an EBG are revealed in two ways: the suppression of surface-wave propagation travels along the structure in specified frequency bands and is guided in a direction that is desirable by forbidding the propagation of EM waves into certain frequency bands, and the in-phase reflection coefficient [1]. Therefore, if the EBG structure is applied to

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the mobile phone antennas, the undesired electromagnetic waves can be prevented [2] , and the band frequency can be notched [3]. Surface-wave suppression helps to improve an antenna's performance by increasing the antenna gain and reducing back radiation [4]. Various EBG structures have been studied extensively in the last decade [5,6,7,8, 9]. Linear array of microstrip antennas are popular candidates for multiple input multiple output (MIMO) systems and radar applications such as spatial tracking. An important requirement for these applications is high integration densities to utilize available substrate space efficiently.

Initially, adjoining the elements of an antenna array to one another was a potential approach to reducing the total size of an array. However, as separations between the elements of the array are reduce, mutual coupling caused by the excitation surface waves between antennas, become stronger. As a result, the introduction of a structure "into an antenna array" reduces the inter-elemental spacing, however, the integrity of each element is sacrificed as a direct consequence. In [10] and [11], about 16 dB reduction in mutual coupling is achieved by inserting multiple rectangular defected ground structures (DGS), but the back lobe radiation has been increased because of the existence of the slots in the ground plane.

In this paper, we propose a novel compact mushroom-like EBG configuration with a band gap centered at WLAN band 5.8GHz. Information about the band gaps are calculated from their transmission coefficient responses, dispersion diagram and reflection phase characteristics. The reflection phase of the EBG surface varies continuously from 180^o to -180^o with frequency, and near the high impedance resonance, a plane wave is reflected in-phase ($+90^o$ to -90^o) in [12] the frequency band where the reflection phase which is helpful for low profile antennas to achieve good return loss is in the range of $90^o \pm 45^o$, instead of out of phase as on a PEC surface and thereby the EBG surface satisfies the PMC-like condition in this frequency band. The introduction of the EBG structure between the array elements has demonstrated its capability of suppressing the surface waves and reduction of the mutual coupling at the resonance frequency. Simulated results for the E-plane coupled microstrip antennas are depicted. The patch antenna has a size of $14x11.4mm^2$, and the antenna array resonated at a frequency of 5.8GHz. A reduction of mutual coupling about 26 dB has been achieved when the EBG structures are used between the array elements which have been separated $0.58\lambda_{5.8GHz}$ (30 mm), where $\lambda_{5.8GHz}$ is the free space wavelength at the antenna resonance frequency of 5.8GHz.

In other words, as compared to the array without EBG, our proposed array has a relatively larger directivity. The optimization to the new center frequency was conducted using HFSS a commercial electromagnetic simulator from Ansoft, based on FEM algorithm.

Nomenclature

EBG Electromagnetic Band-Gap
HFSS High Frequency Structural Simulator
WLAN Wireless Local Area Network
MIMO Multiple Input Multiple Output
DGS Defected Ground Structures
PEC Perfect Electrical Conductor
PMC Perfect Magnetic Conductor
FEM Finite Element Method

2. EBG Structures

The mushroom-like EBG structure was first proposed in [13], it consists of four parts : a ground plane, a dielectric substrate, metallic patches, and connecting vias. This EBG structure exhibits a distinct stop band for surface-wave propagation. Fig.1 shows a square unit cell of the mushroom-like EBG structure used in the proposed configuration. This structure exhibits interesting behaviors in the microwave frequencies [12,13].

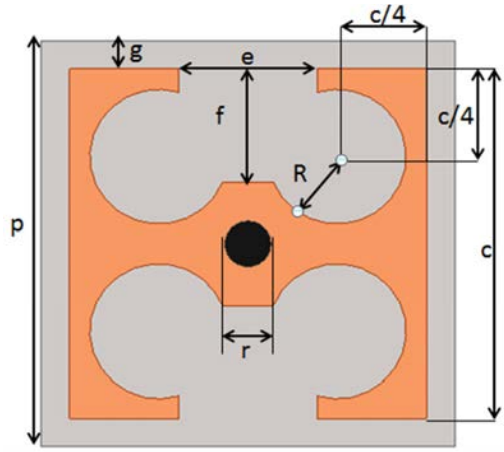

Fig. 1. Unit cell of mushroom-like EBG structure

The frequency band-gap of the EBG structure can be tuned by changing the geometrical dimensions of each unit cell. In the case at hand, the antenna resonant frequency is selected at 5.8 GHz. The parameters of the EBG structure are designed in a way that the desired frequency band-gap can accommodate the resonant frequency of the antenna. To observe the desired band-gap, the dispersion diagram was used since it is an effective tool for studying band-gap properties of the EBG structures. The design parameters of the EBG structure are labeled in Fig. 1.

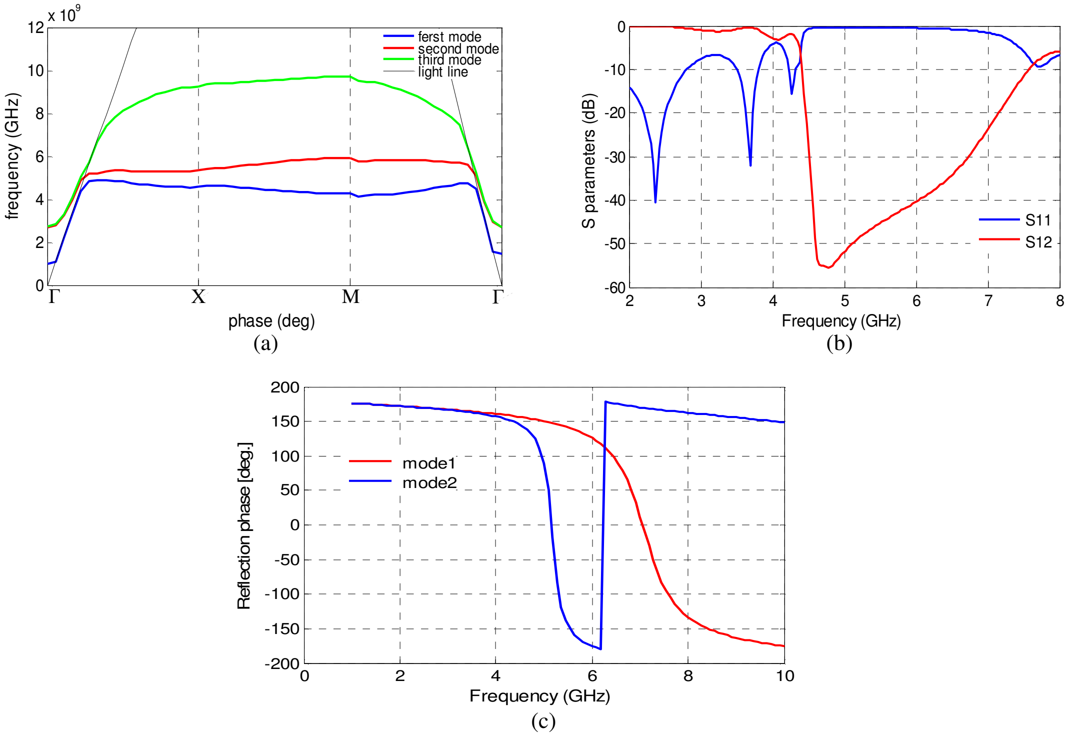

Fig. 2. (a) The computed dispersion diagram; (b) S-parameters varies with frequency; and (c) Reflection phase characteristics.

The dimensions of the EBG cells are optimized to have WLAN-band rejection at 5.8 GHz. All the dimensions of this work are given in Table 1. The stop band gap property of the EBG structure can be validated using an open air-filled microstrip transmission line; it is observed from Fig. 2(b) that the transmission coefficient S12 less than -20 dB ranging from 4.5GHz to 7GHz indicates the stop band behavior of the structure. The dispersion diagram of the proposed EBG structure in Fig. 2(a) shows a stop band gap between the first-second and second-third modes which is obtained in the frequency range (4.8 GHz – 5.2 GHz and 5.8GHz – 6.8GHz) very close to the frequency band shown in Fig. 2(c) which shows a reflection phase in the range of $+90^{o} \pm 45^{o}$ [12].

3. Antenna design and analysis

The geometry of the proposed antenna array is shown in Fig. 3, the antenna is printed on a FR4 substrate with dielectric constant 4.4 and thickness h=1.6 mm.

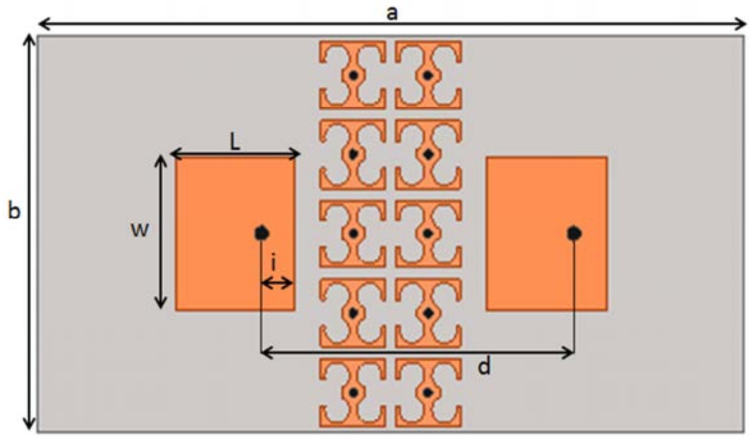

Fig. 3. Patch antenna array with EBG structures.

Table 1. Optimum values of parameters.

Design parameters	Value (mm)	Design parameters	Value (mm)
a	68	i	3.3
b	40	p	7.7
c	6.3	g	0.7
d	30	L	11.4
e	2.4	w	14
f	2	r	1
R	1.2	h	1.6

The proposed periodic structure exhibits a band gap of 4.5 GHz at 7 GHz, where it can suppress the unwanted surface waves. These characteristics are utilized to improve the mutual coupling (or isolation) between a two element E-plane coupled microstrip antenna array. As depicted in Fig. 3, a 2 x 5 EBG matrix is inserted between two rectangular elements of array. The antennas size is 11.4mm 14 mm, and the distance between the antennas is 30 mm. Fig. 4 shows the return loss and the coupling coefficient of the antenna array with and without the EBG structures. It is observed that the antenna resonate around 5.8 GHz. Although the existence of the EBG structure has some effects on the input matches of the antennas, all the antennas still have better than -10 dB matches. Without the EBG structure, the antenna shows a strong mutual coupling of -21 dB. If the EBG structures are employed, the mutual coupling level changes and the reduction of mutual coupling about 23 dB at the resonance frequency has been achieved.

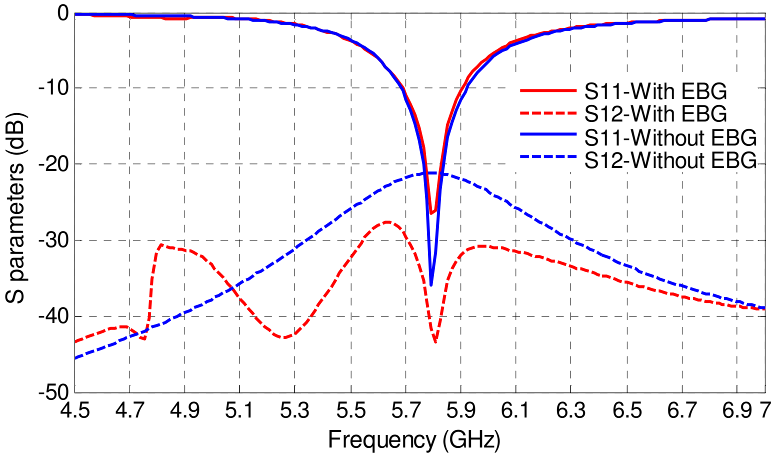

Fig. 4. Simulation S parameters in presence and absence of EBG.

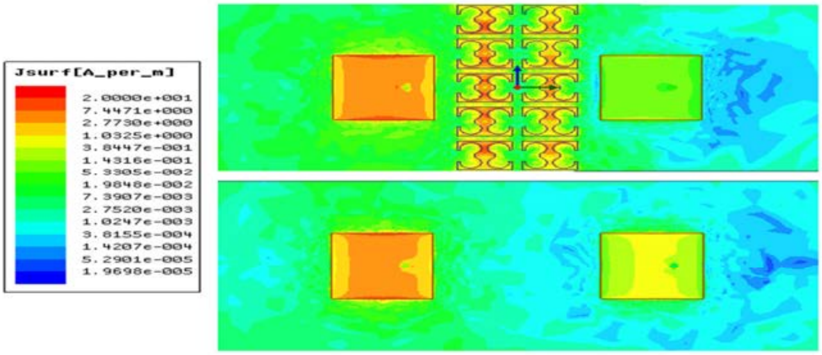

Fig . 5. Surface current distribution with and without EBG structure.

Fig. 5 shows the surface current distribution with and without EBG structure, where it can be noticed that the EBG structure reduces the current density on the antenna surface. These results confirm the suppression of the surface current by the EBG structure, which dictates the reduction in mutual coupling and improvement in the isolation between the array elements.

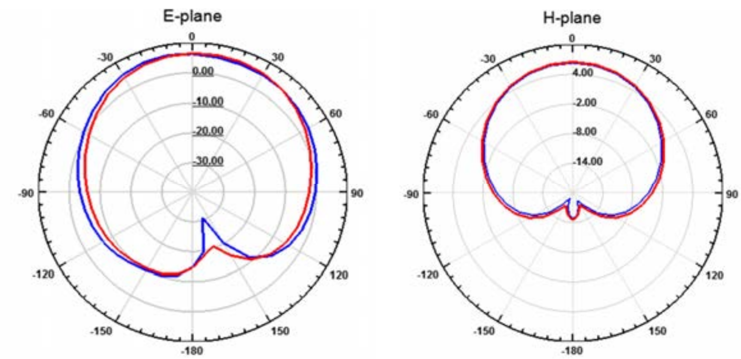

Fig. 6. Radiation pattern of the array antenna at 5.8GHz with EBG (red) and without EBG (blue).

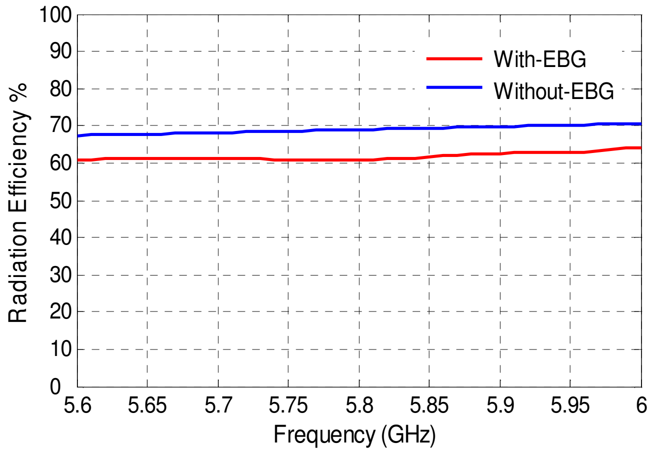

Fig. 7. Radiation efficiency.

Furthermore, the radiation characteristics for the both array configurations are presented in Fig. 6. In presence of EBG structure, the radiation patterns are not disturbed in considerable amount although it is slightly improved. From Fig. 7, the radiation efficiencies show that with EBG there is an improvement by 8% in the vicinity of the resonance frequency.

4. Conclusion

In this paper, a mushroom-like EBG structure for array miniaturization with reduced mutual coupling has been introduced. The EBG structure is analyzed using the Ansoft HFSS. The final results show a -23dB reduction in mutual coupling and a reduction in size compared to antenna array structure proposed in the literature [4]. EBG structures for an operating frequency of 5.8GHz have been presented and several useful properties of the structure have been investigated, like the in-phase band gap reflection coefficient, S-parameters and the dispersion diagram. These properties make the proposed EBG structure a good candidate to enable the design of low profile antennas, and the surface wave suppression band gap property which improves the antenna performance.

References

[1] Mohammad Tariqul Islam, Md. Shahidul Alam. Compact ebg structure for alleviating mutual coupling between patch antenna array elements. Prog Electromagn Res; 2013. Vol.137. p.425–38.

[2] Nurul Hafizah Mohd Hanafi, Mohammad Tariqul Islam, Norbahiah Misran. Analysis of Mushroom-like EBG Structure and UC-EBG for SAR Reduction. Proceedings of ISAP2012, Nagoya, Japan; 2012. p. 696-699.

[3] Abdelmoumen Kaabal, Saida Ahyoud, Adel Asselman. A New Design of Star Antenna for Ultra Wide Band Applications with WLAN-Band-Notched Using EBG Structures. Int J Microw Opt Technol; 2014. Vol.9. p.544–8.

[4] Fan Yang, Yahya Rahmat-Samii. Microstrip Antennas Integrated With Electromagnetic Band-Gap (EBG) Structures: A Low Mutual Coupling Design for Array Applications. IEEE Trans Antennas Propag; 2003. Vol. 51. p.2936–46.

[5] Zeev Iluz, Reuven Shavit, Reuven Bauer. Microstrip Antenna Phased Array With Electromagnetic Bandgap Substrate. IEEE Trans Antennas Propag; 2004. Vol. 52. p.1446–53.

[6] M.S.Mohamad Isa, R.J.Langley and al. Microstrip Patch Antenna Array Mutual Coupling Reduction using Capacitive Loaded Miniaturized EBG. J Telecommun Electron Comput Eng; 2012.Vol.4. p. 27-34.

[7] Hossein Sarbandi Farahani, Mehdi Veysi, Manouchehr Kamyab, Alireza Tadjalli. Mutual Coupling Reduction in Patch Antenna Arrays Using a UC-EBG Superstrate. IEEE Antennas Wirel Propag Lett; 2010. Vol.9. p. 57-59.

[8] Baharak Mohajer-Iravani, Omar M. Ramahi. On the Suppression Band and Bandgap of Planar Electromagnetic Bandgap Structures. Hindawi Publ Corp Int J Antennas Propag; 2014.

[9] Nagendra kushwaha, Raj Kumar. Study of Different Shape Electromagnetic Band Gap (EBG) Structures for Single and Dual band Applications. J Microwaves Optoelectron Electromagn Appl; 2014. Vol.13. p. 16-30.

[10] Asieh Habashi, Farnaz Mirzamohamadi, Sajjad Habashi, Javad Nourinia. A Simple Defected Ground Structure (DGS) for Reduction of Mutual Coupling in Closely-Spaced Microstrip Arrays. J World's Electr Eng Technol; 2013. Vol.2. p. 13-16.
[11] A. B. Abdel-Rahman. Coupling reduction of antenna array elements using small interdigital capacitor loaded slots. Prog Electromagn Res C; 2012. Vol.27. p.15-26.
[12] Fan Yang, Rahmat-Samii Y. Reflection phase characterizations of the EBG ground plane for low profile wire antenna applications. IEEE Trans Antennas Propag; 2003. Vol.51. p.2691–2703.
[13] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolus, E. Yablonovitch. High-impedance electromagnetic surfaces with a forbidden frequency band. IEEE Trans Microw Theory Tech; 1999. Vol.47. p.2059–2074.