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Mutual Coupling Reduction in Patch Antenna Using Electromagnetic Band Gap (EBG) Structure for IoT Application

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***Abstract*—Design of compact patch array for Internet-of-things (IoT) application is presented in this paper. A Two Via Slot Type Electromagnetic Band-Gap (TVS-EBG) structure is used for mutual coupling reduction in patch antenna. Design and simulation of TVS-EBG structure is done by using Ansoft High Frequency Structure Simulator (HFSS). TVS-EBG structure increases the equivalent value of C and L per unit EBG cell by making slot on square patch of the TVS-EBG cell and two via between square patch of the TVS-EBG cell and ground plane. Application of TVS-EBG structure in patch array for reducing mutual coupling has been designed and validated at ISM band. The TVS-EBG structure has been designed using FR4 substrate with dielectric constant (ϵ_r) = 4.4 and thickness (h) = 1.60 mm. Experimental results show that 7.1 dB reduction of mutual coupling is obtained in patch array by inserting two columns of TVS-EBG structure between two patch antennas.**

I. Introduction

The word Internet-of-Things (IoT) identifies everything that is connected to the internet and that goes beyond classical computers or mobile phones. A report by Cisco [1] has recently indicated that over 50 billion objects will be connected to the internet by 2020. IoT systems are characterized by the transmission of small amounts of data and low transmission rate, which reduce the bandwidth requirements [2]. In this work, some aspects related to the design of compact antennas for IoT applications using Electromagnetic Band Gap (EBG) structure is presented. Compactness is a key point in dealing with IoT devices. EBG structures are defined as artificial periodic objects that prevent the propagation of Electro-Magnetic waves in a specified band of frequency for all incident angles and all polarization states [3]. EBG structures can be implemented by using periodic arrangement of metallic conductors and dielectric materials [4]. In recent years several EBG structure have been investigated for patch antenna application. Dan Sievenpiper presented hexagonal type EBG surface which consists of an array of metal hexagonal shape patch on metal sheet and arranged in two dimension lattice [5]. Fan Yang investigated the application of Conventional Mushroom Electromagnetic Band Gap (CM-EBG) structure in patch antenna array to improve parameters and in reduction of mutual coupling of array [6]. It has been reported that period of EBG surface has to be a half wavelength at the stop band frequency in early EBG design [3], so the EBGs usually have a large size at lower frequency. To solve this problem many small and compact EBGs are investigated. Q. Zheng and N. Yuan [7] reported spiral type EBG with band gap centered frequency at 3.25 GHz and 30.9% size reduction as compared to CM-EBG. M. Coulombe and C. Caloz [8] investigated Elongated Mushroom Electromagnetic Band Gap (EM-EBG) structure in which compactness of the EM-EBG has been presented. Increase in capacitance value gives the less Band Gap Bandwidth (BG-BW) as compared to CM-EBG [7]- [13]. In our previous work [14], we presented simulation and measurement of band gap of TVS-EBG at 3.32 GHz using truncated microstrip line method. In this work, we are introduced application of TVS-EBG for mutual coupling reduction at 5.80 GHz ISM band for Internet of Things (IOT) application. Section II presents a prototype of TVS-EBG at 5.80 GHz frequency , its design and corresponding dispersion diagram. We described reduction of mutual coupling in patch antennas using TVS-EBG in Section III, with the simulated and experimental results. Finally, conclusions are provided in section IV.

II. Prototype of EBG, and Dispersion Diagram

The Conventional Mushroom Electromagnetic Band Gap (CM-EBG) structure reported in [6] gives 8 dB reduction of mutual coupling between two patch antennas but as compared to patch size; the size of each CM-EBG cell is 83.1%.

For EBG, the band-gap center frequency (f_c) and the band gap bandwidth are approximately determined by [6].

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

and

$$BW = \frac{\Delta\omega}{\omega} = \frac{\sqrt{LC}}{\eta_0} \tag{2}$$

From (1), in order to design a compact EBG structure, the equivalent values of C and L should be increased. Value of L depends on μ_0 which is constant and h is kept constant from design point of view. Therefore to increase the value of L, adding one more via per EBG cell, is the way to increase its value. In CM-EBG as shown in Fig. 1 width of the patch is used to increase the value of C, by adjusting the distance between two adjacent EBG cell. The area of the EBG patch is not utilize efficiently to get compactness.

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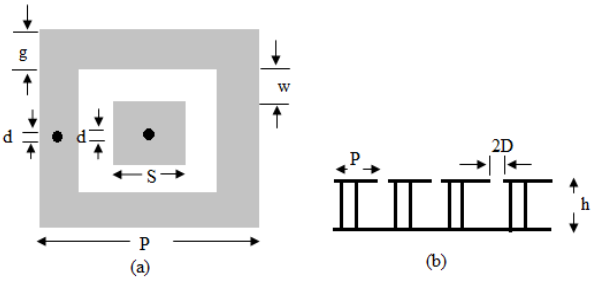


Fig. 1. Two Via Slot type Electromagnetic Band Gap (TVS-EBG) structure at ISM 5.80 GHz (a) top view (b) side view.

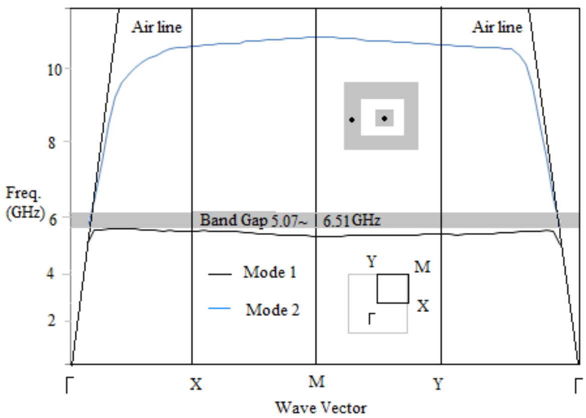
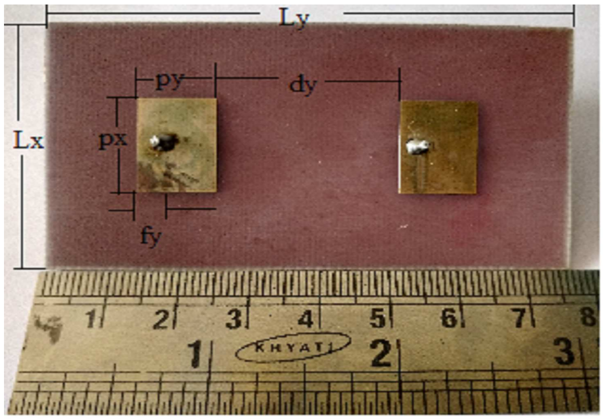
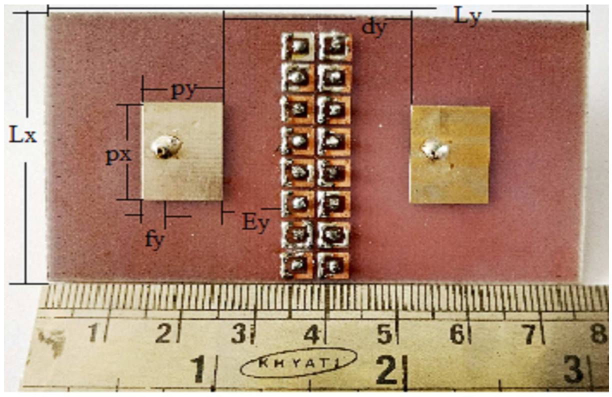


Fig. 2. Dispersion diagram of TVS-EBG structure with (2D) = 0.25 mm, (P) = 4.50 mm, (w) = 0.25 mm, (g) = 1.00 mm, (S) = 2.00 mm, (d) = 0.80 mm.

The TVS-EBG structure as shown in Fig. 1 uses this unutilized EBG patch area for increasing the equivalent C by making slot on it. From (1), to get compact EBG structure, the equivalent value of C should be increased. However, due to increase in C and from (2), band gap bandwidth (BW) reducing as compared with CM-EBG. To verify the properties of the proposed TVS-EBG structure, a TVS-EBG structure is simulated in Ansoft HFSS [15] [16]. For the TVS-EBG structure, as shown in Fig. 1, size of each element is chosen as follows: the gap between two EBG is (2D) = 0.25 mm, the periodic spacing (P) = 4.50 mm, the gap between inner square patch and outer slot is (w) = 0.25 mm, the width of outer slot (g) = 1.00 mm, width of the inner patch (S) = 2.00 mm, the diameter of each via (d) = 0.80 mm.The dispersion diagram TVS-EBG structure is shown in Fig. 2. From dispersion diagram we observe that frequency band gap between mode 1 and mode 2 for TVS-EBG exists [16]. As shown in Fig. 2, the band gap is centered at 5.79 GHz with lower frequency cutoff (f_l) = 5.07 GHz and higher frequency cutoff (f_h) = 6.51 GHz with BG-BW 24.87%. Application of the TVS-EBG structure for mutual coupling reduction is presented in section III.



(a)



(b)

Fig. 3. Photograph of E-plane coupled patch array (a) without TVS-EBG (b) with 2×8 TVS-EBG cells, where substrate dimensions are (L_y) = 75.75 mm and (L_x) = 43.00 mm, each patch size (p_y) = 11.31 mm and (p_x) = 15.74 mm, probe fed placed along Y-axis with (f_y) = 3.10 mm, distance between two patches (d_y) = 25.94 mm, and distance between TVS-EBG and each patch (Ey) = 8.22 mm

III. Mutual Coupling Reduction and Expereimental Results

In microstrip structures, mutual coupling depends on the substrate dielectric constant (ϵ_r), substrate thickness (h) and the distance between patches [17]. In antenna array, strong mutual coupling affects the performances of an antenna in terms of Side Lobe Level (SLL), beam shape, input impedance mismatch, grating lobes and scan blindness [17] [18] . When the values of ϵ_r and h are high then there is a strong mutual coupling between patches and therefore must be reduced. There are several methods to reduce the mutual coupling but from experimental results reported in [6], it is observed that the lowest mutual coupling results when EBG structure is inserted between two patches. As reported in [6], mutual coupling in the E-plane is stronger than the H-plane coupling; therefore we will focus on the mutual coupling in E-plane only. Photographs of proposed patch array without TVS-EBG and with TVS-

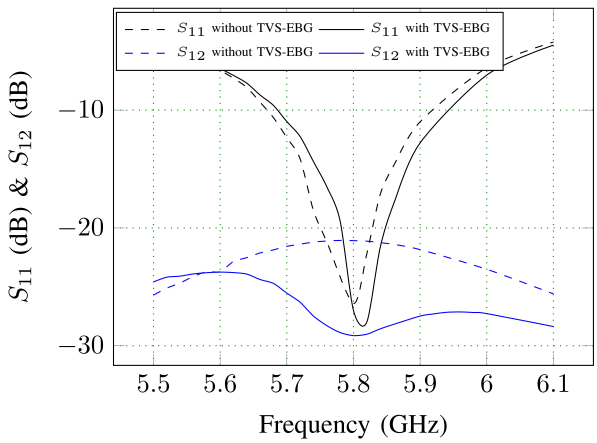


Fig. 4. Compared full-wave simulated (Ansoft HFSS) scattering parameters of the E-plane coupled patch array with and without TVS-EBG structure.

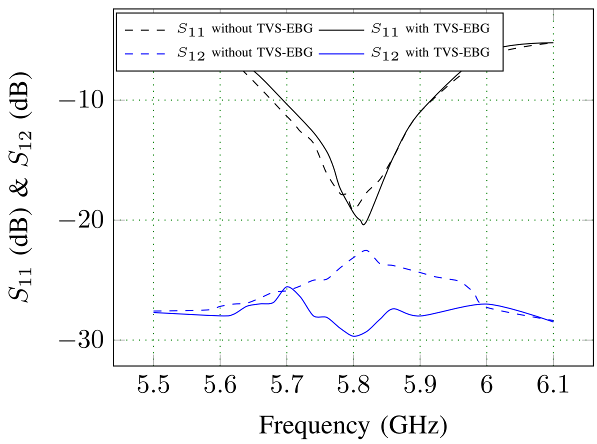


Fig. 5. Compared measured scattering parameters of the E-plane coupled patch array with and without TVS-EBG structure.

EBG are shown in Fig. 3.

The distance between two patches is kept $\lambda_o/2$ [19], where operating frequency (f_o) = 5.80 GHz. Fabrication of both array with TVS-EBG and without TVS-EBG structure are done on glass epoxy with dielectric constant 4.4 and substrate height 1.60 mm.The simulated and measured mutual coupling (S_{12}) and return loss (S_{11}) for both the cases i.e. with TVS-EBG and without TVS-EBG structure, are shown in Fig. 4 and Fig. 5 respectively. In the fabrication process, due to presence of two via and other parameter, δ is set 0.035mm for fabrication constraints. From measured results, without TVS-EBG structure a strong mutual coupling of -23.13 dB occurs at 5.79 GHz between two patch antennas. When two columns of the TVS-EBG are inserted between two patch antennas, a 7.01 dB mutual coupling reduction is obtained at 5.81 GHz. Comparison of simulated and measured results are given in table I. Due to two via per TVS-EBG cell, there is small shifting of operting frequency patch antennas but which is in the range of bandwidth. This Comparison proves the capability of the TVS-EBG structure to reduce the mutual coupling.

TABLE I
COMPARISION OF SIMULATED AND MEASURED RESULTS FOR ARRAY STRUCTURE WITH TVS-EBG AND WITHOUT TVS-EBG

Array sructure	Simulated results		Measured results	
	f_0 (GHz)	S_{12} (dB)	f_0 (GHz)	S_{12} (dB)
Without TVS-EBG	5.80	-21.06	5.79	-23.13
With TVS-EBG	5.81	-29.15	5.81	-30.14

IV. CONCLUSION

In this paper, reduction of mutual coupling of patch antenna at 5.80 GHz frequency using TVS-EBG is presented. The period size of the TVS-EBG structure is $0.087\lambda_o$ at the band-gap center frequency. Presented structure for patch array is implemented by inserting two rows of EBG structure between two patch antennas to reduce the mutual coupling. Experimental results shows that the mutual coupling reduction of 7.1 dB is achieved using TVS-EBG structure. Presented mutual coupling reduction in patch antenna is very useful in IOT application where compactness is highly desirable.

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