Mutual Coupling Reduction in Patch Antenna Arrays Using EBG Structure

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Abstract

Periodic structures can help in the reduction of mutual coupling by using their capability of suppressing surface waves propagation in a given frequency range.
In this paper, firstly, the band-gap feature of HIS Mushroom-like EBG has been studied, this HIS structures are integrated into an antenna arrays system to reduce the mutual coupling for both frequency domain. The results shown that the performance of the array changes if EBG parameters such as EBG size, spacing between EBG, number of column of the EBG inserted between the elements and also the shape of the patch are changed.
Keywords: *Electromagnetic band-gap (EBG), microstrip antennas, mutual coupling, surface wave.*

1. Introduction

In recent years, there has been growing interest in utilizing electromagnetic band-gap (EBG) structures in the electromagnetic and antenna community. The EBG terminology has been suggested in [1] based on the photonic band-gap (PBG) phenomena in optics [2] that are realized by periodical structures. These structures are implemented by periodic dielectric and various metallization patterns. There are a wide range of applications associated with EBG structures for two main properties. First they can suppress propagation of surface waves along the structure. Eliminating surface waves by means of EBG structures can enhance the radiation efficiency of different kinds of antennas. The second remarkable property of EBG structures is their reflection phase characteristics which vary continuously from 180° to -180° in a frequency band [3]. Since the mutual coupling between the antenna elements and arrays is principally carried by the wave surface, the use of HIS can help to attenuate their level if the topology and implementation are carefully designed.[4][7]

This paper focuses on the design and optimization of the high impedance surfaces; the Mushroom like EBG has been studied by HFSS (high frequency simulator structure) at 10 GHz. In order to validate our study the mushroom-like EBG structure is inserted between antenna elements. When the EBG parameters are properly designed, the pronounced surface waves are suppressed, resulting in a low mutual coupling.

2. EBG structure configuration

High Impedance Surface has a zero degres phase reflection coefficient within the band-gap and presents a very high effective impedance surface which is opposed to the case of a perfect conducting surface.
The operation mechanism of EBG structure can be explained as a distributed LC network with specific resonant frequencies. The electromagnetic properties of the EBG unit cells can be described using lump-circuit elements—capacitors and inductors, as shown in Figure 1. In the frequency range where the surface impedance is very high, the equivalent LC circuit acts as a two-dimensional electric filter to block the flow of the surface waves.
The central frequency of the band gap is
$f_0 = 1/2\pi\sqrt{LC}$. The inductor L results from the current flowing through the vias, and the capacitor C due to the gap effect between the adjacent patches. Thus, the approach to increase the inductance or capacitance will naturally result in the decrease of band gap position. [5-6]

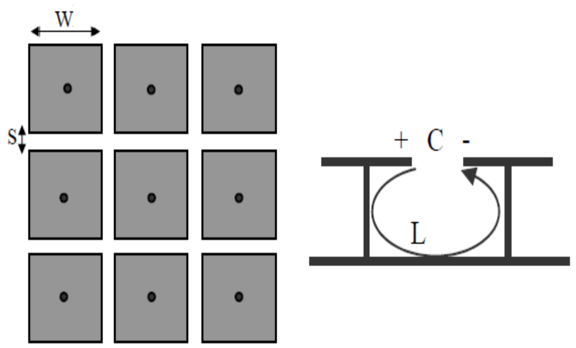

Fig.1 Equivalent lump-circuit elements of a typical EBG unit cells, Mushroom cells (with via) The dimensions are, w=3.5mm,s=1mm,r_{via} =0.2mm

3. Simulation of linear array antenna integrated with EBG

The microstrip antenna is excited by a coaxial probe and the feed point is located at the distance (dx=1.7mm) away from the edge of the patch. The length L and the width W have been taken as 8.3and 11.34mm.

Simulation of the linear array antenna integrated with mushroom-like EBG is presented. Since substrate (80*80mm) having dielectric constant $\varepsilon r = 2.5$ has high surface wave, we are expecting that improvement in term of mutual coupling after EBG inserted into array antenna. The first simulation starts with substrate having 1.588mm thickness and dielectric constant of 2.5 with 15 mm (half wavelength) spacing between patch with one column of mushroom-like EBG ($3.5*3.5mm^2$) with 1mm spacing between EBG as shown in Figure 2.

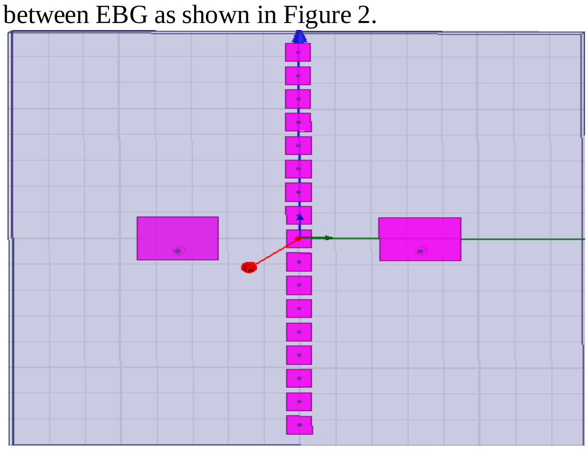

Fig. 2 Microstrip patch antenna separated by mushroom-like EBG structure

Figure 3 shows that there is a band gap produced by the EBG, antenna integrated with one row of conventional mushroom like EBG patches produces a higher mutual decoupling, by inserting mushroom-like EBG row, the mutual coupling reduce from -32.10 dB to -44.5dB. A 12.4 dB mutual coupling reduction is achieved, which proves that the surface wave is suppressed.

The return loss dropped drastically. This is due to the effect of inserting the EBG with vias inserted in the middle of EBG structures in the substrate, increases the permeability values and change the tangential loss of the substrate.

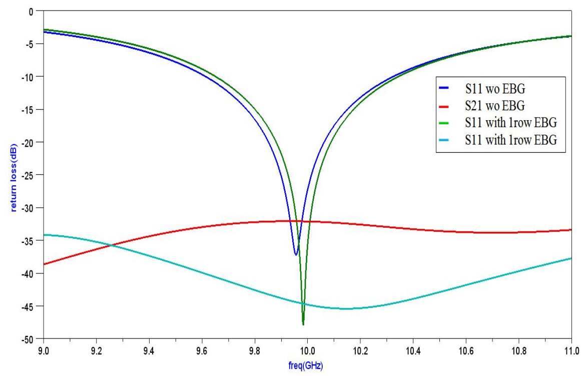

Fig.3 Simulated S11 and S12 without and with EBG row.

In figure 4, three different EBG size with 1 mm spacing were simulated and the results are shown in Table 1. The results clearly shown that although different size of EBG inserted between patches, the performances produced by the antenna with EBG (wEBG) are about the same with the antenna without EBG (woEBG). When the 2.5mm EBG case is used, its band gap is higher than the resonant frequency 10 GHz. Therefore, the mutual coupling is not reduced and a strong coupling of 30.6 dB is still noticed. For the 3.5mm EBG case, the resonant frequency 10.01 GHz falls inside the EBG band gap so that the surface waves are suppressed. When the size of the mushroom-like EBG is increased to 4 mm, its band gap decreases, and is now lower than the resonant frequency. Therefore, the mutual coupling is not improved and is still as strong as 32 dB.

Table 1: Comparisons details between the results obtained with and without EBG for
g = 15 mm, s = 1mm, vary EBG size

	S11 (dB)	S21 (dB)	Gain (dB)	BP (GHz)
Wo EBG	-36.55	-32.07	7.19	0.71
W EBG				
2.5*2.5	-31.48	-30.43	7.15	0.69
3*3	-36.75	-35.96	6.93	0.735
3.5*3.5	-47.72	-45.72	7.1	0.694
4*4	-32.16	-32.85	7.18	0.71

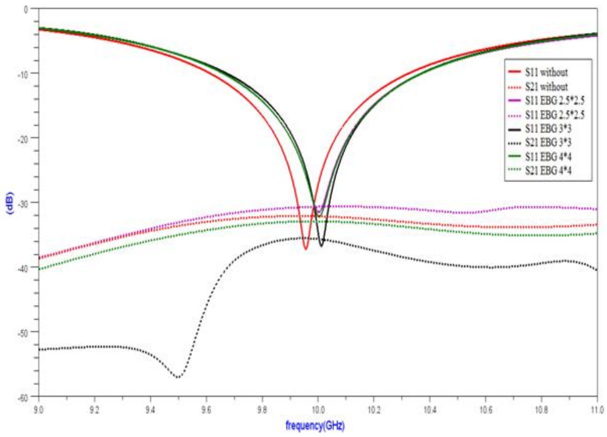

fig.4 Simulated S11 and S12 for different size of EBG with 1 mm spacing

In this part, EBG size of (3.5mmx3.5mm) was used for these simulations with half wavelength spacing between antenna elements. The spacing between EBG was varied from 0.5mm to 1.5mm. The detail results obtained from these simulations is shown in Table 2 and simulated S11 and S12 graph are shown in Fig. 5.

Comparing the performance between the antenna with EBG and without EBG, with EBG the performance (gain) is dropped for all parameters. The mutual coupling before the EBG is inserted between the patch is -30.07dB. The changes of mutual coupling are clearly shown After the EBG is inserted, the mutual coupling is increased to 41.39 dB at 10 GHz. the spacing between EBG is the most dominant parameter to decrease the coupling between antenna.

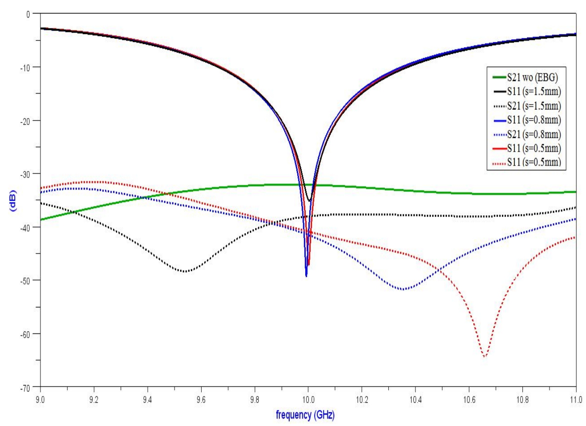

Fig.5 Simulated S11 and S12 for (3.5mmx3.5mm) EBG size with variation of spacing between EBG

Table 2. Comparisons details between the results obtained with and without EBG for g = 15mm, EBG of (3.5mmx3.5mm), vary s

	S11 (dB)	S21 (dB)	Gain (dB)	BP (GHz)
Wo EBG	-36.55	-32.07	7.19	0.71
W EBG				
S=0.5mm	-47.12	-40.78	7.1	0.69
S=0.8mm	-49.45	-41.39	6.8	0.68
S=1.5mm	-35.2	-37.53	6.96	0.68

The same process in the previous part is repeated. The only different, the simple square geometry patch is replaced by the metallic patch in the form of the square Koch fractal of the 1st iteration, as shown in figure 6 (a).
The simulation results obtained is shown in figure 7. Fractal antenna integrated with one row of conventional mushroom like EBG patches produces a lower mutual coupling. The mutual coupling reduce from -31.47dB to -41.5dB. A 10 dB mutual coupling reduction is achieved at the resonant frequency10GHz, which proves that the surface wave is suppressed but the bandwidth decreases with 0.3 GHz.

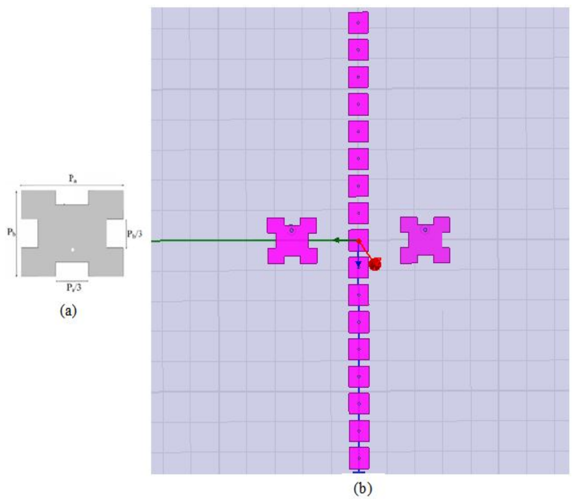

Fig. 6 Schematic illustration of 1-iteration microstrip Koch planar antenna (a) Fractal patch antenna dimensions are: P_a=8.8mm, P_b= 7.59mm (b) Simulated antenna

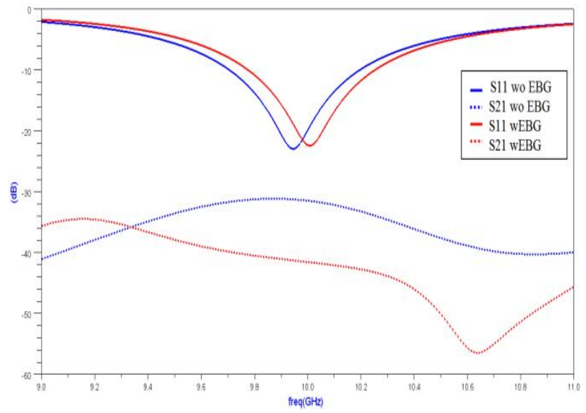

Fig.7 Simulated S11 and S12 for microstrip Koch planar antenna

The conclusion from these two simulation results, mutual decoupling with rectangular patch better than Koch planar patch.

The same process in the previous part is repeated in this part. The only different is that the spacing between patch is wider, that is 22.5mm (three quarter wavelength) from edge to edge. Figure 8 shows the simulation result.

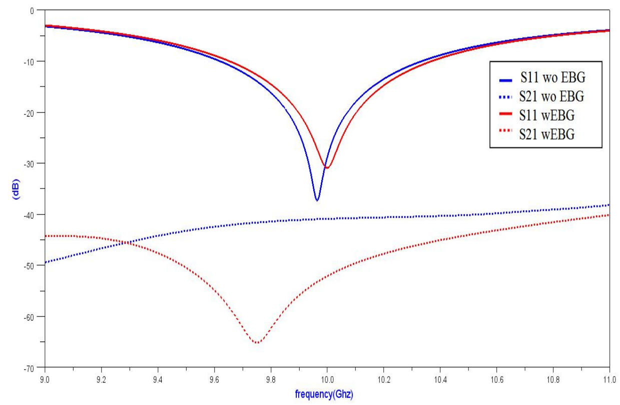

Fig.8 Simulated S11 and S12 of patch antenna.

The performance of the antenna without EBG is about the same as the antenna with EBG except that the return loss is dropped from -37.2dB to about-30.91dB. Mutual coupling obtained by 22.5mm spacing is better than 15mm spacing. This improvement is due to the spacing between the patch itself not due to the EBG effect. In fact, the return loss produced after the EBG is inserted is worse than the antenna without EBG.

All the simulation done previously is using only one column of EBG between the patch. In this part, the number of column is varied from one column to 3 columns with fix spacing of 1mm between EBG and (3.5mmx3.5mm) EBG size. Table 3 shows the simulation results and Figure 9 shows the simulated S11 and S21. The results show that at frequency of 10 GHz, the performance is dropped when the number of column is increased. One column of EBG produced the best performance compared to two and three columns. bandwidth suddenly decreases which is the indication of cavity effect domination.

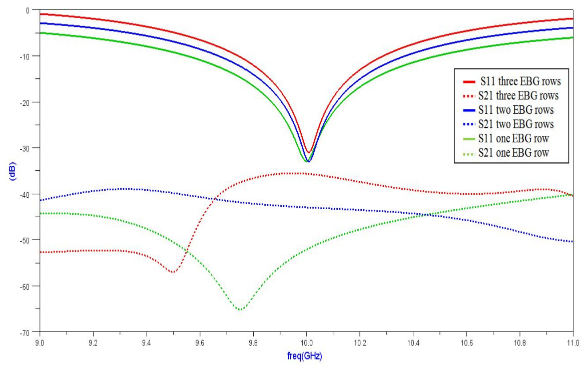

Fig. 9 Simulated S11 and S12 spacing between EBG of 1mm, EBG size of (3.5mmx3.5) mm with variation number of column.

Table 2. Comparisons details between the results obtained with and without EBG for g = mm, EBG of (3.5mmx3.5mm), mm with variation number of column.

	S11 (dB)	S21 (dB)	Gain (dB)	BP (GHz)
Wo EBG	-37.2	-32.07	7.19	0.71
W EBG				
One row	-32.51	-51.2	7.4	0.72
Two rows	-32.3	-42.9	6.86	0.68
Three rows	-30.27	-35.6	6.8	0.64

4. Conclusion

In this paper, we studied a high impedance surfaces and applied it to reduce the mutual coupling effect between two arrays antennas. All the simulations are analyzed by HFSS (high frequency simulator structure). The EBG structure is then inserted between the antenna elements reduce the mutual coupling with 14 dB.

The results shows that not all the EBG structure suitable to improve the performance of the antenna. In fact there are some case showed that the performance of antenna become worse when the EBG inserted between the micro-strip patch. The selection of the size of EBG, the number of column and the spacing/gap between the patch play an important role in order to improve the performance of the antenna.

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