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Research Article

Design and Analysis of Rectangular Microstrip Array based Electromagnetic Band Gap (EBG) Structure for Microwave Applications

Priya Pathania†, Arushi Bhardwaj† and Rajat Arora‡*

†Dept. of ECE, Sri Sai College of Engineering & Technology, Badhani Pathankot India
‡Dept. of ECE, GNDU Amritsar, India

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Abstract

Patch antennas decreases the antenna efficiency due to excitation of surface waves on the substrate. In this work, a mushroom like electromagnetic bandgap structure (EBGs) is designed and analyzed using Comsol Multiphysics. Five element microstrip patch antenna array on a uniform substrate has been employed that forms strong mutual coupling due to the pronounced surface waves. The excitation frequency domain for the proposed designed used is in-between 2.1 GHz to 2.35 GHz. The minimum wavelength selected is 0.127 m. The results showed successful design implementation for a resonant frequency 2.14 GHz.

Keywords: *Electromagnetic Band Gap structure, patch antenna, s-parameters, finite element method, array elements.*

1. Introduction

Micostrip patch antennas are always a necessity for wireless and satellite communication devices due to several advantages like; low cost, nominal weight, compact low profile antennas and are also capable of maintaining high performance over a wide band of frequencies (Rajat Arora *et al*, 2014) (Rajat Arora *et al*, 2013) (Sandeep Arya *et al*, 2012). Its flat profile as compared to the parabolic reflectors made it more attractive for airborne and spacecraft applications (Sandeep Arya *et al*, 2012). The main elements of microstrip patch antenna are dielectric substrate, ground plane and a radiating patch (M. N. Srifi *et al*, 2010). It is possible to increase the number of metallic patches in a periodical spacing on a same dielectric substrate. This kind of device is familiar with the name Electromagnetic Band Gap (EBG) structures (A. Pirhadi *et al*, 2010). EBG structures can also be made by combination of dielectric only. The concept of electromagnetic band gap (EBG) structures originates from the solid state physics and optic domain, where photonic crystals with forbidden band gap for light emissions were proposed in 1987 and then widely investigated in the 1990s. (Fan Yang *et al*, 2010). Thus, the terminology, photonic band gap (PBG) structures, was popularly used in the early days. After successful implementation of PBGs in photonics, they became widely used also in microwave and antenna engineering as electromagnetic band gap (EBG) surfaces. EBG structures have properties such that, in a particular frequency band they stop the propagation of surface waves and also reflect back any incoming wave with no phase change (F. De Paulis *et al*, 2012) (Y. Rahmat-Samii *et al*, 2001) (F. Yang *et al*, 2002). This property makes EBG structures different from other radiating devices due to improved characteristics (Y. Rahmat-Samii *et al*, 2002). overall gain of an antenna can also be improved by using EBG structure in two ways, that is, EBG structure as a superstrate and EBG structure as a ground plane (D. F. Sievenpiper, 1999). The main advantage of EBGs is the quality to suppress the noise and reduction of EMI in high speed circuits.

In this paper, single band EBG structure has been designed using finite element method based design software. The insertion losses were estimated while simulation and the results confirmed the successful design and study of the proposed EBG structure based model at low microwave frequency. The analysis for the proposed EBGs is presented in the next section. The design methodology, results and discussions are proposed and discussed in the subsequent sections.

2. Design Considerations

It consists of four parts: a ground plane, a dielectric substrate, metallic patches, and connecting vias. For surface-wave propagation EBG structure exhibits a distinct stop-band. The operation mechanism of this EBG structure can be explained by an LC filter array (C.

*Corresponding author **Rajat Arora** is a PhD Student; **Priya Pathania** a PG Student **and Arushi Bhardwaj** is working as Assistant Professor

Chang *et al*, 2003): the inductor L results from the current flowing through the vias, and the capacitor C due to the gap effect between the adjacent patches.

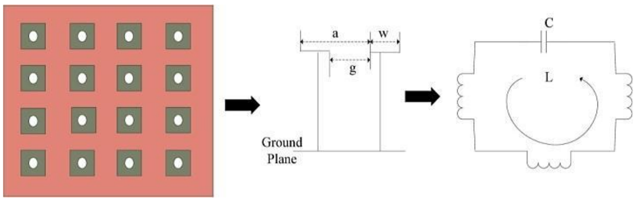

Fig. 1: EBG structure containing various elements; Geometry of EBG's; Equivalent circuit.

For an EBG structure with patch width W, gap width g, substrate thickness h and dielectric constant εr, the values of the inductor L and the capacitor C are determined by the following formula (L. Yang *et al*, 2003).

$$L = \mu_0 h$$

$$C = \frac{W\varepsilon_0(1+\varepsilon_0)}{\pi}\cosh\frac{(2W+g)}{g}$$

μ0 is the permeability of free space and ε0 is the permittivity of free space. Reference (C. Chang *et al*, 2003) also predicts the frequency band gap as

$$\omega = \frac{1}{\sqrt{LC}}$$

where η is the free space impedance which is 120π.
The surface impedance, as shown in figure 1, as the equivalent circuit, equals to the impedance of a parallel resonant circuit of the EBG structure f0 is calculated as following:

$$Z = \frac{j\omega L}{1-\omega^2 LC}$$

3. Design Simulation

The model was designed using FEM supported COMSOL Multiphysics software in electromagnetic wave domain solver. Figure 2 shows the geometry of the simulated device. It consists of a common substrate with array of micro-patches over it. The micro-patches are EBG elements that resemble shapes like mushroom.

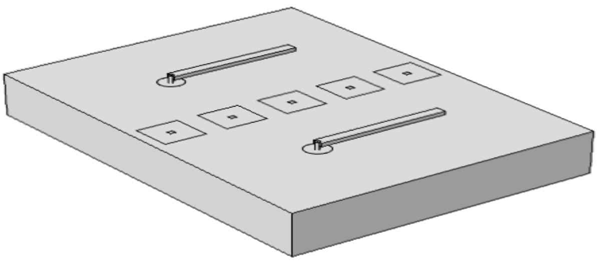

Fig. 2: 3D Structure of proposed device

The whole designed structure is enclosed in the sphere containing air inside it. The air was selected inside the sphere to simulate and obtain the results almost equivalent to the experimental results as shown in figure 3. For this experiment, the diameter of the sphere selected as 120 mm. The thickness of sphere was chosen to be 30 mm.

Thus the EBG structure is designed and analyzed for operating in the air or atmosphere. Another reason to enclose the simulated structure in a spherical air domain surrounded by a perfectly matched layer (PML) is to absorb the radiation from the device with minimum reflection.

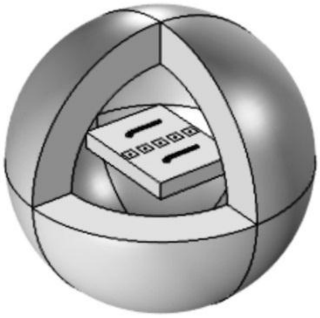

Fig. 3: 3D Structure of proposed device enclosed in sphere

The dimensions along with material selected for the simulated device is shown in table 1.

Table 1: Dimensions selected for the simulated device

Parameters (mm)	Material	Length	Width	Height
Substrate	Epoxy Resin	60	80	12
Mushroom Stem	Epoxy Resin	1	1	12
Patch	Epoxy Resin	24	8	12

4. Results and Discussions

Figure 4 shows the meshing design of EBG structure. For the large domain computation, tetrahedral meshing is preferred. The maximum element size selected is 14.

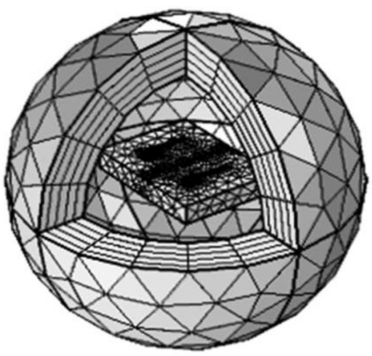

Fig. 4: 3D Structure of proposed device after meshing

The design was simulated on the computational machine having 2.6 GHz processor speed. The virtual memory used while simulation was 1.8 GB. Higher element size is selected to reduce the computational load and to attain the convergence plot.

To improve more accuracy in the results, finer mesh size are recommended where the field gradients are steep. The electric field generated while simulating the device is shown in Fig. 5. Fig. 5 shows the electric field radiated without EBG while Fig. 6 shows the radiated electric for EBG structure.

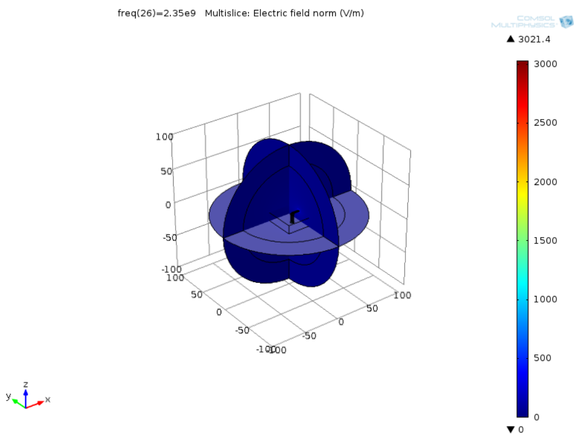

Fig. 5: Electric field radiated for the design without EBG structure

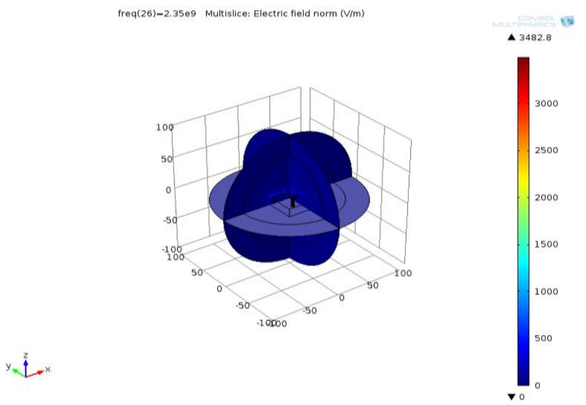

Fig. 6: Electric field radiated for EBG structure

Figures 7 show the variation in return losses to the domain of frequencies applied to the EBG structure. The frequency domain selected for simulation is in-between 2.1 GHz to 2.35 GHz. The minimum wavelength selected is 0.127 m. The high value of return loss means that the reflection wave return back to the source is very small and the amount of radiation power is very high. This characteristic is very important in radiator devices such as antennas. From the plot, it is estimated that the resonant frequency of the device is 2.14 GHz.

Conclusions

In this paper, the EBG structure was studied and analyzed to design it for simple five element patch antenna array. The designed structure was studied for a finite frequency band in order to ascertain the resonant frequency. The properties of the designed EBG structure were tested by computer simulation in finite element method based Comsol Multiphysics software. Results confirmed a good impedance matching and satisfactory surface wave suppression for the investigated frequency domain.

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