Band Gap Evaluation for Single, Dual and Triple Band Electromagnetic Band Gap Structures with Applied Geometrical Modifications

Ilia Iliev[1], Marin Nedelchev[1], Evgeniy Markov[1]

Abstract – **In this paper, the bandpasses and bandstops of six different electromagnetic bandgap (EBG) structures are examined. Different shapes of the structures, with different geometrical modifications, are investigated. Using full wave analysis of the structures, one, two and three rejection band EBG structures are examined. One known EBG structure with two different modifications is compared to two novel EBG structures with four modifications. The conclusions could be a useful tool for the engineer’s work when designing EBG structures with predictable bandgap characteristics.**

Keywords – **EBG design, band gap, periodic structures, transmission line analysis, full wave analysis, FDTD**

I. INTRODUCTION

Electromagnetic bandgap structures (EBG) are defined as periodic structures that prevent or assist the propagation of electromagnetic waves in a given frequency bands. They show frequency rejection properties in their bandstop regions, and also in-phase reflection coefficients. These unique properties have led to an increasing interest in the development, analysis and applications of EBG structures in many different fields of microwave and propagation engineering fields.

Microstrip patch antennas have found application in a wide variety of applications, such as wireless communication systems, GPS applications, RFID, satellite communications, due to their low-profile, ease of fabrication, possibility for dual frequency operation and circular polarization. The drawbacks of the patch antennas are small bandwidth of operation, low gain and surface wave propagation. In the recent years, there’s been an immense growth in the interest of the EBG structures, since these structures can significantly reduce the drawbacks of some microwave devices. The EBG structures are used in improving the characteristics of patch antennas [1-3], patch antenna arrays [4], microwave filters [5]. Another perspective application of dual frequency rejection band EBG structure is in slot patch antennas that use as a reflection an EBG surface, instead of a metalized layer. Introducing the EBG surface to the design improves the gain and the propagation diagram of the slot antenna [6].

The paper gives insight of the dependencies of physical parameters of EBG structures, and their bandgap characteristics, which can be of important help to engineers, when applying the properties of EBG to different microwave designs and circuits. Six different shapes of EBG structures are examined, with two of them already known in the scientific community, and four of them as a novel EBG shapes. The structures are analyzed with applied geometrical modifications, with graphical data summarized into conclusions for the behavior of the EBG periodic structures.

II. THE EBG STRUCTURES AND THEIR APPLICATION IN MICROWAVE DEVICES

In general, the EBG structures can be divided into three categories – three dimensional, volumetric structures, two dimensional, planar structures, and one dimensional, transmission line structures. Two examples for the 3D EBG structures can be seen in Fig. 1 – Fig. 1(a) is a woodpile configuration of dielectric rods [7], Fig. 1(b) is a multilayer tripod configuration with via interconnections, investigated in [8].

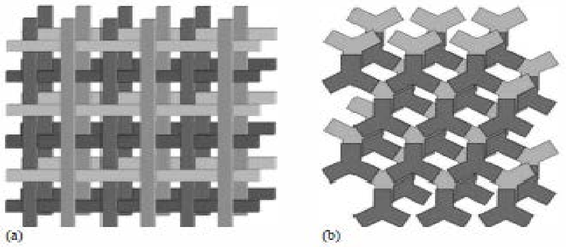

Fig. 1. (a) 3-D woodpile dielectric structure (b) 3-D multilayer tripod configuration with via interconnections

The 2-D EBG structures are shown on Fig.2. The most used configurations are the mushroom type [9] and the uni-planar type, without the vertical vias [10]. The 1-D EBG structures are used as transmission line configurations, which enhance the properties of a microstrip line - a microstrip transmission line with an array of dielectric holes in the bottom grounded layer [11], and a left-right composite transmission line, exhibiting left handed behavior [12].

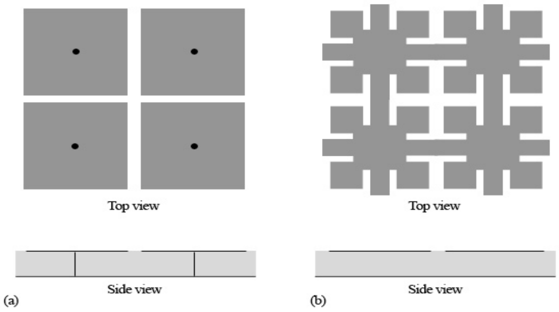

Fig. 2. (a) 2-D mushroom periodic structure (b) 2-D uniplanar periodic structure

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[1] Assoc. Prof. lia Iliev, Assist. Prof. Marin Nedelchev and Evgeniy Markov are with the Faculty of Telecommunications at Technical University of Sofia, 8 Kl. Ohridski Blvd, Sofia 1000, Bulgaria, E-mails: igiliev@tu-sofia.bg, mnedelchev@tu-sofia.bg, ekmarkov@tu-sofia.bg.

In this paper, the analysis is focused on 2-D mushroom type EBG periodic structures, with different topologies. The analysis is based on the finite difference time domain method (FDTD). Among various numerical techniques, the FDTD method has demonstrated desirable and unique features for analysis of electromagnetic structures. It simply discretizes Maxwell’s equations in the time and space domains, and electromagnetics behavior is obtained through a time evolving process. A significant advantage of the FDTD method is the versatility to solve a wide range of microwave and antenna problems. It is flexible enough to model various media, such as conductors, dielectrics, lumped elements, active devices, and dispersive materials. Another advantage of the FDTD method is the capability to provide a broad band characterization in one single simulation. Since this method is carried out in the time domain, a wide frequency band response can be obtained through the Fourier transformation of the transient data [13].

III. INVESTIGATED EBG TOPOLOGIES AND PARAMETER VARIATIONS

The EBG schematics, investigated in this paper can be seen in Fig. 4. The first investigated EBG structure is the Jerusalem cross, or JC-EBG, shown in Fig. 3(a). The JC-EBG has been analyzed in different scientific researches and utilized in antenna applications [14]. The second structure is a diagonal shaped slited EBG – the second structure in Fig. 3(a). The third structure is a H-shaped doubled EBG, shown in Fig. 4(a). Inserting the slits into the design is increasing the serial capacitance, changing the resonance behavior of the structures. In Fig. 3(b) are the same designs, with increased length of the lines, coupled to the neighboring unit cells. Increasing the length of these lines, and connecting them with the lines of opposite direction is generally changing the behavior of the investigated structures.

An insight of parameter variation, created by changing the sizes of the slits, gaps and overall size of the EBG structures, can be given by the transmission line theory.

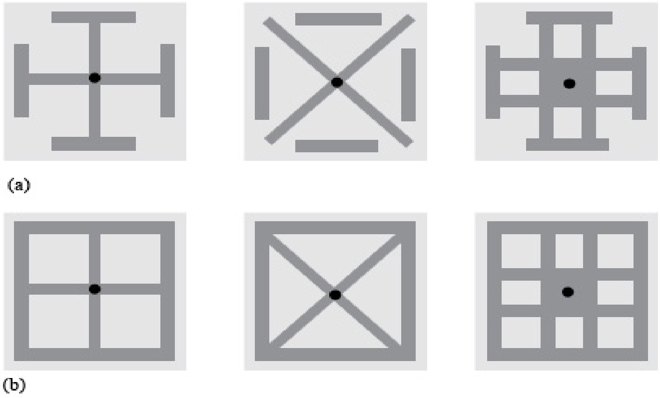

Fig. 3. (a) JC-EBG, Diagonal shaped slitted EBG, H-shaped doubled EBG, with dual and triple band rejection properties (b) JC-EBG, Diagonal shaped slitted EBG, H-shaped doubled EBG with single band rejection properties

An analysis insight is useful through the transmission line analysis technique, which approximates the examined EBG structures according to their constitutional parameters. The physical parameters of the structures can be seen in Fig. 4.

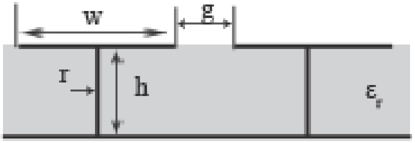

Fig. 4. Physical parameters of periodic EBG structures

The characteristic impedance of a transmission line section is those of a lossless parallel plate transmission line, given by

$$Z_{TL} = \frac{\eta_0 h}{\sqrt{\varepsilon_r} w} \tag{1}$$

where η_0 is the characteristic impedance of free space - 377Ω, εr is the relative permittivity of the substrate, and w and h are the width of the patch and the height of the dielectric substrate. The value of the inductance, that is inserted into the design with the via, and the value of the parallel capacitance are:

$$L = \frac{\mu h}{4\pi}\left(\log\left(\frac{1}{q}\right) + q - 1\right) \tag{2}$$

$$C = \frac{w\varepsilon_0(1+\varepsilon_r)}{\pi} cosh^{-1}\left(\frac{2w}{g}\right) \tag{3}$$

where q is the ratio of the via cross sectional area to the EBG unit cell area

$$q = \pi\left(\frac{r}{a}\right)^2 \tag{4}$$

where a is the length of the unit cell of the periodic structure. The resonant frequency of the structure can be found with the equation for the resonant frequency of an L-C network model, where the resonant frequency is given by (5)

$$f_{res} = \frac{1}{\sqrt{LC}} \tag{5}$$

The transmission line method is used when an approximate solution to given structures is needed. For the purposes of initial analysis of different EBG structures, the method would be an appropriate choice. The structures, shown in Fig. 3, are investigated with different dimensions of *g*. The size of *w* is also changed. As can be seen from the figure, the structures, aligned in periodic arrays, form coupled lines with the adjacent cells. Both parameters change the value of the EBG structure’s capacitance. The values of the inductance can be changed with variations of the via’s radius. Previous analysis of such variations has shown small impact on the structure’s behavior [15]. In this paper, only the capacitance values are to be varied.

IV. ANALYSIS OF THE ONE, TWO AND THREE BAND EBG STRUCTURES

Full wave analysis is applied on the structures. The unchanged parameters are the height of the dielectric substrate $h = 0.04\lambda_{l,4GHz}$, the radius of the via $r = 0.0123\lambda_{l,4GHz}$ and the unit cell size ($w + g = 0.55\lambda_{l,4GHz}$). For the dielectric substrate, FR-4 substrate is used, with $\varepsilon_r = 4.4$.

A full wave FDTD analysis is applied to all structures. The structures are analyzed with 50Ω transmission lines for 4GHz frequency of operation. The dimensions of the coupled lines are changing from 0.1 to $0.45\lambda_{l,4GHz}$. When an interconnection of the transmission lines in the corners of the different structures occurs, the electromagnetic behavior changes. The structures express dual frequency band rejection for the JC and diagonal EBG, and triple band rejection for the H-shaped EBG. When the transmission lines connect, with the increase of their size, the structures express a single band of frequency rejection. The width of the rejection band is greatly increased.

The first series of simulation are summed up in Fig. 5, applied on the structures, shown in Fig. 3a.

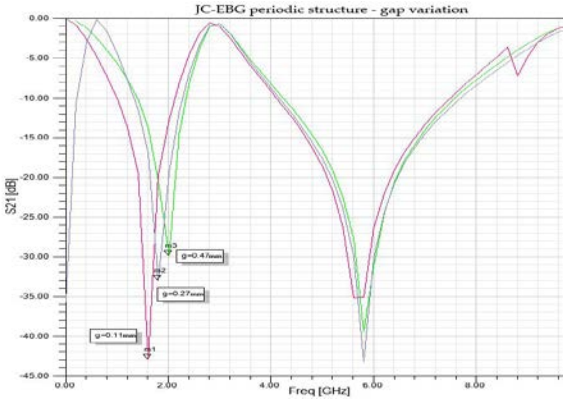

Fig. 5. Gap variation for JC-EBG

The bandgaps can be clearly seen in Fig. 5. The JC-EBG structure posses two bands of rejection at frequencies, centered at 1.8GHz and 5.8GHz. The gap variation is shown in Fig. 5, and the width variation is shown in Fig. 6. The exact position of the bandgap can be tuned by variation of the lengths. According to Eq. (5), increasing the serial capacitance, the resonant frequency drops, which can be confirmed by the simulated results.

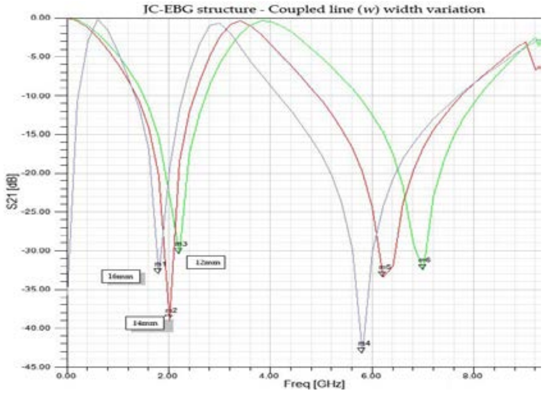

Fig. 6. Width of coupled lines variation for JC-EBG

The diagonal EBG also has two rejection bands, resonating at frequencies around 3.6GHz and 7GHz. In this specific shape of EBG structure, by changing the widths of the coupled lines, the overall behavior of the structure is not significantly altered, as can be seen in Fig. 7. This can be based on the fact, that the diagonal lines are defining the bandgaps of the structure, while the coupled lines are not of a great significance to the structure's behavior.

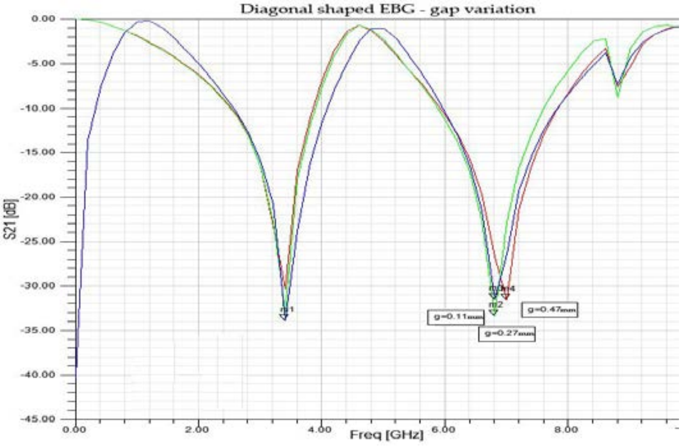

Fig. 7. Gap variation for Diagonal Slitted EBG

The transmission characteristics of the H-shaped EBG are shown in Fig. 8. The structure exhibits triple bandgap behavior, due to the serial coupled lines, with resonances at 3.6GHz, 7GHz and 9GHz. The structure is showing narrow bands and good rejection characteristics with S_{21} dropping to over -40dB. The triple band behavior can be used in many complicated antenna designs, since it can improve multiband antenna applications. As can be seen in Fig. 8, the gap variation is affecting the resonant frequency in the first resonances most significantly.

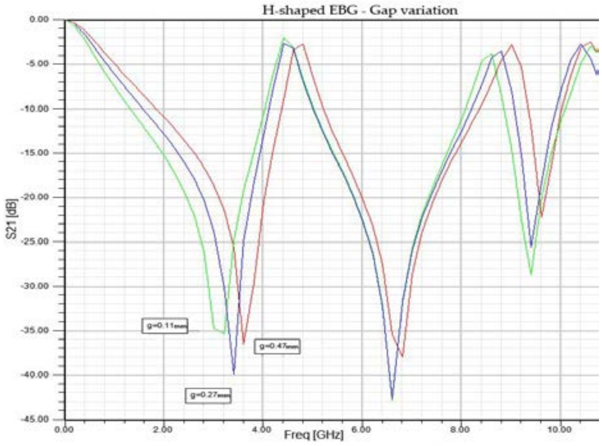

Fig. 8. Gap variation for H-shaped EBG

In Fig. 9 are the transmission characteristics of the structures with increased length of w. The lines are connected in the edges of the unit cell, which alters the behavior of the EBG structures, changing it from dual and triple band to single bandgap behavior. This behavior is repeating for all investigated structures. In the figure, only the graphical representation for the JC-EBG structures is shown, since the simulation results for the other structures are showing similar behavior.

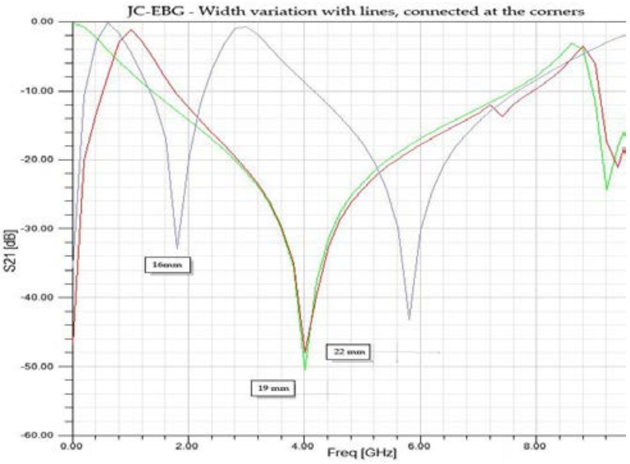

Fig. 9. JC-EBG structure with coupled lines, connected at the corners of the structure – from dual to single band behavior

The rejection of the structures is at 0.5λ for the resonant frequency 4GHz. The rejection drops to -50dB and the width of the bandstop is from 1.8GHz to 7.8GHz, which can be applied in antenna and antenna array applications.

V. CONCLUSIONS

In this paper, six different EBG structures are analyzed and simulated. An analysis of the structures, with variations of the serial capacitance and the lengths of the coupled transmission lines is performed. The conclusions are in line with the theoretical assumptions for the behavior of EBG materials. The structures are expressing triple, dual and single bands of frequency rejection, with suppression dropping to under -35dB. A frequency tuning technique, using the length of the coupled lines and the gap width is proposed. The frequency properties of the structures can be used for many applications in microwave patch antennas, antenna arrays, reflective surfaces, filter designs and so on. In the future work of the authors, such devices are going to be simulated and measures, showing the level of improvement, when applying EBG structures to real microwave designs.

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