Spiral Electromagnetic Bandgap Structure for EMI Reduction

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Abstract_ **The concept of using Electromagnetic Band Gap (EBG) structures is to provide excellent suppression of noise or interference (EMI) at GHz frequencies. In this work, a 3x3 spiral EBG planar structure was developed to achieve suppression of electromagnetic interference covering frequency range of 4 to 6 GHz considering the integration of EBG structure into the High Speed printed Circuit Board design (HSPCB).**

Keywords— Electromagnetic band gap (EBG), Electromagnetic Interference (EMI), optimization, genetic algorithm (GA), CST Microwave Studio (CST MWS), Printed Circuit Board (PCB).

I. INTRODUCTION

Electromagnetic radiation of high-speed digital and analog circuits is considered one of the most critical challenges to the electromagnetic interference, compatibility and reliability of electronic systems. The world of electromagnetic interference (EMI) and electromagnetic compatibility (EMC) design has undergone significant changes as the speed of processors, clocks, and digital communications links has increased. Electromagnetic interference is a complex mechanism that takes place at different levels including the chassis, board, component, and finally, the device level [1-4]. Switching noise is one of the major concerns for electromagnetic compatibility engineers in modern designs and that could cause serious signal integrity (SI) and power integrity (PI) problems in the form of EMI for the high-speed circuits. Electromagnetic interference is the lack of EMC [5], since the essence of interference is the lack of compatibility. EMI is the process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths (or both). In common usage, the term refers particularly to RF signals. EMI can occur in the frequency range commonly identified as anything greater than DC to daylight. Periodic structures are abundant in nature, which have fascinated artists and scientists a like [15-20]. When they interact with electromagnetic waves, exciting phenomena appear and amazing features result. In particular, characteristics such as frequency stop bands, pass bands and band gaps could be identified using Electromagnetic Band gap Structure [6-14]. Generally speaking, (EBG) structures are defined as artificial periodic (or sometimes non-periodic) objects that prevent/assist the propagation of electromagnetic waves in a specified band of frequency for all incident angles and all polarization states [9].

II. SPIRAL EBG STRUCURE

A. *Lumped Elements Structure*

The proposed model of EBG unit cell is spiral with 15 lines trace to be represented mathematically using Greenhouse Formulas using lumped elements representations as in Fig1.

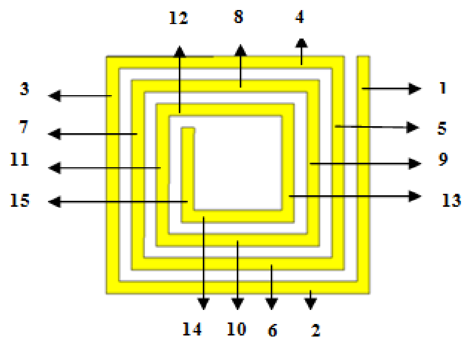


Fig. 1. : Metallic Network of spiral EBG

B. *Greenhouse Formulas for Lumped Elements*

Greenhouse [23] has provided expressions for inductance for both rectangular and circular geometries based on self-inductance of inductor sections and mutual inductances between sections. These relations are also known as Greenhouse formulas for spiral inductors as shown in equations (1), (2) and (3).

$$L(nH) = 2x10^{-4} Li \; [ln \; (\frac{Li}{w+t}) + 1.193 + \frac{w+t}{3Li}]. Kg \quad (1)$$

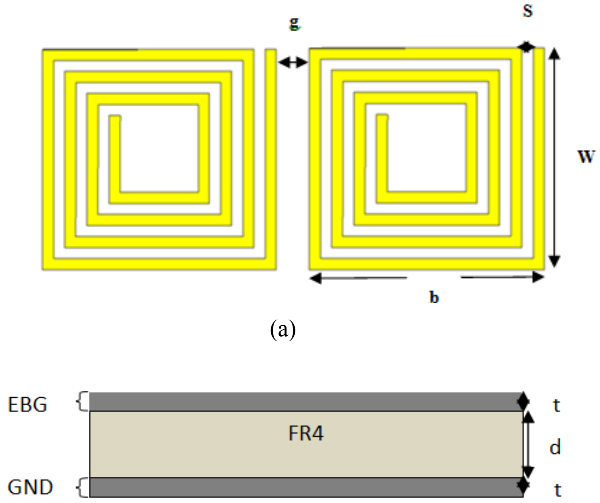
$$M = 2\text{x}10^{-4} Li[ln \{\frac{Li}{d} + \sqrt{(1+\frac{Li^2}{d^2})}\} - \sqrt{(1+\frac{d^2}{Li^2})} + \frac{d}{Li}] \quad (2)$$

$$C\,(pF) = 16.67\text{x}\,10^{-4}\,Li\,\frac{\sqrt{\varepsilon r}}{Zo} \quad (3)$$

Where L represents the self inductance, M is the mutual inductance and C is the capacitance of the spiral EBG structure, Zo surface impedance , (w, Li, d, t and S) geometrical Parameters, $\mathcal{E}r$ dielectric constant and kg spacing constant which can be calculated using equation (4).

$$kg = 1 + 0.333(1+\frac{S}{w}) \quad (4)$$

All geometrical parameters are shown in Fig.2.



(a)

(b)

Fig. 2. : (a) Geometrical Parameters for L-C structure, (b) Metallic and Dielectric Thicknesses

III. MATHMATICAL MODEL AND DESIGN

The design of this EBG structure is an iterative process consisting of the following proposed steps. First step was to determine the resonance frequency of the L–C Lumped Elements. Resonance frequency can be calculated using equation (5).Then, the values of L and C to achieve the resonance frequency that were determined in pervious step to be chosen while maintaining the L–C ratio relatively high to obtain a wide stop band. Now once L and C were known, the dimensions of the unit cell of the EBG structure were calculated. Finally, if the calculated dimensions are not realizable with available and cost-effective substrates, then restart again with slightly different resonant frequency that will match the need [21].The center frequency of this stop-band configuration can be expressed as:

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (5)$$

While the relative bandwidth is proportional to:

$$\Delta BW \; \alpha \sqrt{\frac{L}{C}} \quad (6)$$

Therefore, an increase of the value of L has the effect to benefit the range relative bandwidth as elaborated in equation (6). By referring to the problem statement, EMI suppression is carried with range of 4 to 6GHz on HSPCBs. Then, we have to calculate C, L to obtain self-inductance, mutual inductance and parasitic capacitance in order to design an EBG unit cell.

A. EBG Design Concept

EBG structure mechanism operations can be explained as a distributed L-C network with specific resonant frequencies. The properties of the EBG unit cells can be described using lumped circuit elements—capacitors and inductors, as shown in Fig.1. In the frequency range where the surface impedance is very high, the equivalent L-C circuit acts as a two-dimensional electric filter to block the flow of the surface waves [21-22].

B. Waveguide Model

The input port of waveguide is excited and the other port was terminated with a rectangular unit cell of the EBG structure. For any periodic surface with different shapes we should use its rectangular unit cell [5]. To construct a waveguide which supports a propagating plane wave we assign PEC boundary condition to two parallel walls of the waveguide and PMC boundary condition to the other two walls as shown in Fig.3. This propagating plane wave is polarized parallel to the PMC walls and normal to the PEC walls. If we change the position of PEC and PMC walls, we can obtain the reflection phase for an orthogonal polarized plane wave.

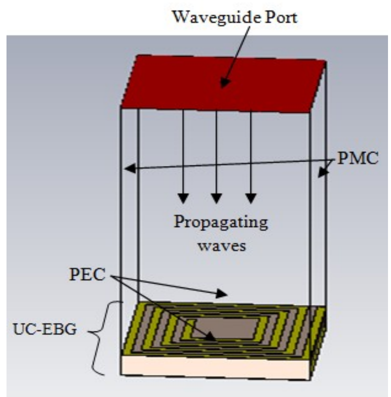


Fig.3. : Boundary Condition of the waveguide model

To obtain the reflection phase, the scattering parameter of a single port waveguide was extracted. Calculation of scattering parameters is a very simple and direct procedure in most commercial EM solvers such as CST MWS. Phase of scattering parameter is the reflection phase of the EBG surface at a specified distance from the surface.

IV. Results and Discussion

A. *Geometrical Parameters*

From the resulting inductance L and capacitance C, the geometric parameters in Fig.1. and Fig.2. were obtained as shown in TABLE I. The EBG unit cell structure was simulated using waveguide model and Genetic Algorithm (GA) optimization has been done in order to improve the band stop and the phase reflection. In the last few years, different methods have been utilized for the design and test of EBG structures. Goals for all these methods include but are not limited to describing the behavior of EBG structures, studying the effect of various design parameters [1-5] (e.g., patch shape, patch size, via diameter, gap diameter, dielectric constant of the substrate, etc.) and deriving new EBG structures for more effective noise suppression (e.g., higher bandwidth).

TABLE I : Geometrical Parameters

Element Name		Value (mm)	Description
Li	1,2	2	Lumped Elements Components as shown in Fig.1. & Fig.2.
	3	1.9	
	4,5	1.7	
	6	1.6	
	7	1.5	
	8	1.4	
	9	1.3	
	10	1.2	
	11	1.1	
	12	1	
	13	0.9	
	14	0.8	
	15	0.7	
t		0.005	Metallic Thickness
S		0.1	Gaps width
W		2	Unit Cell length
b		2.1	Unit Cell width
a		2.1	Unit Cell length + g
g		0.1	Gap between unit cells
d		0.8	Dielectric Thickness

B. *CST Microwave Studio (MWS) Simulation*

Reflection phase bandwidth of the unit cell EBG is defined as the ratio of frequency bandwidth in which the reflection phase is between 90 ± 45 degrees to the center frequency. As illustrated in Fig.4. the reflection phase bandwidth of the unit cell structure is 12.2%. Fig.4. shows the reflection phase results of a plane wave normally incident on the EBG surface.

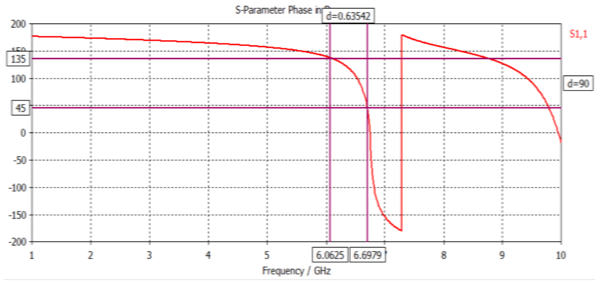


Fig.4. : UC-EBG Reflection Phase using CST MWS

C. *Spiral EBG planar Characterization*

To verify the properties of the proposed spiral EBG planar, it was constructed on a 1mm thick FR4 and Roger5880 substrate with the relative permittivity of 4.3 and 2.2 respectively as shown in Fig.5.

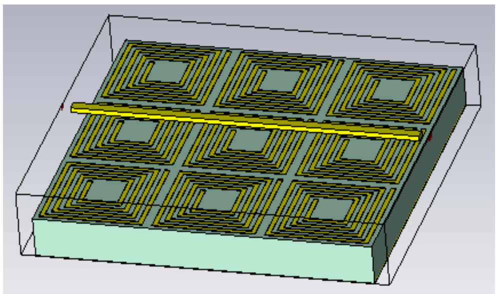


Fig.5. : 3x3 Spiral EBG planar with size of 6.6mm x 6.9mm

D. *EBG Planar Characteristics Simulation*

A 3x3 spiral EBG planar has been simulated considering open boundary conditions with size of 6.6mm x 6.9mm where a transmission line was placed 0.41mm above the EBG planar with length of 7.1mm and thickness of 0.1mm. The simulated result S21 is shown in Fig.6. for FR4 substrate and Fig.7. for Roger5880. The relative bandwidth is achieved to be 6% considering the frequency range of 4 to 6 GHz for FR4 as illustrated in Fig.6. only. The reflection phase of Roger5880 has better result where the relative bandwidth was improved to be 86% compared to FR4 as the permittivity was reduced.

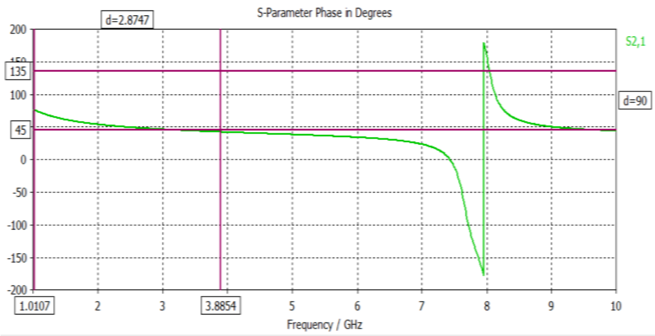


Fig.6. : Reflection Phase using CST MWS for FR4

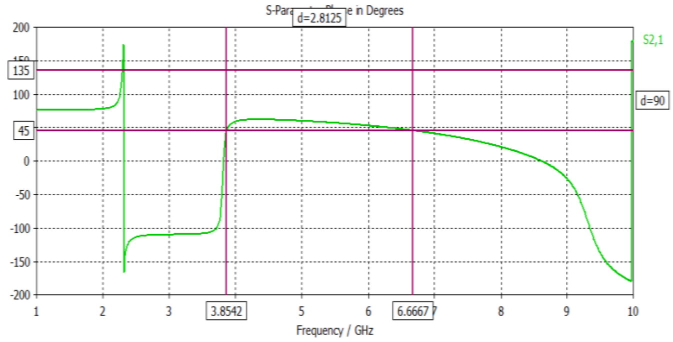


Fig.7. : Reflection Phase using CST MWS for Roger5880

V. CONCLUSION

A spiral EBG unit cell structure has been investigated. This structure has been designed and simulated. The S-parameter simulation results showed good suppression for the EBG structure. This spiral EBG structure finds potential application in wideband rejection on high speed circuitry for EMI application. . For the next task, a bad high speed PCB design has to be done with emitted radiation and predetermined board dimensions. As the planar of spiral EBG was investigated, The EBG planar with Roger5880 has brought better results than FR4 as the dielectric constant is decreased. Further work, fabrication and measurement will take place to be embedded on designed or proposed bad PCB.

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