

Studying the Interactions between Mushroom-type EBGs, Transmission Lines and Vias

Ivan Ndip, Stephan Guttowski, Herbert Reichl

Fraunhofer Institute for Reliability and Microintegration (IZM)
Gustav-Meyer-Allee 25, D-13355 Berlin, Germany

Phone: +49 (0) 30 / 46403-679, Fax: +49 (0) 30 / 46403-158

Email: ivan.ndip@izm.fraunhofer.de

Abstract

In this paper, the interactions between mushroom-type electromagnetic bandgap (EBG) structures, transmission lines and vias are studied. The EBG, which has a dimension of 50mm X 80mm, was designed to operate from 750 MHz to 3.2 GHz – a frequency band used for many wireless communication standards (e.g., GSM, UMTS, WLAN, Bluetooth...). Within this band, the proposed EBG creates a stopband, so that SSN caused by digital components can not be coupled to sensitive RF/analogue components. When integrated together with transmission lines and vias between the parallel-plates of a power distribution network (PDN), the EBG prevents the coupling of power away from the transmission lines and vias. The insertion loss of each of these interconnects become free of resonances and hence, signal integrity is preserved. Our results also revealed that the presence of either transmission lines or vias causes a change in the effective inductance (L) and capacitance (C) of the power-ground cavity. Since the stopband bandwidth of the EBG is dependent on the L & C of this cavity, the presence of these interconnects thus causes a change in the filtering properties of the EBG.

Keywords: Mushroom-type EBG, power-ground plane pair, SSN, stripline, through-hole via.

1. Introduction

The continuous demand for portable and multifunctional electronic products causes system designers to integrate different components (e.g., high-speed digital processing and RF/analogue components) in very close proximity to each other in compact System-in-Package modules. Such heterogeneous integration doesn't only enable the size and weight requirements of the product to be met, but may also lead to a reduction in cost. However, as a result of this compact placement, simultaneous switching noise (SSN), caused by digital components, can easily couple to sensitive RF/analogue components, leading to a deterioration of the electrical performance. To prevent or minimize such coupling, mushroom type (e.g., [1]-[3]), planar (e.g., [4]-[6]) and hybrid (e.g., [7]-[8]) electromagnetic bandgap (EBG) structures have been proposed. Since Mushroom-type EBGs lead to compact designs, they have received considerable attention within recent years. However, most of the published works focus mainly on the following areas: 1) Studying the filtering properties of mushroom-type EBGs (e.g., in [9]). 2) Reducing the size of a unit cell and hence, the entire EBG structure (e.g., in [10]). 3) Extending the stopband

bandwidth by using a variety of techniques (e.g., in [11]). However, since these EBGs are normally integrated together with transmission lines and vias between a power-ground plane pair, it is very important to understand the impact of the interactions between the EBG, the transmission lines and vias. Based on this understanding, design rules/measures that take into consideration this interaction can be extracted and used for efficient and reliable system design and integration.

In this contribution, we present an in-depth study of the interactions between mushroom-type EBGs, transmission lines and vias. A stripline will be used as an example of the transmission line and a through-hole via used as an example of the via. In this paper, the stripline and the via are also called "interconnects".

The design and analysis of a mushroom-type EBG will first be presented in section two. In section three, the modeling of striplines and vias routed between/through a power-ground plane pair will be discussed. This will then be followed by a study of the impact of EBGs on striplines and vias in section four as well as a study of the impact of

the interconnects on the performance of the mushroom-type EBGs in section five.

This work is an extension of the work presented in [12].

2. EBG Design (Without Striplines and Via)

The top view of the mushroom-type EBG that was design is shown in Figure 1 (bottom). It has the following dimensions; length = 80 mm, width = 50 mm, and is made up of 40 unit cells, arranged in a 5 X 8 array. These dimensions were chosen such that the designed EBG would operate from approximately 750 MHz to 3.2 GHz, since most of the wireless communication standards (e.g., GSM, UMTS, WLAN, Bluetooth, etc.) use this range. Consequently, it could be integrated in compact and portable wireless communication products used in almost all continents.

Figure 1 (top) shows a cross-sectional view of a unit cell. Each unit cell consists of a square patch having a dimension of 9 mm X 9 mm. A via of diameter 0.4mm and height of 0.742 mm, connects the patch to the ground (or reference) plane. The patches are separated from each other by a distance of 1mm and are placed at a distance of 0.05 mm from the power plane. FR4 ($\epsilon_{r1} = \epsilon_{r2} = 4.4$

and $\tan \delta = 0.02$) was used as the substrate material, with the upper and lower substrates having dimensions of $h_1 = 0.05$ mm and $h_2 = 0.742$ mm, respectively.

For the EBG design, Ansoft HFSS was used. HFSS is a full-wave solver which employs the Finite Element Method (FEM) to numerically solve Maxwell's equations in the frequency domain. The structure shown in Figure 1 was simulated from 100 MHz to 4 GHz. A continuous power-ground plane pair, having the same dimensions (dielectric thickness = 0.792mm, width = 50 mm, length = 80 mm) and the same substrate material as the EBG, was also simulated and used as the reference.

Figure 2 shows a comparison of S_{21} obtained from the EBG and the reference power-ground plane pair. It can be seen from this figure that within the required frequency range (750 MHz to 3.2 GHz), the proposed EBG structure creates a stopband, thus preventing the propagation of electromagnetic waves within the cavity. Consequently, SSN caused by digital components can not be coupled to sensitive RF/analogue components. Approximately 2.5 GHz stopband bandwidth (considering the -40dB bandwidth) and 2.2 GHz stopband bandwidth (considering the -60dB bandwidth) was achieved.

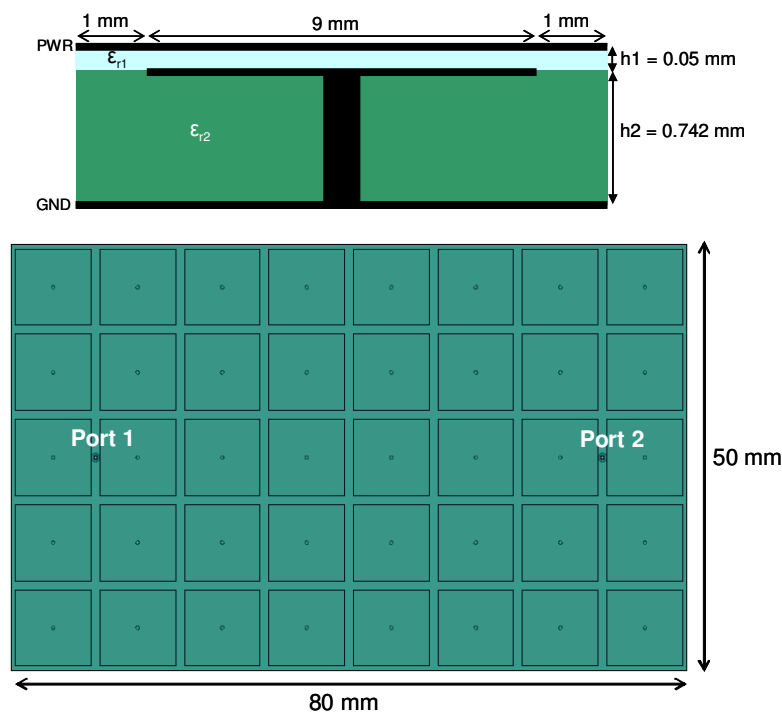


Figure 1: Cross-sectional view of a unit cell (top); Top view of EBG (bottom) [12].

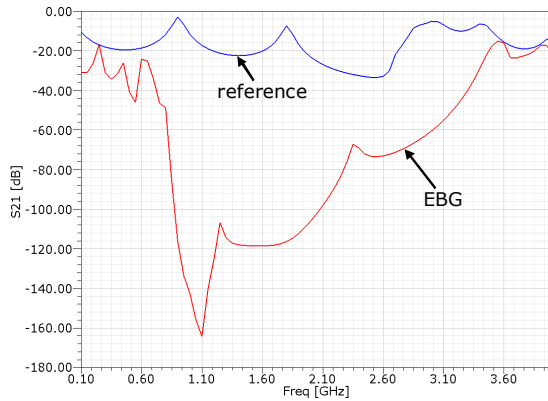


Figure 2: S_{21} of EBG and a continuous power-ground plane pair (reference).

3. Modeling of Stripline and Via (Without EBG)

The stripline and through-hole via that were studied are shown in Figure 3. The stripline has a width of 0.34mm, thickness of 0.035mm and a length of 30 mm. It was designed to have a characteristics impedance of 50 Ω . The line is routed

between the power-ground plane pair whose dimensions are given in the previous section. In order to develop the via, two additional metal and pre-preg layers, whose dimensions are given in Figure 3, were added to the original layer stack-up. However, the thickness of the power-ground cavity remains the same for all cases (0.792 mm). The through-hole via (pad radius=0.2mm; hole radius=0.1mm) was then used to interconnect signals between the two outer layers. The stripline and via were separately simulated using HFSS in the same frequency range as the EBG (100 MHz to 4 GHz). In Figure 4, the insertion loss of each of the interconnects is shown.

As can be seen in the S-parameters, there are dips in the insertion loss of both the via and the stripline. These dips can be explained as follows: When the stripline and the via are routed between or through the power-ground plane pair, their return-currents excite parallel-plate modes between the planes.

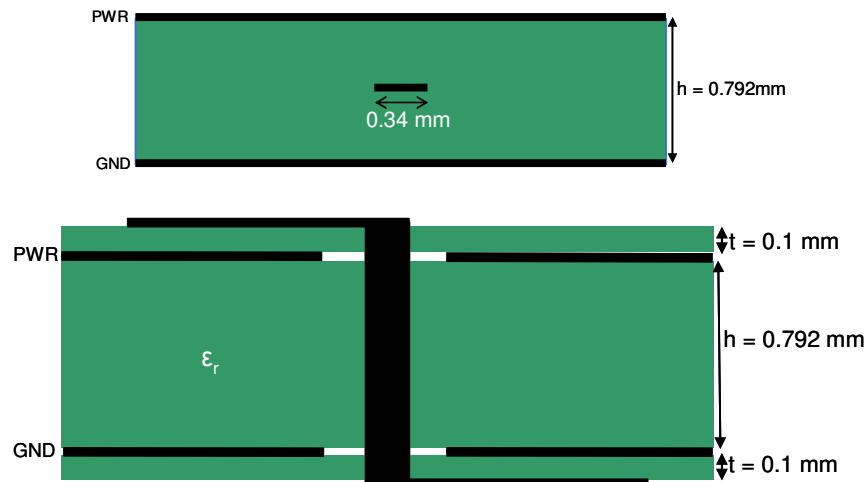


Figure 3: Cross-sectional view of stripline (top) and through-hole via (bottom) routed between/through a power-ground plane pair.

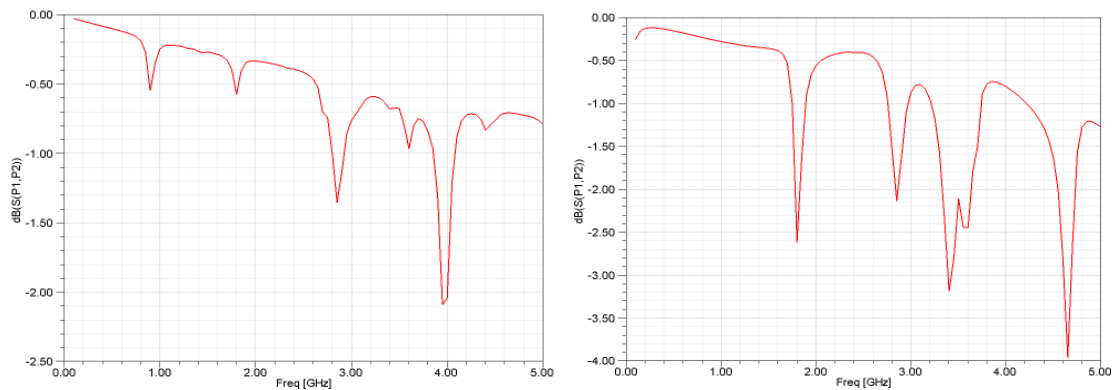


Figure 4: Insertion loss of stripline (left) and through-hole via (right) routed between/through power-ground plane pair.

This excitation leads to the generation of waves within the cavity. Since the edges of the package are terminated with an open circuit, the waves reflect back and forth, leading to the formation of standing waves. These waves cause strong electromagnetic coupling between the stripline, the through-hole via and the power-ground planes at or near the resonance frequencies of the planes. Consequently, much power is coupled from the transmission lines and vias. Some of the coupled power is radiated at the edges of the package. The dips in the insertion loss lead to the degradation of signal integrity.

4. Impact of EBG on the Stripline and Via

In order to understand the impact of the mushroom-type EBG on the stripline and through-hole via, the EBG, the stripline and the via were integrated together between the parallel-plates of a PDN. To have a clearer picture, the interconnects were integrated one at a time and they were studied separately. The simulations were also performed with HFSS. The S-parameters obtained from the study of the interactions were compared to those obtained when each interconnect was analyzed alone (without the EBG). The results of this comparison are shown in Figure 5 and Figure 6. As seen from these figures, the EBG has the same effect on both the via and the stripline. Within its stopband bandwidth (750 MHz to 3.2 GHz), the EBG blocks the propagation of waves in the cavity. Consequently, no power is coupled either from the stripline or the via to the planes. Hence, there are no dips in the insertion loss. Outside the stopband, the resonances are still present for both cases. Therefore, the mushroom-type EBG proposed in this paper has positive effects on the signal integrity behavior of stripline and through-hole vias as it filters out the resonances in the insertion loss and minimizes undesired coupling.

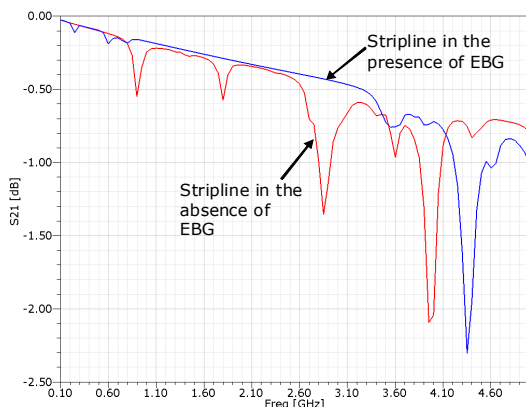


Figure 5: Impact of EBG on insertion loss of stripline.

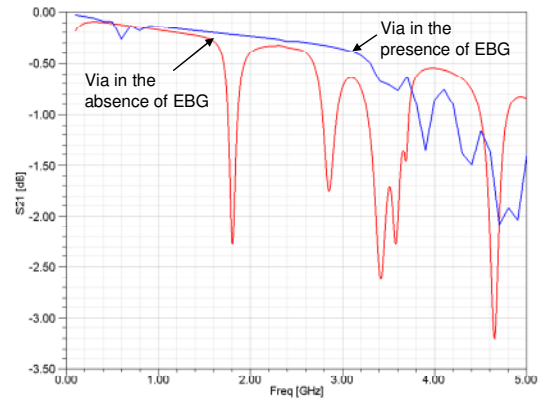


Figure 6: Impact of EBG on insertion loss of via

5. Impact of Stripline and Via on EBG

The presence of either striplines or vias in the power-ground cavity causes a change in effective capacitance and inductance of the cavity. Since the stopband bandwidth of the EBG is dependent on these capacitances and inductances, it implies that the filtering properties of the EBG will be altered, when striplines and vias are integrated. The magnitude of the shift in the stopband of the EBG depends on the number and position of the striplines and vias.

To illustrate the impact of striplines and vias on the filtering characteristics of the EBG, the EBG was simulated together with 64 striplines and 8 vias. The impact of each of these interconnects were studied separately. Considering the impact of striplines as an example, a comparison of the S-parameters when the EBG was modeled alone and when it was modeled with the stripline is shown in Figure 7.

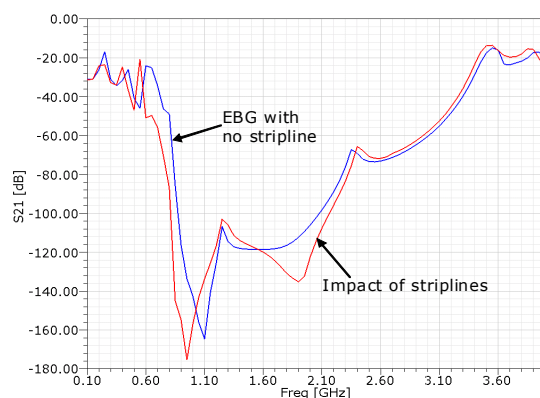


Figure 7: Impact of striplines on EBG

As expected, these striplines cause an increase in the net capacitance and inductance, which in turn leads to a shift of approximately 150

MHz in the stopband centre frequency to lower frequencies.

6. Summary

We studied the interactions between mushroom-type electromagnetic bandgap (EBG) structures and integrated interconnects (striplines and vias). The EBG prevents/minimizes electromagnetic coupling between these interconnects and the power-ground cavity, thereby eliminating resonances in the transmission coefficient of the S-parameters of the interconnects. Since the interconnects cause a slight change in the inductance and capacitance of the power-ground cavity, they also cause a shift in the stopband bandwidth of the EBG. The magnitude of the shift depends on the number and positions of the striplines and vias.

References

- [1] Shahparnia, S.; Ramahi, O.M.; "Miniaturized electromagnetic bandgap structures for ultra-wide band switching noise mitigation in high-speed printed circuit boards and packages", *IEEE 13th Topical Meeting on Electrical Performance of Electronic Packaging*, 2004 Page(s): 211 – 214.
- [2] Rajo-Iglesias, E.; Inclan-Sanchez, L.; Vazquez-Roy, J.-L.; Garcia-Muoz, E.; "Size Reduction of Mushroom-Type EBG Surfaces by Using Edge-Located Vias" *IEEE Microwave and Wireless Components Letters*, Volume 17, Issue 9, Sept. 2007 Page(s): 670 – 672.
- [3] Shahparnia, S.; Ramahi, O.M.; "Design, implementation and testing of miniaturized electromagnetic bandgap structures for broadband switching noise mitigation in high-speed printed circuit boards", *9th IEEE Workshop on Signal Propagation on Interconnects*, 10-13 May 2005, Page(s): 39 – 40.
- [4] Qin, J.; Ramahi, O.M.; "Ultra-Wideband Mitigation of Simultaneous Switching Noise Using Novel Planar Electromagnetic Bandgap Structures" *Microwave and Wireless Components Letters*, IEEE Volume 16, Issue 9, Sept. 2006 Page(s): 487 – 489
- [5] Sung-Ho Joo; Dong-Yeop Kim; Hai-Young Lee; "A S-Bridged Inductive Electromagnetic Bandgap Power Plane for Suppression of Ground Bounce Noise", *Microwave and Wireless Components Letters*, IEEE, Volume 17, Issue 10, Oct. 2007 Page(s): 709 – 711.
- [6] Jinwoo Choi; Govind, V.; Swaminathan, M.; "A novel electromagnetic bandgap (EBG) structure for mixed-signal system applications", *2004 IEEE Conference on Radio and Wireless*, 19-22 Sept. 2004, Page(s): 243 – 246
- [7] Ki Hyuk Kim; Schutt-Aine, J.E.; "Design of EBG Power Distribution Networks With VHF-Band Cutoff Frequency and Small Unit Cell Size for Mixed-Signal Systems", *Microwave and Wireless Components Letters*, IEEE Volume 17, Issue 7, July 2007 Page(s): 489 – 491.
- [8] McKinzie, W.E.; "A Hybrid Electromagnetic Bandgap (EBG) Power Plane with Discrete Inductors for Broadband Noise Suppression", *IEEE Electrical Performance of Electronic Packaging*, 2007, 29-31 Oct. 2007 Page(s): 91 – 94
- [9] Tavallaee, A.; Abhari, R.; "2-D characterisation of electromagnetic bandgap structures employed in power distribution networks", *IET Microwaves, Antennas & Propagation*, Volume 1, Issue 1, February 2007 Page(s): 204 – 211.
- [10] Li Yang; Mingyan Fan; Fanglu Chen; Jingzhao She; Zhenghe Feng; "A novel compact electromagnetic-bandgap (EBG) structure and its applications for microwave circuits", *IEEE Transactions on Microwave Theory and Techniques*, Volume 53, Issue 1, Jan. 2005 Page(s): 183 – 190.
- [11] Zhang, Fengmin; Du, Zhengwei; Wang, Qiang; Gong, Ke; "A Novel Approach to Enhance the Bandwidth of Mushroom-like EBG Structures" *International Conference on Microwave and Millimeter Wave Technology*, 2007. ICMMT '07, 18-21 April 2007 Page(s): 1 – 4.
- [12] Ivan Ndip, Stephan Guttowski, Herbert Reichl, "On the Interactions between Mushroom-type EBGs and Striplines", *Asia-Pacific Symposium on Electromagnetic Compatibility and 19th International Zurich Symposium on Electromagnetic Compatibility*, 2008. APEMC 2008. 19-23 May 2008 Page(s): 435 – 438.