NOVEL CONCEPTS FOR NOISE MITIGATION IN HIGH-SPEED BOARDS AND PACKAGES USING METALLO-DIELECTRIC ELECTROMAGNETIC BAND GAP MATERIAL – THEORY, SIMULATION, AND MEASUREMENTS

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Abstract: As digital circuits become faster and more powerful, direct radiation from printed circuit boards (PCB) and simultaneous switching noise become significant concerns for EMC and signal integrity engineers. In this paper, we introduce an effective method for suppressing PCB radiation from their power bus over an ultra wide range by using metallo-dielectric electromagnetic band-gap (EBG) structures. The source of PCB radiation is the unwanted voltage fluctuations on the power bus of a PCB arising from the resonance of the parallel-plate wave-guiding system created by the power bus planes. Laboratory PCB prototypes were fabricated and tested revealing appreciable suppression of radiated noise over specific frequency bands of interest, thus testifying to the effectiveness of this concept.

Key words: EMI, EMC, switching noise, metamaterial, high-impedance surface. Electromagnetic band gap material.

1. Introduction

Electromagnetic interference (EMI) in high-speed digital and analog circuits is considered one of the most critical challenges to the electromagnetic reliability of modern-day electronic systems. These challenges are exacerbated by the decrease in the threshold level in digital logic, and by the increase in clock and bus speeds that have already exceeded the 1GHz mark. Electromagnetic interference is a complex mechanism that takes place at different levels including the chassis, board, component, and finally, the device level. Each one of these represents a stage in the overall electromagnetic coupling mechanism. Mitigation of the electromagnetic noise follows certain modalities and strategies that depend directly on physical topology and material. In most previous works, the most traditional approach to mitigate EM noise is through hardening, variation of topology, variation of material, or through alternate electronic circuitry design techniques, which can include the use of additional circuitry components [1]-[4]. While it is expected that excellent shielding can always be achieved, however, the consequent cost can be significant, especially in a sizable sector of electronic systems that are very cost-sensitive. Therefore, new noise mitigation paradigms are becoming more relevant and necessary.

In this work, we discuss the novel concept of using metallo-dielectric electromagnetic band gap material, also known in recent publications as high impedance surfaces (HIS), to address critical electromagnetic noise problems in high-speed circuit, packages, boards, and cavities. We show that the HIS offer significant advantages in a class of applications that far exceeds the narrow range of antenna applications. Furthermore, we introduce the concept of cascading HIS of different topologies to provide ultra-wide band suppression for switching noise that is considered a fundamental bottleneck in high-speed printed circuit board design.

2. EMI Suppression Using EBG Surfaces

In this study, EBG structures originally introduced in [5] are used for the purpose of EMI mitigation in printed circuit boards. The proposed technique consists of placing a ribbon of HIS around the board connected to one of the power planes. If the internal circuits generate switching noise with a frequency within the band-stop region of the HIS ribbon, the presence of the ribbon prevents waves generated within the parallel plate, from radiating from the sides of the board. Fig. 1 shows a diagram illustrating the lateral view of a board employing this
concept. This concept for EMI mitigation is a natural extension of [6] where HIS structures were used to mitigate simultaneous switching noise with unprecedented effectiveness.

![Diagram](Image)

Fig. 1. Lateral view of the diagram for the switching noise model which includes the EBG structures as a ribbon around the board (only two rows are shown).

### 2.1. Design through Simulation

When inserting an HIS in a parallel-plate waveguide, the overall resonant circuit is composed of the top plate, a single patch, the corresponding via and the plane that connects the vias together [6]. In fact this circuit provides a low-impedance path to high-frequency currents in the power-planes therefore shorting the planes (resonance) at the physical location of the patches within the band-stop frequency range, thus suppressing radiation.

EBG structures can be designed using either S-parameter simulations or dispersion diagrams. Fig. 2 shows a diagram of the model used for S-parameter simulations. The model consists of two ports and a 2D periodic EBG structure located between them. Since the presence of the EBG structure between the ports prevents wave propagation between them within a frequency range, the $S_{21}$ parameter, a representative for the transferred power, will reflect the effect of the EBG structure.

Another tool widely used for the study of periodic structures is the dispersion diagram. In a two dimensional periodic structure in the $x$-$y$ plane, due to symmetry and periodicity, redundant propagation vectors can be grouped in a region known as Brilliouin zone [7]. By tracing $k_x$ and $k_y$ (respectively the $x$ and $y$ components of the propagation constant) as variables, on the border of the irreducible zone, using eigenmode simulation the frequency of different propagating modes are calculated. For the simple patches of the EBG structure used in this work, this region is shown at the left upper corner of Fig. 3. In this diagram the bandgap is represented by the frequency range in which there is no propagating mode for any value of $k_x$ and $k_y$.

As an example of the type of results obtained using the above mentioned two methods, we show in Fig. 3 the dispersion diagram for a periodic structure with patch size of 5mm, via diameter of 0.8 mm, via length of 1.54 mm, board thickness of 3.08 mm, gap size of 0.4 mm on commercial FR-4 derived by simulation using HFSS. Fig. 4 shows the $S_{21}$ parameter for the same structure when implemented as the model in Fig. 2. From both simulations, it is clear that the stop-band lies approximately between 4 and 8 GHz.

### 2.2. Fabrication and measurements

EBG structures used in printed circuit boards are fabricated using commercial PCB manufacturing technology.

![Diagram](Image)

Fig. 2. Simulation set up for S-parameter simulation. Waves generated on port 1 do not reach port 2 within the band-stop region. (a) Top view of the mid layer (patch layer). (b) Side view which includes the sources as a replacement for the SMA connectors used in experiments.

![Diagram](Image)

Fig. 3. Dispersion diagram for an infinitely periodic structure with PS = 5 mm, VD = 0.8 mm, VL = 1.54 mm, GS = 0.4 mm on commercial FR-4 ($\varepsilon_r = 4.4$) derived by HFSS simulation using periodic boundary conditions.

Fig. 5 shows a picture of a printed circuit board fabricated to test the proposed radiation suppression concept. The signal was fed to the parallel-plate...
environment through an SMA connector to the middle of the board using a vector network analyzer. The amount of radiation from the edges of the board is measured by measuring the scattering parameters \( S_{21} \) as a representative for the radiated power \( S_{21} \) at a distance of 5 cm from the edge of the board.

3. Wide-Band EMI Reduction

Widening the suppression band-gap can be accomplished by using cascaded high-impedance surfaces (CHIS) with different structures around the board, creating an ultra wide-band stop band for the propagating wave. As an example, we consider the configuration shown in Fig. 7 with a board size of 20 cm x 16 cm, and a signal source positioned at the center and connected to the board through an SMA connector. In this configuration an EBG structure with a patch size of 10 mm (HIS Type 2) is added to a structure with a patch size of 5 mm (HIS Type 1). Cascading HIS structures is based on the same concept of cascading filter stages in order to achieve larger bandwidths (either pass-band or stop-band), multiple bands or larger attenuation. This concept was first introduced in [8] for ultra-wide band suppression of switching noise in PCBs but the same idea can be used here since the noise generation mechanism is identical. Fig. 8 shows the measured \( S_{21} \) response for this configuration at the same test point considered earlier (i.e., at 5 cm from the edge of the board). Notice that an additional gap between 2 GHz and 4 GHz is introduced by the added structure (with a period of 10.4 mm). This property is especially relevant to cases in which the suppression of a fundamental frequency is as important as the suppression of the harmonics of that frequency. As an example, as illustrated in Fig. 8, the design in Fig. 7 is capable of suppressing not only a noise at 3 GHz but also its second and third harmonics at 6 GHz and 9 GHz, creating ultra-wide band suppression radiation from printed circuit boards employing such design.

4. Summary and Conclusions

This study introduces the novel concept of using electromagnetic bandgap (EBG) structures for the
suppression of electromagnetic radiation generated by high-speed and high-current switching, also known as switching noise, from power busses of printed circuit boards. Ultra-wide band suppression of such radiation is achieved by cascading different configurations of high-impedance surfaces. The significance of ultra-wide band suppression lies in the fact that CHIS structures provide a practical way to suppress radiation not only at the fundamental frequency of the noise but also its harmonics.

Fig. 7. Cascading two EBG structures with different configurations (5 mm and 10 mm patches, 4 rows each, the other dimensions similar to the ones in Fig 5), for an ultra wide-band suppression of radiation from the edges of the PCB (20.6 cm x 16.6 cm).

PCB prototypes were designed, developed and tested showing unprecedented level of EMI reduction over an ultra-wide band of frequencies that can encompass the clock frequency and its immediate harmonics.

References


Fig. 8. Measured $S_{11}$ for the structure in Fig. 15 within a power bus configuration, at test point TP4, d3 =5 cm, with and without the HIS structure.