A Wave Model for EBG in Power Plane Noise Mitigation

Xin Wu
ICE Electronic Division, Fluent Inc., Austin, TX 78746, USA
http://www.fluent.com

Abstract

An analytical model for the stopband of electromagnetic bandgap structure applied to PCB power/ground plane is developed based on modal analysis. Comparing with the measured data, the model predicts the stopband behavior precisely such that it can be used for EBG design for power plane noise suppression without running numerical full wave simulations.

Introduction

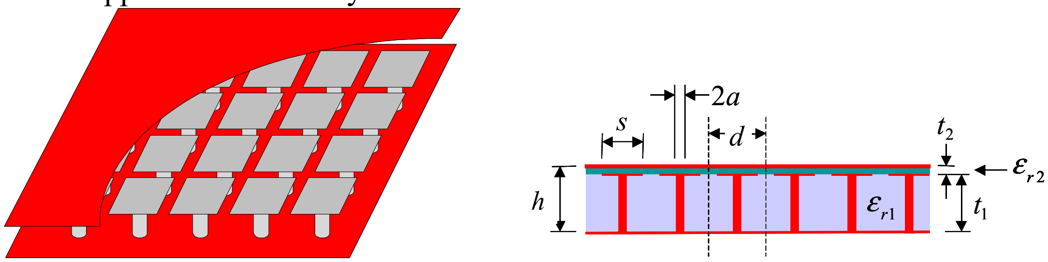
Power plane and ground noise may be generated by large numbers of simultaneously switching gates. Power ground pairs are required to have low impedance over a wide range of frequencies. Due to the submicron silicon feature sizes and reduced power supply voltage level for lower power dissipation, the voltage fluctuation budget becomes more limited. An ideal power distribution network is expected to present a voltage source of very low and flat impedance over all harmonics generated by the connected clocking circuits. For instance, a high-end system today with single-ended signaling may have 10A transient current in the signal-return paths of buses and may require 50mV maximum ripple on the power distribution network. This converts into 5 milliohms impedance of required power-distribution network impedance [1].

In the range of hundreds of MHz or couple of GHz clocking rate, the harmonics of the clocking frequencies brings the power plane geometry size comparable or larger than the wavelength of the maximum harmonics of interest. Hence, the impedance of the power plane pairs cannot be expected to be flat because of the inherent resonance characteristics of the power plane pair. Electromagnetic bandgap (EBG) layers for reducing digital switching noise in power planes were first proposed in [1]-[2], and successfully being prototyped in high-speed mixed signal system [3]. In the power plane resonance suppression, EBG, an array of conducting patches is added between the power and ground planes with vias connected the patches to the ground plane. It is shown that the key to increasing stopband bandwidth lies in maximizing the capacitance between the patch layer and the plane above it [4].

In this paper, an analytical model based on modal superposition is developed to compute the stopband of EBG structure applied to power plane. The comparison with measurements shows a very good agreement on the EBG behavior estimation.

Modal Analysis Model for EBG Applied to Power/Ground Plane

The application of electromagnetic bandgap (EBG) materials to suppress the high-frequency power plane noise has been explored and numerous results have been reported. A typical application of EBG to power plane noise suppression is illustrated in Figure 1. In this work, we propose a theoretical model for the EBG within the framework by using modal analysis to characterize the power plane noise suppression efficiency with EBG.



(a). 3D view (b). side view

Figure 1. EBG for power plane noise suppression.

Recently, a modal analysis approach for characterizing the power/ground plane was reported based on the superposition of the modes of a PMC wall backed resonator [5]. The voltage distribution V(x,y) within a rectangular power/ground plane structure due to a current source I_0 at (x_0,y_0) can be obtained as

$$V(x,y)=\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}V_{mn}(x,y)\,, \tag{1}$$

with the modal voltage

$$V_{mn}(x,y)=\frac{I_0F_{mn}(x_0,y_0)F_{mn}(x,y)}{Y_{mn}}, \tag{2}$$

where

$$F_{mn}(x,y)=\cos(k_{xm}x)\sin c(k_{xm}P_x/2)\cos(k_{yn}y)\sin c(k_{yn}P_y/2)$$

the modal admittance is given as:

$$Y_{mn}(x,y)=\frac{W_xW_y(k_{xm}^2+k_{yn}^2-k^2)}{j\omega\mu W_zC_mC_n}, \tag{3}$$

where, $k=\omega\sqrt{\mu\varepsilon}(1-\frac{j}{2Q})$, and,

the quality factor:

$$Q=1/(\tan\delta+\frac{1}{W_z}\sqrt{\frac{2}{\omega\mu\sigma}}), \text{ and,}$$

$$k_{xm}=\frac{m\pi}{W_x},k_{yn}=\frac{n\pi}{W_y},C_m=\begin{cases}1,m=0\\2,m\neq 0\end{cases},C_n=\begin{cases}1,n=0\\2,n\neq 0\end{cases}.$$

with

W_x,W_y and W_z are dimensions of the power/ground pair in x,y,z direction, respectively. P_x and P_y denote the port widths in x,y direction centered at (x,y), which must be much smaller than the wavelengths of interest. Although the modal analysis requires an infinite summation of the modes supported in the power plane structure, for the problem we considered, the contributions from higher order modes are negligible [6].

Considering that an EBG is to be a periodic structure with its featured size smaller than the wavelengths of interests, the EBG can be modeled as an equivalent circuit. Ignoring the conductor loss of the EBG structure, an equivalent series LC circuit can be constructed for EBG, with lumped capacitance and inductance computed as [4]:

$$C = \frac{\varepsilon_0 \varepsilon_{r2} s^2}{t_2}, \text{ and } L = \frac{t_1 \mu}{4\pi}[\ln(\frac{1}{\alpha}) + \alpha - 1],$$

with $\alpha = \pi a^2 / d^2$. α is the ratio of the via cross section to the cross section of the entire unit cell. μ is the permeability of the dielectric substrate, which is μ_0 ($4\pi \times 10^{-7}$ H/m) for non-magneto materials. ε_0 is free space permittivity (8.85×10^{-12} F/m). The equivalent shunt admittance of the LC circuit is

$$Y_e = - j/(\omega L - 1/\omega C), \quad (4)$$

If a power plane is excited at a port location by a current source I_0, the resulting voltage distribution V(x,y) will consequently generate a current I_e going thru the EBG equivalent LC circuit. The current I_1 is given

$$I_e(x_e, y_e) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} I_{emn}(x_e, y_e), \quad (5)$$

since each of the modal voltages V_{1mn}(x,y) generates a corresponding modal current I_{1mn} going through the EBG unit cell at (x_e,y_e), also, we have

$$I_{emn}(x_e, y_e) = Y_e \cdot V_{emn}(x_e, y_e), \quad (6)$$

If we treat this current I_1 similar to the current source I_0, the resulted voltage distribution across the board due to the implanted EBG structure is

$$V(x, y) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} \frac{I_0 F_{mn}(x_0, y_0) F_{mn}(x, y)}{Y_{mn} + \sum_{e=1}^{N} F_{mn}(x_e, y_e) F_{mn}(x_e, y_e) Y_e}, \quad (7)$$

In this case, the port geometry factor Px, Py becomes the patch size, thus

$$F_{mn}(x_e, y_e) = \cos(k_{xp} x_e) \sin c(\frac{k_{xm} P_{xe}/2}{k_{xm} P_{xe}/2}) \cos(k_{yp} y_e) \sin c(\frac{k_{yn} P_{ye}/2}{k_{yn} P_{ye}/2}), \quad (8)$$

The factor $F_{mn}(x_e,y_e)$ characterize the local propagation around the EBG patch area. In the EBG patch area, the currents thru EBG structure, when flowing in the via, they are confined within the substrate where the EBG embedded thanks to the discontinuity of the patch. When the displace currents in the supperstrate being considered, the currents effects in the power/ground plane cavity can be characterized by the *sinc*(·) function.

Results and Comparison

In this section, we apply the developed model to a power plane which consists of a set of EBG patches sandwiched in the substrate. The overall power/ground height h=2.84mm(112mil), a=0.51mm(20mil), d=8.00mm(315mil), g=0.76 mm(30mil), s=7.24 mm(285mil), t_1=2.36mm(93mil), epsr1=4.3, er2=4.0. In Etenna's board, the overall board dimension is 191×140mm with two ports located at(31.8,74.6)mm and (127.0,7.46)mm. There are 11 unit EBG patches between two ports [4].

The analytical model computed S21 parameter and the measurement data reported in [4] are plotted in Figure 2. The predicted stop band by the model agrees very well with the reference.

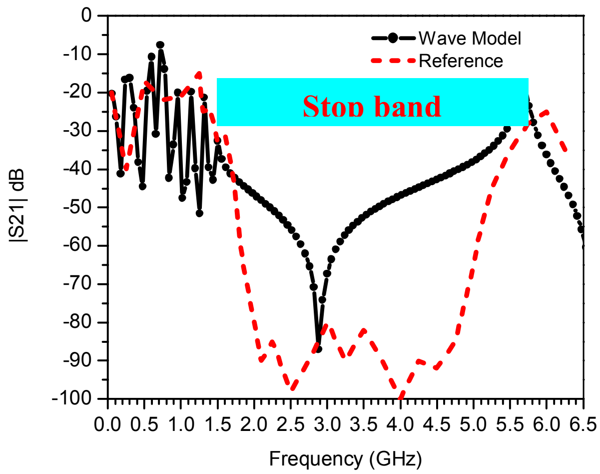


Figure 2. the wave model computed S21 vs. measured data.

Conclusion

In this paper, a cavity based wave model is presented to analyze the EBG embedded in PCB power plane for power plane noise suppression. With the developed analytical model, the EBG stop band can be well predicted. The model can be applied to EBG design which usually requires a computational resource expensive numerical simulations.

References:

[1] R. Abhari and G. V. Eleftheriades, "Suppression of the parallel-plate noise in high speed circuits using a metallic electromagnetic band-gap structure," 2002 IEEE MTT-S Int. Microwave Symp. Dig, June 2002, pp. 493-496.

[2] T. Kamgaing and O. M. Ramahi, "High-impedance electromagnetic surfaces for parallel-plate mode suppression in high speed digital systems," IEEE 11th Topical Meeting on Electrical Performance of Electronic Packaging, Oct 21-23, 2002, Monterey, CA, pp. 279-282.

[3] S. Rogers, X. Wu, A. Waltho and D. Xu, "Noise reduction in digital/RF daughter card with electromagnetic bandgap layers," IEEE 13th Topical Meeting on Electrical Performance of Electronic Packaging, Oct 21-23, 2004, Portland, OR, pp. 203-206.

[4] S. D. Rogers, "Electromagnetic-bandgap layers for broad-band suppression of TEM modes in powerplanes, IEEE Trans. Microwave Theory and Tech., vol. 53, no. 8, pp. 2495-2505, Aug. 2005.

[5] G. Lei, R. W. Techentin, and B. K. Gilbert, "High-frequency characterization of power/ground-plane structures," IEEE Trans. Microwave Theory and Tech., vol. 47, no. 5, pp. 562-569, May 1999.

[6] M. Hampe, and S. Dickman, "Improving the behavior of PCB power-bus structures by an appropriate segmentation," in Proc. IEEE EMC symposium, vol.3 , no.8-12, pp. 961-966, Aug. 2005 Chicago, IL.