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Analysis of Noise Coupling from Printed Circuit Board to Shielding Enclosure

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Abstract: The power distribution network in a printed circuit board (PCB) inside a compact-size enclosure is an effective path for high-speed digital noise to be coupled to the RF receivers inside the same enclosure, causing RF interference (RFI) issues. This noise coupling mechanism from PCB to shielding enclosure is investigated in this paper using the cavity model and the segmentation technique. In this approach, the structure of an enclosure with a PCB inside is divided into cavities with both horizontal and vertical connections. Modeling result agrees well with full wave simulations, and the simulation time is considerably reduced. Furthermore, the relationship among the noise coupling, the PCB-related resonances, and the enclosure-related resonances is studied as well.

I. Introduction

The simultaneous switching noise (SSN) is one of the critical problems in high-speed PCBs. It can easily propagate in the power/ground plane pair, resulting in various signal integrity and electromagnetic interference issues. Among them, the noise radiated by the board edges is a challenging problem for compact mixed-signal systems where the PCB is placed inside a metal enclosure. The enclosure can be excited by this PCB noise, further resulting in degraded performance in RF receivers. Noise coupling inside a PCB and an enclosure is investigated in [1] and [2], respectively. This paper will extend the prior work to study the noise coupling from PCB to enclosure.

Using full-wave numerical techniques, such as finite element (FEM) and finite difference time domain (FDTD) methods, to study this noise coupling problem is challenging, since the PCB and the enclosure geometries have significantly different dimensions. Full-wave simulations will be very time-consuming, if not impossible. Therefore faster algorithms are needed for practical engineering designs. The cavity model [3] is extensively adopted for rectangular PCB plane-pair and enclosure modeling for its fast simulation speed. Combined with the segmentation technique [4-6], the approach can be effectively extended to much more complicated shapes [7-8]. Further, in [1] and [2], vertical connections between cavities have been introduced in the segmentation method to analyze multiple power/ground plane pair in PCBs and multiple cavities in enclosures. In this paper, the approach is extended to study the mixed-scale noise coupling problem from PCB to enclosure.

The rest of the paper is organized as follows. Part II describes the problem and briefly overviews the modeling approach. An example case is analyzed in Part III with discussions, followed by the conclusions in Part IV.

II. Problem Description and Modeling Approach

Fig. 1 shows a PCB (simplified as a pair of power and ground planes) inside a metal enclosure. As shown in the top view in Fig. 1(a), the PCB touches the enclosure at three sides. The PCB itself forms a parallel-plane cavity. In addition, it divides the rest of the geometry into three more cavities, as shown in the side view in Fig. 1(b). The relative permittivity and tangential loss in Cavities 1, 3 and 4 are denoted as ε_{r1}, $\tan\delta_1$, and as ε_{r2}, $\tan\delta_2$ in Cavity 2. A z-directional noise current source P_1 is set inside the PCB, and an observation port P_2 is set in Cavity 4. Since all the four cavities are rectangular, an impedance matrix can be easily obtained using the cavity model for each individual cavity. To further connect these cavities using the segmentation technique, a number of auxiliary ports, illustrated as B_1, B_2, and B_3 in Fig. 1(a), are needed along the interface boundaries between the cavities. Notice that all the cavities have three PEC sidewalls and one PMC sidewall. The same is true for Cavity 2 formed by the PCB planes, since it touches the metal enclosure walls at three sides.

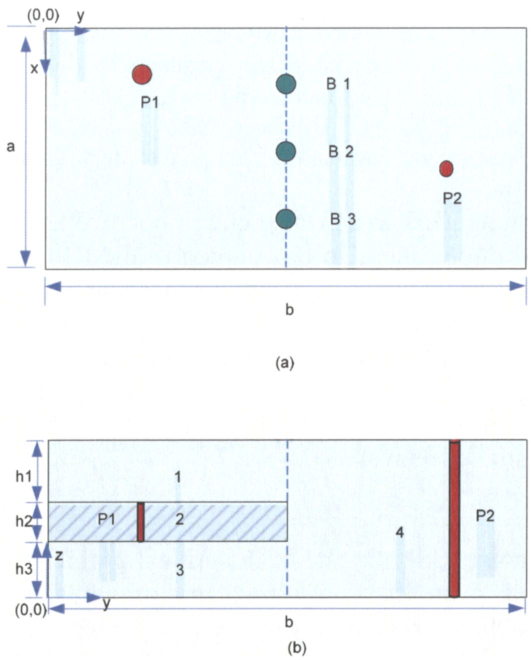

Figure 1: The geometry of the test example, (a) top view, and (b) side view.

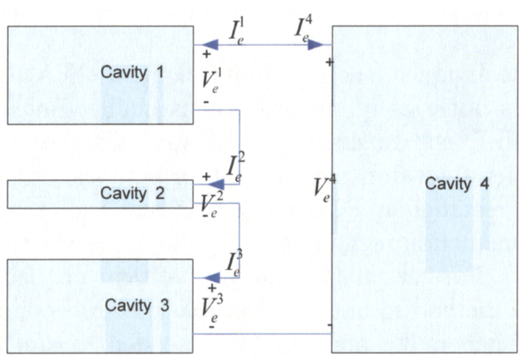

Figure 2: Connecting cavities by enforcing current and voltage continuities.

The impedance matrices, and thus the cavities, are connected by enforcing current and voltage continuities at the auxiliary ports. As shown in Fig.2, the voltage and current continuities can be described as:

$$V_e^4 = V_e^1 + V_e^2 + V_e^3, \quad I_e^1 = I_e^2 = I_e^3 = -I_e^4$$

III. Results and Discussions

A simple example case shown in Fig. 1 is studied. The dimensions of the enclosure are $5\ cm \times 10\ cm \times 2\ cm$. The PCB is located in the left half of the enclosure, and has dimensions of $5\ cm \times 5\ cm \times 2\ mils$. The thickness of PCB copper planes is ignored, and the heights of Cavities 1 and 2 are approximately *0.99746 cm*. The enclosure is filled with a dielectric material with a relative permittivity of 1 and a loss tangent of 0.02, while the PCB dielectric has a relative permittivity of 4.4 and a loss tangent of 0.02. The conductivity of the enclosure walls as well as the PCB metal planes is $5.8 \times 10^7\ S \cdot m^{-1}$. P_1 is located in the PCB between the two copper planes and is *1 cm* from the left sidewall and *2 cm* from the front sidewall. P_2 is located in Cavity 4 between the top and bottom enclosure walls and is *3.0 cm* from the left side wall and *8.5 cm* from the front side wall.

To validate the approach, the transfer impedance between P_1 and P_2 was obtained using the method introduced in Part II, and is compared with a full-wave simulation using the CST Microwave Studio in Fig. 3. It can be seen that the two results agree well, with some discrepancies at the resonant peaks only.

In order to further understand how the noise is coupled from the PCB to the enclosure, impedance matrices of the PCB plane pair and the enclosure structure are calculated using the cavity method introduced earlier. They are compared with the transfer impedance result between P_1 and P_2 obtained from the CST Microwave Studio simulation in Figure 4. By comparing the three curves, it becomes obvious that most of the noise coupling from the PCB to the enclosure is due to the resonances of the PCB structure, although the resonances associated with the enclosure also contributes some. The underlying reasons for the coupling mechanisms need further investigations.

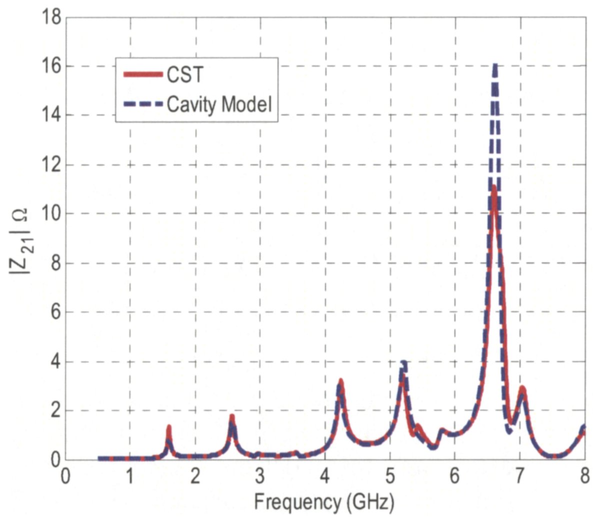

Figure 3: Approach validation by comparing with a full-wave simulation.

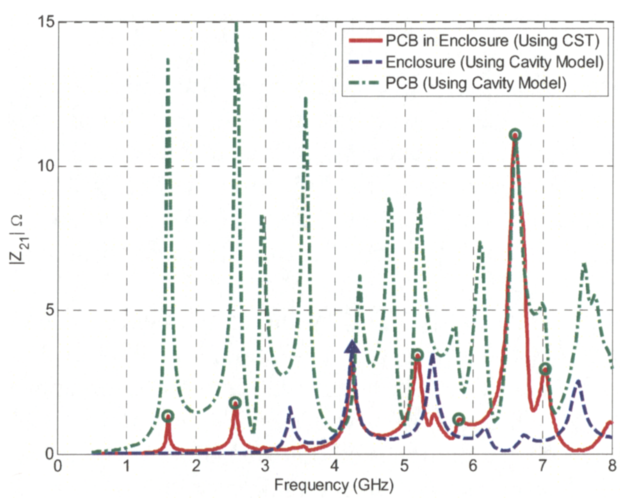

Figure 4: Noise coupling from the PCB to the enclosure caused by the resonances associated with the PCB and the enclosure.

Since all the cavities are rectangular, the distributed resonant frequencies can be estimated using some simple closed-form expressions. For the PCB cavity, since it has three PEC sidewalls due to its touching with the enclosure, its resonant frequencies can be calculated as

$$f = \frac{1}{2\pi}\sqrt{(\frac{2m-1}{2a}\pi)^2 + (\frac{n\pi}{b})^2}\frac{c}{\sqrt{\varepsilon_r}} \quad (1)$$

where m and n are the wave numbers along the x and y directions, a and b are the dimensions of the PCB along the x and y directions, c is the free-space velocity, and ε_r is the relative dielectric constant of the PCB dielectric.

Similarly, the resonant frequencies associated with the enclosure can be calculated as

$$f = \frac{1}{2\pi}\sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2}\,\frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

where m and n are the wave numbers along the x and y directions, a and b are the dimensions of the enclosure along the x and y directions, c again is the free-space velocity, and ε_r is the relative dielectric constant of the dielectrics filled inside the enclosure.

The corresponding resonant modes for the frequencies shown in the transfer impedance result between P_1 and P_2 can then be identified using the Equations (1) and (2), and they are listed in Table 1.

Table 1: Resonances associated with the PCB and the enclosure contribute to the noise coupling from the PCB to the enclosure.

Frequency in the transfer impedance result (GHz)	1.595	2.57	4.25	5.195	5.795	6.59	7.032
Resonant mode (m, n) associated with the enclosure	\	\	(1,2)	\	\	\	\
Resonant mode (m, n) associated with the PCB	(1, 1)	(2,1)	\	(4, 1)	(4, 2) (1, 4)	(5,1) (4, 3)	(5, 2)

IV. Conclusion

The cavity model and the segmentation technique are used to analyze the noise coupling problem from a PCB to an enclosure. The approach has been validated by comparing with a full-wave simulation, and it is demonstrated to be an effective and fast way to model the mixed-scale layered structures. Further study compares the transfer impedance with the resonances associated with the PCB and the enclosure. It is found that most of the noise coupling from the PCB to the enclosure is contributed by the PCB resonances. The underlying physics needs further investigations.

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