Modeling Radiated Emissions from Cables Attached to Printed Circuit Boards Driven by Power Bus Noise

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Abstract—**This paper describes a two-step technique for modeling the radiated electromagnetic emissions from a printed circuit board with attached cables when the source of the emissions is noise between the board's power and ground planes. The first step calculates the electric fields at the edges of the power-ground plane pair. The second step replaces the power plane with equivalent sources embedded within the ground plane structure. Examples are provided that demonstrate the accuracy of this approach.**

Keywords-power bus noise; circuit board modeling; method of moments; boundary element modeling

I. INTRODUCTION

Printed circuit board geometries present a significant challenge to 3-D numerical modeling tools. The size discrepancy between the small detailed noise source configurations on a typical circuit board and the relatively large enclosures or cables attached to these boards makes it difficult to model these structures efficiently.

Among the most difficult source geometries to model are closely spaced power plane structures. 3-D modeling of the volume between a power plane pair requires small model elements with a maximum dimension comparable to the distance between the planes. If the same 3-D model is used to analyze the entire structure including an attached cable, much larger elements must be used to model the cable. Unfortunately, employing elements that vary in size by several orders of magnitude in the same model, can generate significant numerical error making it difficult or impossible to get useful results.

This paper presents a two-step approach to modeling radiated emissions from printed circuit boards with cables or enclosures driven by power bus noise. The approach presented can greatly reduce the computational resources required to model boards with power planes and attached cables or enclosures. It also provides helpful insight regarding the "physics" of the power-bus-noise-to-cable coupling that can be useful when attempting to minimize this coupling.

II. DESCRIPTION OF THE METHOD

Typically, active components connected to the power planes induce voltages between the planes that may result in unacceptable levels of radiated emissions. Although the sources of this noise are on the board, the "antennas" are often larger metallic objects connected to the board such as cables or enclosures. The goal of the method described here is to model the electromagnetic coupling between the noise on the planes and these attached structures.
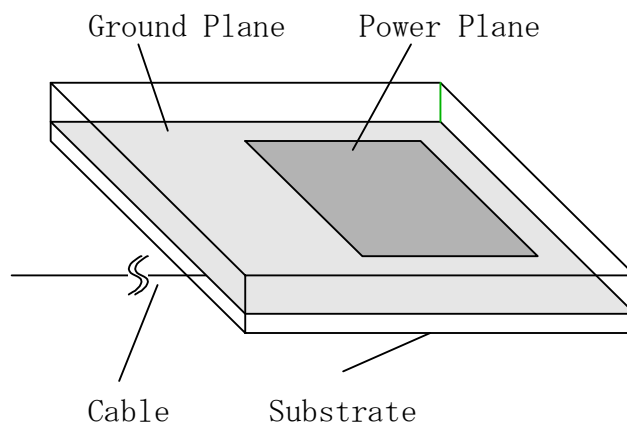

Figure 1. Sample structure to be modeled.

Figure 1 illustrates a simple printed circuit board geometry consisting of two power planes separated by a dielectric substrate. The lower plane (designated as the *ground* plane in the figure) is connected to a relatively long cable.

The method consists of two steps. In the first step, the attached cable is removed and the voltage distribution between the power and ground planes is calculated. This geometry is illustrated in Figure 2(a). Generally, the voltage between the planes is not significantly influenced by external objects attached to the ground plane. The voltage between the planes can be efficiently calculated using cavity resonance models [1], circuit models [2], or 2-D or 3-D numerical models. The voltage between the planes at the edge of the power plane is

simply the product of the electric field at the edge and the plane separation distance. This is represented by the quantity V_{DM} in the figure, where the subscript indicates a *differential mode* voltage (i.e. a voltage between two different conductors).
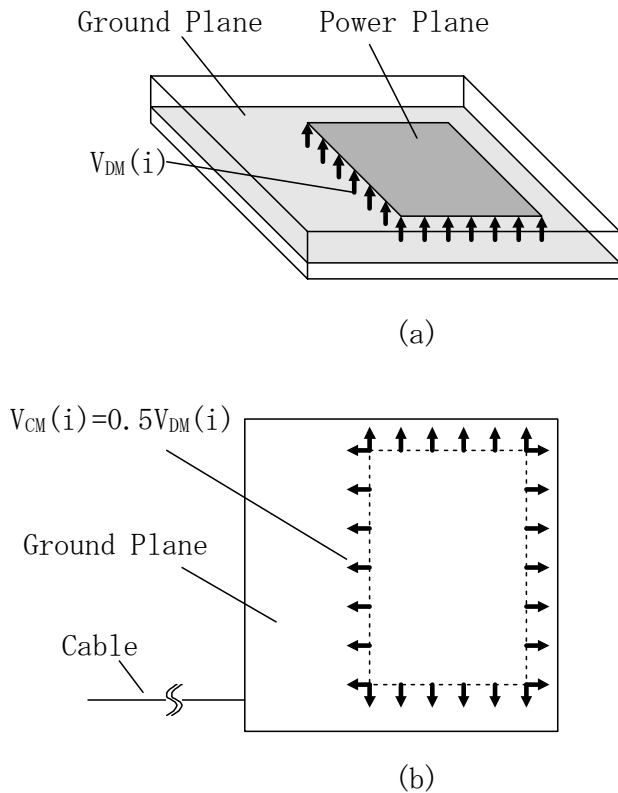

(a)

(b)

Figure 2.   Modeling steps for sample structure.

In the second step, the cable is replaced and the power plane is removed from the model. Voltage sources are placed within the ground plane where the edge of the power plane used to be. These sources are represented by the arrows in Figure 2(b). The value of each *common-mode* voltage source is one-half the value of the corresponding differential mode voltage in the previous step. The factor of ½ is due to the fact that the equivalent magnetic current sources associated with the common-mode voltages generate electromagnetic fields both above and below the planes, while the equivalent sources associated with the differential-mode voltages generate fields only above the planes. We refer to the new voltage sources as common-mode sources because they drive common-mode currents on the metal plate attached to the cable.
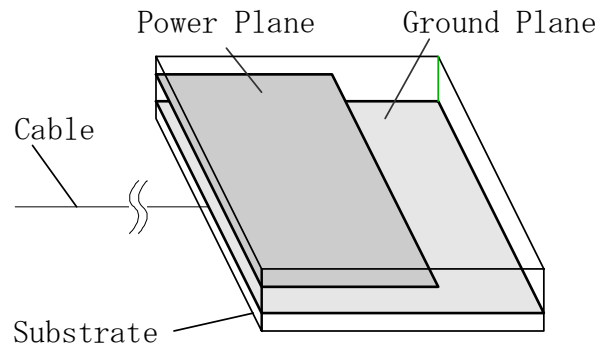

Figure 3.   Power plane sharing 3 edges with ground plane.

In situations where some edges of the power plane coincide with edges of the ground plane, it is not necessary to place voltage sources along the common edges. Figure 3 shows a circuit board configuration where the power and ground planes share 3 edges. In this case, one can neglect common-mode voltage sources along the common edges except at the point, where the cable is attached to the ground plane. From a circuit theory point of view, one can say that the common-mode voltages are induced wherever there is a change in the balance of the system [3].
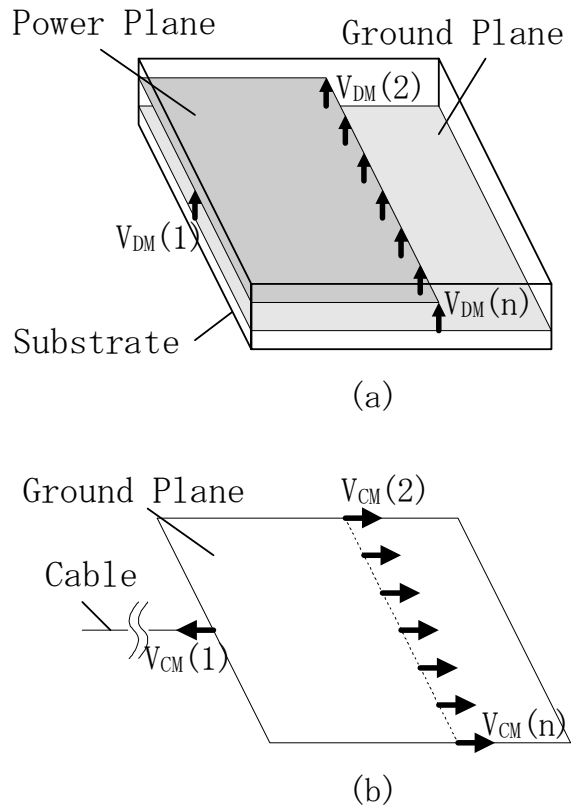

(a)

(b)

Figure 4.   Modeling the geometry in Figure 3.

The approach introduced here is much more efficient than directly applying a 3-D numerical method. The number of elements required to accurately model the configuration in Figure 4(b) is much lower than that required to model the entire problem including the power plane. Boundary element methods are particularly efficient for this application.
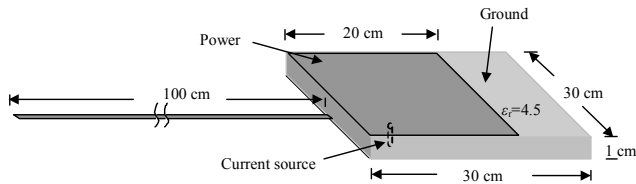

Figure 5. Example 1 geometry.

III.   NUMERICAL RESULTS

The procedure described in the previous section was used to calculate the current induced on a cable attached to a PCB as illustrated in Figure 5. The size of the dielectric board is 30 x 30 x 1 cm. The relative permittivity of the dielectric is 4.5. The bottom layer is a solid ground plane. The top layer is a 30 x 20 cm power plane. A 1-m long cable is attached to the board. A 1-ampere current source is placed between the planes to excite the PCB. The current induced on the cable near the point where it connects to the PCB was calculated using a full-wave moment-method technique [4] and the results are plotted in Figure 6 (the curve labeled "original"). In this model, the long cable is modeled as a flat metal strip with a width of 1 cm. The cable and planes are modeled as perfect electric conductors (PECs).
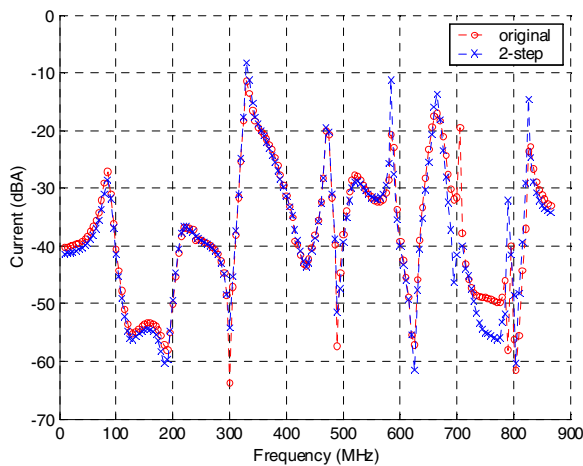

Figure 6. The current amplitude in dB on the cable

The same code was then used to solve the problem using the two-step procedure described in the previous section. First the voltages between the planes were calculated for the board without the cable as shown in Figure 7. Voltages were obtained at the point where the cable was attached and at the edge of the power plane, as shown in the figure. Next the current was calculated using the simplified model shown in Figure 8. This model contains only the ground plane and the cable. The ground plane was divided into two parts and voltage sources were placed between them. Another voltage source was placed between the plane and the cable. In this model, the amplitudes of the common-mode sources are one-half the amplitudes of the corresponding differential-mode sources. The common mode current on the cable is calculated with this model and the result is indicated by the curve labeled "2-step" in Figure 6. The agreement between the full solution and the much simpler 2-step solution is very good.
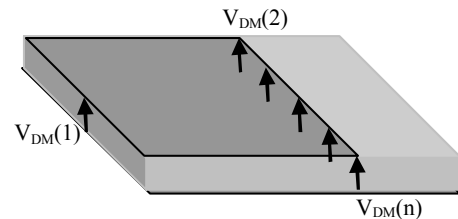

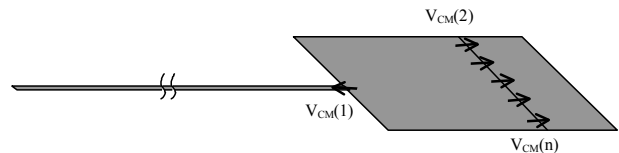Figure 7. The model for differential voltage calculation

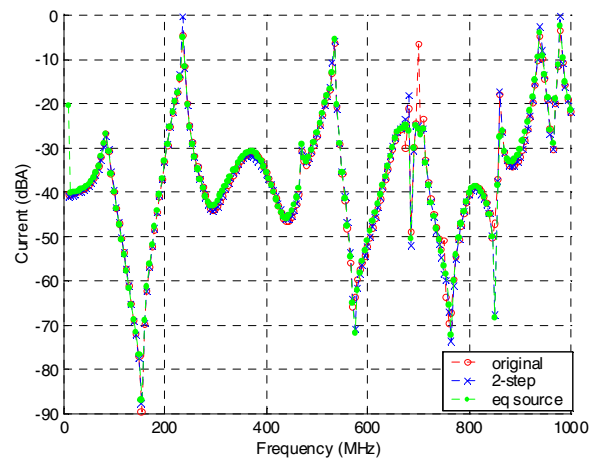Figure 8. The model for common-mode current calculation

Figure 9. Currents on the cable of the second model

To further explore this modeling technique, another model was analyzed. This model is similar to the configuration in Figure 5 except the power plane covers the whole top layer. Consequently, the model for the current calculation in the two-step procedure requires only one equivalent source located at the PCB-cable junction. There is no need to calculate the

voltages at other points along the edge of the planes in this case. The results of the second example calculated using the two modeling methods are shown in Figure 9. Although there is generally very good agreement between the "original" and "2-step" curves in Figures 9, there are a few frequencies where the results are not the same. In order to determine whether the differences were due to numerical errors or due to the fact that the power plane was removed in the 2-step procedure, the power plane was left in place while calculating the common mode current in the second step. This result is indicated by the curve labeled "eq source". The results suggest that the presence or absence of the power plane does not affect the calculation significantly.

IV. CONCLUSIONS

A simple 2-step procedure for modeling the coupling between power-ground plane pairs and attached cables or enclosures has been presented. This approach significantly reduces the amount of time and computational resources required to perform a full-wave electromagnetic analysis of these geometries.

This approach also provides insight that may help the designers of printed circuit boards to reduce power bus noise coupling to objects connected to the ground plane. Common-mode sources in this model only appear at places where the edge of the power plane does not coincide with the edge of the ground plane. On a board where all the power and ground edges line up, the equivalent common-mode voltage driving a cable is one-half the inter-plane voltage at the point of the cable attachment. This suggests that common-mode currents on a cable due to power bus noise can generally be minimized by controlling the power bus noise voltage in the immediate vicinity of the cable attachment.

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