The Validity of Using Image Plane Theory to Predict Printed Circuit Board Radiation

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Abstract

In order to reduce the radiated emissions of a printed circuit board **(PCB)**, a conductive plane is often placed beneath the PCB. Image theory has been used in the literature to explain why conductive planes have this effect. The validity of using image plane theory in analyzing printed circuit boards is questionable because of the finite size of these planes. Furthermore, some effects of the conductive planes are due to the additional load which these planes put on the source. This effect is not predicted at all using image theory.

Introduction

The subject of this paper is to show that image plane theory should not be used to analyze printed circuit boards. This paper uses the **Electromagnetic Surface Patch (ESP)** code [1] and **Numerical Electromagnetics Code (NEC)** [2] to model various printed circuit configurations. By analyzing the behavior of these circuit configurations, the validity of applying the image theory to a printed circuit board is examined.

The ESP is a program based on the method of moments solution for antenna and scattering problems. This ESP program can analyze geometries consisting of perfectly conductive polygonal plates, thin wires, wire/plate junctions and plate/plate junctions. The program can compute the usual quantities of interest such as current distribution, input impedance, radiation efficiency and mutual coupling etc...

The NEC is a program used to analyze the electromagnetic response of different metal structures. It also uses the method of moments solution to analyze antenna configurations. NEC can not model thin plate, but it analyzes wire configurations more efficiently than ESP.

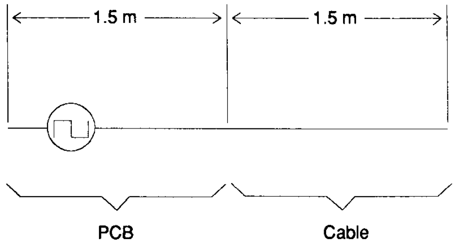

Figure 1: Circuit Model for PCB and its Attached Cable

Image plane and source impedance

A PCB without a ground plane and its attached cable can be modeled by the simple circuit diagram shown in Figure 1 [3]. Using perfectly conductive wire, a voltage source (1+j0 volts) at 50 MHz, and the dimensions shown in Figure 1, the ESP code calculates the magnitude of the current near the source to be **2.79 mA**. The real part of the input impedance is **343.73 ohms** and the radiated power is **1.34 mW**.

By adding a 5 by 5 meter perfectly conductive plate 0.1 meter under the model as shown in Figure 2a, the current magnitude increases to **26.25 mA** and the real part of the input impedance becomes **3.97 ohms**. The radiated power is **1.37 mW**. Notice that the image plane covers both the PCB and the cable and the radiated power is about the same as that of the model shown in Figure 1.

Attempting to apply image theory to the previous configuration results in the model shown in Figure 2b. The current magnitude calculated for this configuration, however, is **0.743 mA**. The real part of the input impedance is **0.7819 ohms** and the radiated power is **$2.16*10^{-7}$ W**.

Analysis of the configurations in Figures 2a and 2b show that image theory can not always be applied to finite-sized conductive

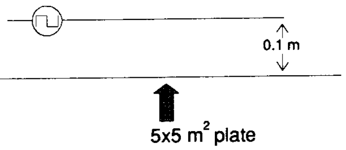

Figure 2a: Image Plane Under Both the PCB and the Cable

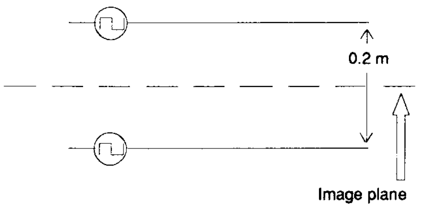

Figure 2b: Image Theory Model of Figure 2a

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plates. In this particular case, applying image theory (Figure 2b) to model the configuration in Figure 2a significantly underestimates the radiated power.

In Figure 3, the size of the conductive plate is reduced thus the cable part of the model is not above the conductive plate. The current magnitude 0.75 m from the end of the cable is **4.00 mA**. This compares with a current magnitude of **4.38 mA** calculated without the conductive plate.

A paper by German, Ott and Paul [4] correctly suggests that by properly connecting a cable to a conductive plate as illustrated in Figure 4a, the radiation due to currents on the cable can be significantly reduced. The application of image theory implies that the current on the cable should approach zero regardless of the dimensions of the circuits, plate, or cable (See Figure 4b.).

However, using the NEC code to analyze the image plane model illustrated in Figure 4b, the current magnitude 0.75 m from the end of the cable is found to be **3.37 mA**. This current is nearly as great as the current on the cable without the conductive plate. The image plane model does not predict the significantly reduced radiation measured by German, Ott, and Paul [4].

The reason that conductive plates under printed circuit boards reduce the currents on attached cables is because the sources of common-mode cable currents are shunted by the plates. As the circuit in Figure 5 illustrates, the current from the source has two possible paths. One path takes the current out onto the cables resulting in radiation. The other path couples current through the image plane bypassing the cables. With an ideal source similar to the source used in the ESP model, there is effectively very little source impedance. In this case, the voltage across the Z_{cable} is not significantly affected by the value of $Z_{shunt\ path}$. Thus the current on the cable will be nearly the same with or without $Z_{shunt\ path}$. Sources on printed circuit boards tend to have source impedances with magnitudes on the order of 100 ohms. There-

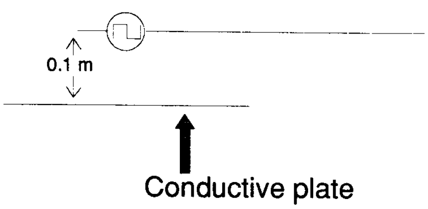

Figure 3: Conductive Plate Under the PCB Only

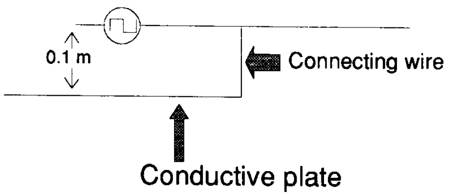

Figure 4a: Connecting the Cable to the Image Plane

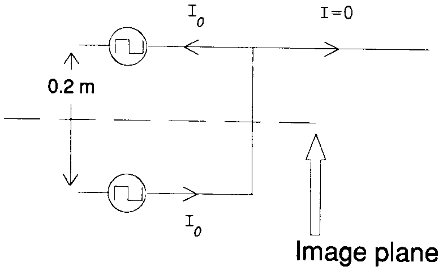

Figure 4b: Image Plane Model of Figure 4a

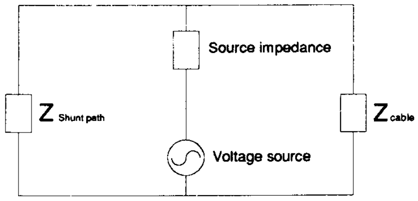

Figure 5: Real Source and Conductive Plate

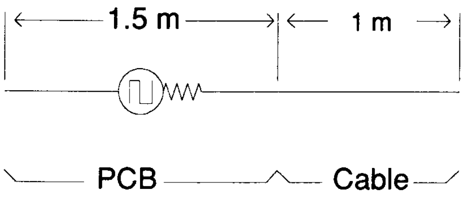

Figure 6: Circuit Model with Input Impedance

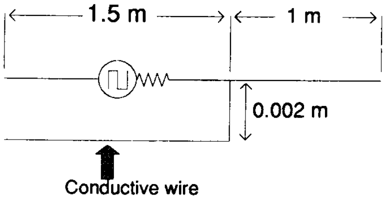

Figure 7: Circuit Model with Conductive Wire Under Source

fore, when $Z_{shunt\ path}$ is on the order of 100 ohms or less, the current through Z_{cable} will be significantly reduced.

The circuit models of Figure 6 and 7 were analyzed using the NEC program. A voltage source of 1 volt at 40 MHz was used in both circuit models and the wire radius was $5*10^{-4}$ m. Figure 8 shows the calculated current in the middle of the cable as a function of source impedance for both models. The cable current of the circuit model shown in Figure 6 gives expected results. The current is stable when there is little or no source impedance. As the source impedance becomes as large as the Z_{cable} , the cable current starts to decrease 20 dB/decade.

A wire connected under the source as shown in Figure 7, presents another path for the current flow. The wire provides a $Z_{shunt\ path}$ for the circuit model as shown in Figure 5. When the source impedance is low, the cable current is affected little by the new current path. The dimensions of the circuit configuration shown in figure 7 are chosen in such way that the $Z_{shunt\ path}$ is less than Z_{cable} as it would normally be for PCB configurations. Figure 8 shows that the new current path starts to reduce the cable current when the magnitude of the source impedance is close to the $Z_{shunt\ path}$. Since the $Z_{shunt\ path}$ is smaller than the Z_{cable} , the reduction of the cable current starts at a lower source impedance. Note that for source impedances greater than $Z_{shunt\ path}$, the cable currents are significantly reduced. The effectiveness of the shunt path depends on the cable impedance, source impedance, and shunt path impedance. The above analogy shows that a conducting plane placed under a PCB could reduce the current in the cable attached to the PCB by loading the real source on the PCB. This effect can not be adequately explained or predicted using image theory.

Consider the circuit model shown in Figure 9. A voltage source of 1 volt at 100 MHz is used. A wire antenna is positioned at different locations above the plate. Note that the distance between the plate and the wire antenna is small compared with other dimensions of the circuit much like a printed circuit board configuration. The radiated power of the wire antenna without a ground plane is $6.37*10^{-7}$ (watts). When the wire antenna source segment is placed above the center of the plate, the radiated power is $7.0*10^{-10}$ (watts). With the wire antenna aligned with the edge of the plate (d=0 m), the radiated power is $2.55*10^{-7}$ (watts). Moving the antenna in 0.03 meters from the edge reduces the radiated power to $1.74*10^{-7}$ (watts). 0.06 meters from the edge, the radiated power is $1.47*10^{-7}$ (watts).

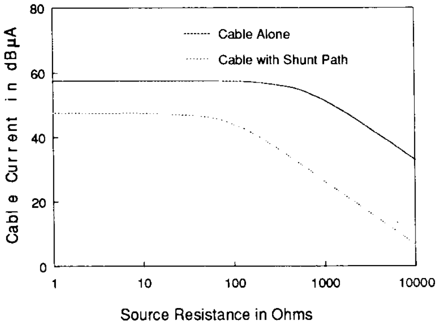

Figure 8: Cable Current vs. Source Impedance

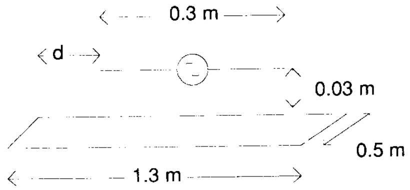

Figure 9: Short Source Segment Above a Conducting Plate

Clearly, the relative position of the antenna above the plate has a significant effect on the radiated power from this configuration. The dimensions and relative positions between a circuit and a finite ground plate are both important parameters of the radiation of the system. Image theory, which models the plate as an infinite plane cannot be applied to this type of configuration.

Concluding remarks

Image theory is based on infinite image planes. Approximating finite-sized conductive plates using image theory is not always valid.

In case of the printed circuit boards, the effectiveness of using an conductive plane for reducing currents on the cables can not be explained using image theory. The dimensions of the configuration and the source impedance of the printed circuit board are important parameters.

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