EMC Coupling to a Circuit Board from a Wire Penetrating a Cavity Aperture

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Introduction
The analysis of printed circuit boards (PCBs) is a problem of recent interest. For example, Ji et al. [1] used FEM/MoM method to analyze the radiation from a PCB, and the partial element equivalent circuit approach (PEEC) has been used to analyze PCB signals [2], [3]. The coupling of an incident wave to the interior of a cavity is another problem that has also been studied. For example, Carpes et al. [4] used FEM to analyze the coupling of an incident wave to a wire inside a cavity. Lecointe et al. [5] analyzed a similar problem using the MoMA methodology that efficiently combines both PCB analysis with field coupling into a cavity is developed here to analyze signal coupling to devices on a PCB from an exterior field that is incident on the cavity.

Of particular interest is the electromagnetic coupling from an exterior field to a circuit component on a PCB inside a conducting cavity (shield) via a direct connection from a wire or cable that penetrates an aperture in the cavity; indeed, this may often be the dominant coupling mechanism. An accurate and efficient analysis of this EMC problem requires the combination of PCB analysis with the analysis of field penetration into a cavity via a penetrating wire, and this is the subject of the present investigation.

In this paper, a hybrid technique for calculating the signal level at the input to a device on a PCB due to an exterior field incident on the cavity is discussed. The technique separates the analysis of the cavity/wire from that of the conductor trace on the PCB, thus enabling an efficient calculation. The method allows a Thévenin equivalent circuit to be obtained at any point on the PCB, such as a point where the PCB conductor trace meets a circuit component of interest on the PCB.

Analysis
Figure 1 shows a schematic diagram of the system under study. It consists of a feed wire that penetrates an aperture in a conducting cavity, and makes contact with a transmission line (TX) wire. For simplicity, a PCB at the bottom of the cavity has been replaced with an air substrate of thickness 1.0 mm, so that the TX wire running above the bottom of the cavity models a PCB trace. An open circuit is placed at the port of interest, where the open-circuit (Thévenin) voltage is to be calculated. (A similar analysis using a short circuit would be used to determine the Thévenin impedance.) A 50-Ω load is connected at one end of the TX line (which serves to model other circuits or components on the PCB).

The hybrid method introduced here separates the PCB analysis, using, e.g., transmission-line theory, from the full-wave analysis of the cavity and feed wire. The calculation steps are outlined below.
Step 1
The interior part of the problem is first considered. The aperture is shorted and replaced by a voltage source $V_g$ between the feed wire and the cavity wall. This voltage source is first set to 1 [V] for convenience (the actual voltage is determined in step 2). Also, the entire PCB is replaced by a frequency-dependent load impedance $Z_{in}$. This load impedance is obtained by analyzing the PCB problem separately to find the input impedance seen looking into the PCB trace at the point of contact with the feed wire. Simple transmission-line analysis can be used to obtain this input impedance for the structure in Fig. 1. The input impedance $Z_{in}$ seen looking into the feed wire from the aperture for this interior system is then calculated directly from the ratio of the source voltage (1 [V]) to the current at the voltage source. The current at the voltage source is calculated using a full-wave solver such as the MoM to analyze the corresponding interior problem, in which the feed wire is terminated at the bottom of the cavity with the impedance $Z_{in}$.

Step 2
In the exterior problem, the aperture is shorted and the impedance $Z_{in}$ is used to connect the exterior feed wire to the cavity. The voltage across the load $Z_{in}$ due to the incident plane-wave, $V_g$, is calculated using a full-wave analysis of the exterior problem, using, e.g., the MoM. The resulting voltage $V_g$ is then used as a scaling factor to obtain the correct currents on the feed wire (found from step 1 for an assumed 1 [V] aperture source voltage).

Step 3
The voltage at the open-circuit Thévenin port is calculated from the current on the feed wire at the contact point, using TX-line theory. In the TX-line model, the known current at the contact point is modeled as a current generator that feeds into the TX line at the contact point.

Step 4
To improve the accuracy of the open-circuit Thévenin voltage calculation, the contribution to this voltage from the fields inside the cavity produced by the feed wire current can also be considered. (This contribution is negligible if the substrate thickness is small.) This is done using distributed TX-line theory, in which the impressed electric field from the feed-wire current (calculated in the presence of the cavity) along the TX line is modeled as a distributed series voltage source along the TX line.

Results
Results are shown for three cases: (1) no feed wire (coupling from the plane wave to the TX-line is through the aperture only); (2) a feed wire penetrates the aperture and continues horizontally to make contact with the opposite cavity wall but does not contact the TX-line wire; and (3) the case shown in Fig. 1, in which the feed wire penetrates the aperture, bends down, and makes contact with the TX-line wire. The first two cases are included for comparison. The last case is done using the hybrid method discussed above, as well as by using a complete full-wave solution in which the entire problem is discretized using the MoM. The incident plane wave is assumed to have an electric field polarized in the same direction as the wire with a magnitude of 1 [V/m]. Figure 2 shows the magnitude of the voltage at the Thévenin port for the first two cases. Clearly, the presence of the feed wire has significantly strengthened the voltage at the Thévenin port.
Figure 3 shows results for case (3). The results show that the coupling from a wire penetrating the aperture with a direct connection to the TX-line is the strongest. Figure 3 also shows that the results from the hybrid method are in good agreement with those from the complete full-wave simulation.

References


Figure 1. Canonical structure used to obtain results. A feed wire penetrates an aperture in a conducting cavity and makes contact with a transmission-line wire. The rectangular aperture is 6×6 cm and is centered on the left side of the box. The feed wire is 0.25 mm in radius, and extends 20 cm inside the box before bending down to make contact with the transmission-line wire. The feed wire extends 12 cm beyond the outside of the cavity. The wire forming the transmission-line has a 0.383 mm radius. The open-circuit Thévenin port is located 10 cm to the left of the contact point, and the load is located 16 cm to the right of the contact point.
Figure 2. Thévenin voltage at the open-circuit port for the cases of radiation coupling through the aperture only (no feed wire) and coupling from a feed wire that penetrates through the aperture and contacts the opposite cavity wall (there is no connection to the transmission line).

Figure 3. Magnitude of the Thévenin voltage at the open-circuit port from a wire penetrating the aperture and connecting to the transmission line, as shown in Fig. 1.