Voltage-Driven EMI Algorithm

Subroutine: *voltage_driven_EMI().*

Purpose of Algorithm

Calculates the radiation due to a noise voltage driving a heatsink or signal trace against the cables attached to the board when the board is not within a shielded enclosure.

Basic Description of Algorithm

The electric fields that couple directly to attached cables from a trace or other structures can induce common-mode currents. This source mechanism is referred to as voltage-driven, since the magnitude of the common-mode current is proportional to the signal voltage and independent of the signal current. Fig. 1 illustrates the voltage-driven mechanism [1].

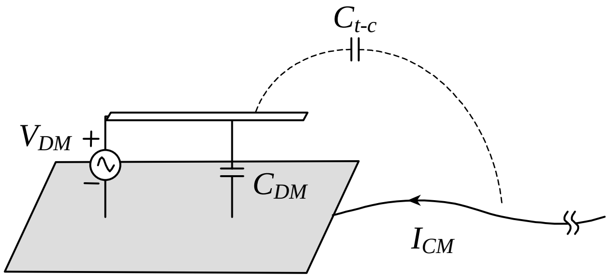

Fig. 1. The voltage-driven mechanism due to an attached cable

Assuming that the board is electrically small, the electric fields coupled to the attached cable can be represented by a capacitance between the trace and the cable, C_{t-c}. The common-mode currents on the cable result in radiated emissions. An equivalent circuit model is shown in Fig. 2.

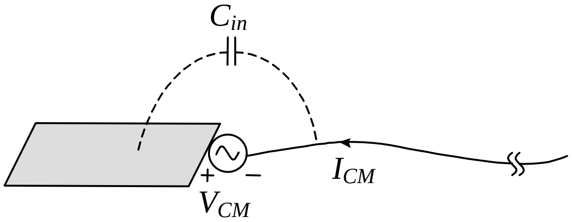

Fig. 2. The equivalent wire antenna modeling of the voltage-driven radiation

In general, the input impedance of a wire antenna is heavily dependent on its location along the wire. The current distribution, however, has approximately the same shape, regardless of the location of the source. This means that the radiation from a wire antenna is independent of the source location if we adjust the magnitude of the source to keep the magnitude of induced common-mode current the same. If the length of the attached cable in Fig. 1 is much longer than the board dimensions, the radiated emissions are dominated by the common-mode current on the cable and the effect of the common-mode current on the other parts of the antenna is negligible. Thus, the radiation from the board can be calculated by modeling the system as a wire antenna with an equivalent common-mode voltage source. The magnitude of the source must be adjusted so that the induced common-mode current is the same as that in the original configuration (Fig. 1). In the model (Fig. 2) developed here, the common-mode voltage source is located on the edge of the board, since there is an abrupt imbalance change at this location.

For the original configuration in Fig. 1, the induced charge on the cable is given by $C_{t-c}V_{DM}$ while that of the equivalent wire antenna model in Fig. 2 is $C_{in}V_{CM}$. Therefore, the magnitude of the common-mode voltage source can be expressed as

$$V_{CM} = \frac{C_{t-c}}{C_{in}} V_{DM} \tag{1}$$

where C_{t-c} is the total capacitance between the trace and the attached cable, and C_{in} is the input capacitance of the wire antenna model.

Assuming that the board is electrically small, the equivalent circuit model shown in Fig. 3 can be used to derive the input capacitance of the antenna model.

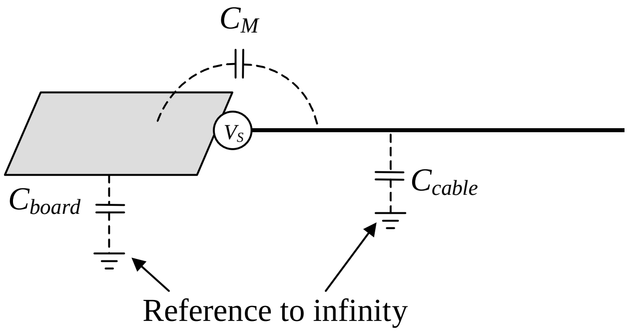

Fig. 3. Equivalent circuit model of the wire antenna model

The input capacitance is the parallel connection of the mutual capacitance C_M and two self-capacitances of the cable and board in series. Since the cable is much longer than the board, the series connection of two self-capacitances is approximately equal to the board capacitance, C_{board}. The input capacitance is given by:

$$C_{in} = C_M + \frac{C_{board} \cdot C_{cable}}{C_{board} + C_{cable}} \approx C_M + C_{board} \tag{2}$$

For typical board-cable geometries, the mutual capacitance is much smaller than the board capacitance C_{board}. Thus, the magnitude of the induced current is limited by the board capacitance C_{board}, not by the mutual capacitance C_M if the cable is thin and much longer than the board dimensions. Therefore, the input capacitance of the wire antenna model can be approximated as

$$C_{in} \approx C_{board} \approx 8\varepsilon_o \sqrt{\frac{\text{Board Area}}{\pi}} \tag{3}$$

Assuming that the dimensions of the system are electrically small, the current induced on the attached cable at the source position is determined by the input capacitance as:

$$I_{cable} \approx 2\pi f \times C_{in} \times V_{CM} = 2\pi f \times C_{t-c} \times V_{DM} \tag{4}$$

In the general case, the total capacitance between the trace (or heatsink) and the attached cable $C_{t\text{-}c}$ is approximately given by:

$$C_{t-c} \approx C_t \text{ or } C_{t-c} \approx C_H \tag{5}$$

Where C_t is the self capacitance of the trace, C_H is the self capacitance of the heatsink, and the self capacitance of the trace and the heatsink are given by

$$C_H = 4\pi\varepsilon_o \sqrt[3]{\text{Volume of heatsink}} \tag{6}$$

$$C_t = \frac{6.189}{\pi} \cdot \frac{h}{W} \cdot \frac{C_{DM} l_t}{\ln\left[1 + 3.845\left(\frac{L}{W}\right)\right]} \tag{7}$$

where h is the height of the trace over the return plane, l_t is the length of the trace, and L and W are the length and width of the board, respectively. C_{DM} is the capacitance of the strip with an infinitely wide return plane, which is given by [2][3]

$$C_{DM} = 2\pi\varepsilon_o \left\{ \ln\left[\frac{F_1 \cdot h}{a} + \sqrt{1 + \left(\frac{2h}{a}\right)^2} \right] \right\}^{-1} \tag{8}$$

where

$$F_1 = 6 + (2\pi - 6)\exp\left\{ -\left(30.666 \times \frac{h}{a} \right)^{0.7528} \right\} \quad . \tag{9}$$

For simplicity, considering an isotropic antenna, the radiated power and the maximum radiated field is then given by:

$$P_{rad} = \oiint \frac{1}{2}\frac{|E|^2}{\eta_0} ds = \frac{4\pi r^2 |E|^2}{2\eta_0} \equiv \frac{1}{2} I_C^2 R_{rad} \tag{10}$$

$$E = \frac{I_C}{r}\sqrt{30R_{rad}} = \frac{2\pi f \times C_{t-c} \times V_{DM}}{r}\sqrt{30R_{rad}} \quad . \tag{11}$$

Assuming a typical, worst-case radiation resistance of 100 ohms, the electric field strength 3 meters from the source is,

$$E = 115 \times f \times C_{t-c} \times V_{DM} \,. \tag{12}$$

Assumptions

- The board is not within a shielding enclosure.
- The board is electrically small.
- There is at least one cable attached to the board. And the cable length is much greater than the board dimension.
- The radiation impedance of the antenna is approximately 100 ohms.

Implementation Details

The function first checks whether there is any cable attached to the board. If there is no cable attached to the board, the function will stop and return a null. Otherwise, for each frequency or frequency block, the function will check to see whether the board is electrically large. The function will only calculate the radiation when the board is electrically small.

Next, the function will go through all the nets on the top or bottom layer of the board. The function calculates the self-capacitance of the trace. Then the function calculates the radiated EMI due to the noise coupled from the trace to the cable. If the radiated field is greater than 10 µV/m, the algorithm stores it with the net name and frequency. The total radiated field due to the noise coupled from the trace to the cable is calculated as the maximum field radiated due to any one trace.

Next, the algorithm goes through all of the components on the board for each frequency or frequency block of interest. The algorithm only considers the components with a heatsink. For each component under evaluation, the algorithm determines the maximum voltage *V(f)* on any signal net connected to the component, the number of the nets reaching this value, N, and the number of ground pins. The noise voltage driving the heatsink and the board is estimated to be,

$$V_{source} = V(f) \times N \big/ \text{(number of ground pins)} \tag{13}$$

Next, the algorithm calculates the radiated field due to the noise source coupled from the heatsink to the cable. If the radiated field is greater than 10 µV/m, the algorithm stores it with the component name and the frequency. The total radiated field due to the noise coupled from the heatsink to the cables is calculated as the maximum field among the radiated fields due to each heatsink. Finally, the total radiated field due to the voltage driven sources is calculated as the maximum trace or heatsink radiation as calculated above.

References

[1] Hwan Woo Shim, "Development of Radiated EMI Estimation Algorithms for PCB EMI Expert System", Ph.D Dissertation, University of Missouri-Rolla, 2004.

[2] K. C. Gupta, R. Garg and I. Bahl, Microstrip Lines and Slot Lines, 2nd ed., Artech House, 1996.

[3] Frank Schnieder and Wolfgang Heinrich, "Model of thin-film microstrip line for circuit design," IEEE Trans. Microwave Theory and Techniques, vol. 49, no.1, pp. 104-110, Jan. 2001.