Current-Driven Common-Mode Radiation Algorithm

Purpose of Algorithm

To estimate the radiation due to the common-mode voltage difference between potential antennas on the board.

Basic Description of Algorithm

Current flowing on the return plane of a PCB induces a common-mode voltage capable of driving current onto the cables and heatsinks attached to the board [1, 2]. The amplitude of this common mode voltage is estimated by another algorithm (see: Grid Point Voltage Algorithm). The algorithm described here estimates the maximum radiated electric field that may result due to the common-mode currents induced on attached cables and heatsinks [3].

Fig. 1 illustrates a typical current-driven common-mode radiation mechanism driven by cables attached to the board. In practice, these antennas could be cables, heat sinks or other metal structures.

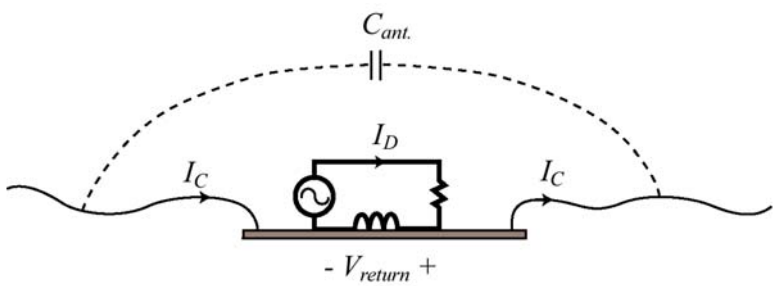

Fig. 1. A simple configuration demonstrating current-driven common-mode radiation

At present, three different EMI antennas are considered – cable-to-cable, cable -to-board and cable-to-heat sink.

Cable-to-Cable Algorithm

This algorithm calculates the radiated field by a pair of cables connected to the board. For convenience, consider an isotropic radiator. Then, the relation between total radiated power and the voltage across the antenna port is

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

where, $\eta_o = 120\pi$. The maximum radiation generally occurs when the EMI antenna resonates. At the resonant frequency, the input impedance of the antenna is equal to the radiation resistance, R_{rad}. Therefore, the common-mode current can be calculated as,

$$I_C = \frac{V_{return}}{R_{rad}} \tag{2}$$

Combining (2) and (1), the maximum E field is

$$E = \sqrt{\frac{30}{R_{rad}}} \cdot \frac{V_{return}}{r} \tag{3}$$

The radiation resistance, R_{rad}, is chosen to be 100 ohms, which is approximately the input impedance of a typical worst-case resonant dipole antenna [4]. The default distance between the DUT and test antenna is 3 meters. The estimate is multiplied by 2 to account for the effect of making this measurement in a semi-anechoic environment. The overall radiation is therefore calculated using the equation,

$$E \approx 2 \times \sqrt{\frac{30}{100}} \cdot \frac{V_{return}}{3} = 0.365\, V_{return} \tag{4}$$

Cable-to-Board Algorithm

Even if only one cable is connected to the board, common-mode current can be drawn against the board itself. This algorithm is similar to the cable -to-cable algorithm, but the common-mode current is limited by the capacitance, C_B, between cable and the board. Therefore, common-mode current is given as,

$$I_C = \frac{V_{return}}{\sqrt{R_{rad}^2 + 1/(\omega\, C_B)^2}} \tag{5}$$

By plugging (5) into (1) and using the same approximations in cable-to-cable algorithm, the radiated emissions are calculated as,

$$E \approx 0.365 \times \frac{100\, V_{return}}{\sqrt{100^2 + 1/(\omega\, C_B)^2}} \tag{6}$$

The capacitance C_B is approximated as the absolute capacitance of the board. This is estimated by using the equation

$$C_B \approx \varepsilon_o \times \sqrt{A} \tag{7}$$

where, A is the area of the board and ε_o is the permittivity of free-space.

Cable-to-Heat Sink

This algorithm calculates the radiated field by common-mode current in an attached cable driven with respect to a heat sink. Figure 2 illustrates the radiation mechanism.

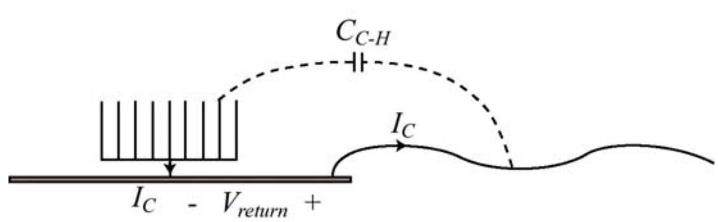

Figure 2. Radiation mechanism of cable-to-heat sink algorithm

The capacitance of an EMI antenna is approximated as the absolute capacitance of the heat sink,

$$C_{C-H} \approx C_H = 4\pi\, \varepsilon_o\, \sqrt[3]{Volume\ of\ \ a\ heat\ sink} \tag{8}$$

As in the cable-to-board algorithm, the common-mode current is limited by the radiation impedance and the capacitance of the radiating structure. The radiated field is calculated as,

$$E \approx 0.365 \times \frac{100\, V_{return}}{\sqrt{100^2 + 1/(\omega\, C_H)^2}} \tag{9}$$

Assumptions

- The measurement position is considered to be in the far-field. Actually, this is not the case for a 3-meter measurement at low frequencies.
- The EMI antenna is assumed to be isotropic. The directivity is not taken into account.
- The common mode current is estimated on condition that an EMI antenna resonates. Estimate may be high.
- The radiation resistance is approximated as the input impedance of a resonant wire antenna. The estimate may be high (or, in rare circumstances, low).
- The capacitances of the antennas for cable -to-board and cable -to-heat sink mechanisms are determined by absolute capacitances of a board and a heat sink. Actual capacitance depends on the details of the geometry and may be frequency dependent.
- The algorithm does not sum the fields due to multiple sources. If more than one antenna is driven simultaneously, the radiated fields will be higher than reported.

Implementation Details

The voltage variation on the board between any two locations is determined by the grid point voltage algorithm, which is described in another document. The voltage differences between connectors and heat sinks are determined by identifying the voltage grid points that are closest to them. This is the source voltage for the corresponding EMI antenna.

The radiated electric field for each algorithm is calculated using Equations (4), (6) and (9). Since it is unlikely that more than one antenna will actually be resonant at a given frequency, fields due to different antennas are not summed. The overall emission reported by the current-driven common-mode radiation algorithm is equal to the field strength of the strongest source.

References

[1] D. M. Hockanson, J. L. Drewniak, T. H. Hubing, T. P. Van Doren, F. Sha, and M. Wilhelm, "Investigation of Fundamental EMI Source Mechanisms Driving Common-Mode Radiation from Printed Circuit Boards with Attached Cables," *IEEE Trans. on Electromag. Comp.*, vol. 38, no. 4, Nov. 1996, pp. 557-566.

[2] D. M. Hockanson, J. L. Drewniak, T. H. Hubing, T. P. Van Doren, F. Sha, C. W. Lam, and L. Rubin, "Quantifying EMI Resulting from Finite-Impedance Reference Planes," *IEEE Trans. on Electromag. Comp.*, vol. 39, no. 4, Nov. 1997, pp.286-297.

[3] Navin Kashyap, *An Expert System Application in Electromagnetic Compatibility*, M.S. Thesis, University of Missouri-Rolla, 1997.

[4] Constantine A. Balanis, *Antenna Theory Analysis and Design*, 2nd ed., 1997.