Radiation by I/O Coupling Algorithm

Subroutine: *coupling_to_IO*(io_net). Returns the radiated electric field due to signals coupled to input/output (I/O) nets and stores the names of the source and I/O nets if the field at 3 meters is greater than 10 *m*V/m.

Purpose of Algorithm

To estimate the radiation due to signals coupled into I/O nets from other parts of the board.

Basic Description of Algorithm

High frequency signals can couple to I/O nets that carry the coupled energy away from the board. The common-mode currents induced on cables attached to I/O nets can result in significant radiated emissions. This emissions mechanism is illustrated in Figure 1.

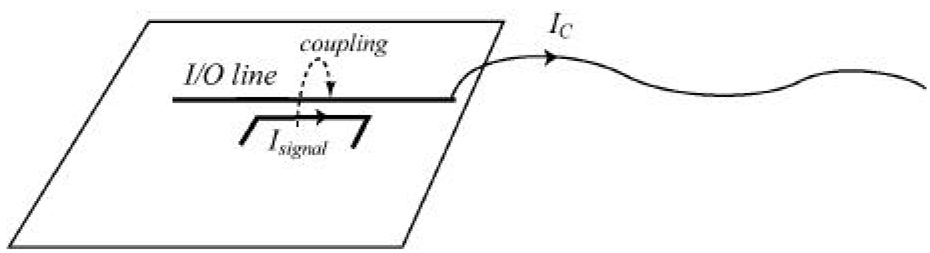

Figure 1. Signal coupling to an I/O line.

Estimation of induced voltage magnitude on an I/O net

If the signal segment and I/O segment are on different layers separated by conducting planes, the algorithm ignores any coupling between segments. Otherwise, the I/O net is divided into segments that are 2 cm or shorter and the following procedures are applied.

The noise signals induced on an I/O line segment due to capacitive and inductive coupling are given as [1]

$$V_{elec} = w\, C_m \times V_{signal} \times l_{eq} \times Z_{rec} \approx w\, C_m \times V_{signal} \times l_{eq} \times 100 \quad (1)$$

$$V_{mag} = w\, M \times I_{signal} \times l_{eq} \quad (2)$$

where, C_m and M are the mutual capacitance and inductance per unit length between the two segments (refer to [2] for complete expressions). V_{signal} and I_{signal} are the voltage and current on the signal traces. l_{eq} is the equivalent length of a pair of parallel segments (refer to [3] for details). C_m and M are calculated by the function *mutual_cap_ind*(IO_seg, dist1). dist1 and l_{eq} are calculated by the function *lies_between_parallels*(IO_seg, R2_net or R3_net). Z_{rec} is the impedance of the parallel combination of the source and load impedances.

The total noise voltage coupled to the I/O net is calculated by summing the induced noise voltage components on each segment of the IO net. The noise voltages induced by both capacitive and inductive coupling are calculated for each I/O net. But, only the maximum of them (V_{mag} or V_{elec}) is stored as the noise voltage (V_n) used to estimate emissions.

Radiated emission by attached cables

Considering an attached cable as an isotropic radiator, conservation of power implies that,

$$\oint\!\!\oint \frac{1}{2}\frac{|E|^2}{\eta_o} ds = 4\pi r^2 \left(\frac{1}{2}\right)\frac{|E|^2}{\eta_o} = \frac{1}{2} R_{rad} I_{CM}^2 \tag{5}$$

where, η_o is the free-space wave impedance ($\cong 120\pi\ \Omega$) and R_{rad} is the input impedance of a lossless resonant wire antenna. The algorithm assigns a typical worst case value of 100 ohms to R_{rad}. The common-mode current (I_{CM}) is calculated by

$$I_{CM} = \frac{V_n}{Z_{ant}}. \tag{6}$$

Because the expert system normally has no information about the construction or orientation of the attached cable, Z_{ant} is determined by the configuration of the connector to which the cable is attached. In an unshielded resonant cable with no return current conductor, the input impedance would be equal to the radiation resistance (~80 ohms). The presence of a nearby return current conductor would reduce the common-mode current (i.e. increase Z_{ant}) moderately. A well-shielded cable with a moderately good shield connection might reduce the common-mode current by 20 dB (i.e. Z_{ant} increased by a factor of 10). If the connector is shielded, Z_{ant} is assumed to be 800 ohms. Otherwise, the number (N) of ground pins in the connector is counted and Z_{ant} is assigned to be the minimum of 800 ohms or 80(N+1) ohms.

Radiated fields are measured over conducting plane, which can increase emissions by factor of two. Finally, the estimate of radiated emissions at 3 meters is calculated by plugging all the above constraints into equation (5) and solving for the magnitude of the electric field strength.

$$E_{rad} = 40\frac{V_n}{Z_{ant}} \tag{7}$$

Assumptions

- Radiated fields are calculated in the far field.
- Signal and I/O nets are assumed to be weakly coupled. The length of net is assumed to be electrically short and the mutual inductance (capacitance) between nets is assumed to be much smaller than self inductance (capacitance) of each net.
- Any phase difference between components of the voltage coupled to an I/O net is ignored. This may cause the calculated coupling from multiple sources to be higher than the actual coupling.
- The polarity of the radiated field is not considered.
- The directivity of the radiating structure is ignored.
- The input impedance of the EMI antenna is assumed to be that of a resonant wire antenna. Although most test procedures require cables to be oriented for worst case emissions, which should occur near resonance, the actual value of the input impedance will depend on the length and orientation of the cable.

Implementation Details

Any signal coupled to I/O nets may contribute to common-mode current on the attached cable. Therefore, this algorithm considers all extended I/O nets (including nets connected to connectors through series passive devices). The subroutine called *create_extended_IO_array*(io_net) identifies the extended I/O nets and creates a list of extended I/O nets.

For all extended I/O nets, the algorithm calculates the coupled noise voltage on each segment using the algorithm described above. Only signal nets with a high radiation classification (R2 or R3) are taken into account. Otherwise, the coupling from the signal nets is neglected.

The algorithm goes through all I/O nets on the board. For each extend I/O net, the estimate of radiated electric field (from Equation 7) is stored. If the estimate due to an I/O net is greater than 10 mV/m, the name of I/O net is stored to report a possible EMI problem. Radiation by coupling into I/O nets for each frequency is calculated using the root mean square of all the estimates in the extended list of I/O nets as

$$E_{total} = \sqrt{E_{I/O\,net\,1}^2 + E_{I/O\,net\,2}^2 + \cdots + E_{I/O\,net\,N}^2} \quad \text{for each frequency} \qquad (8)$$

References

[1] C. Paul, *Introduction to Electromagnetic Compatibility*, New York: Wiley, 1992.

[2] Mutual inductance and capacitance summary.

[3] Coupling segment algorithm summary.