ANALYTICAL SIMULATION OF RADIATED EMISSION FROM POWER BUS NOISE ON PCB WITH LINEAR MACRO-MODEL OF IC/LSI

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ABSTRACT

Modeling and simulation of radiated emission from a digital printed circuit board (PCB) are discussed. Analytical electromagnetic model of a multi-layer PCB and a linear macro-model of IC/LSI are combined to simulate power bus noise. The authors apply the power-current model of IC/LSI to a power-decoupling simulation; internal decoupling technique with a bypass capacitor and a decoupling inductor is tested on an IC module. The simulated far-field EMI spectra correspond with the experimental results within 6 dB. For practical simulation, the power-bus model is expanded to a general shape of PCB consisting of some rectangular segments.+

INTRODUCTION

High-speed simulation of EMI is strongly required as a designing tool of digital equipment. Many works have been done on developing simulation techniques [1]-[3]; however, most of numerical methods, such as FDTD or MoM, are not relevant for practical simulation, since the scale of calculation tends to be large and in consequence calculation with those methods need long time. The authors have been developing an EMI simulator that is based on a combination of analytical electromagnetic simulation of printed circuit boards (PCBs) and linear macro-models of IC/LSI [4]-[9].

LINEAR MACRO-MODEL FOR POWER CURRENT OF IC/LSI

The device model gives RF current on power pins of IC/LSI as a noise excitation source. The model consists of a linear internal circuit and an internal equivalent current source as shown in Fig. 1; both the internal equivalent circuit and the current source are derived from direct measurements of the device [5]-[7].

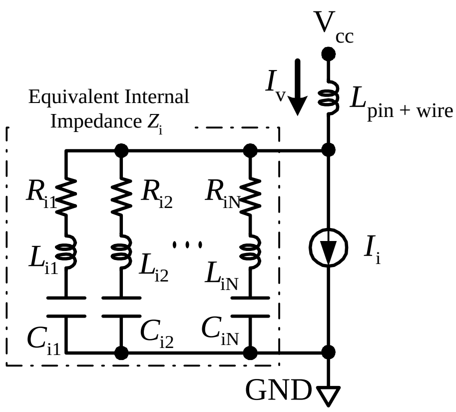

Fig. 1. Linear macro-model for power current.

Table 1. Equivalent internal impedances

	Z_{I1}	Z_{I2}
R_i [Ω]	2.5	0.1
L_i [nH]	5.6	0.5
C_i [pF]	68	30
$L_{pin+wire}$ [nH]	19	

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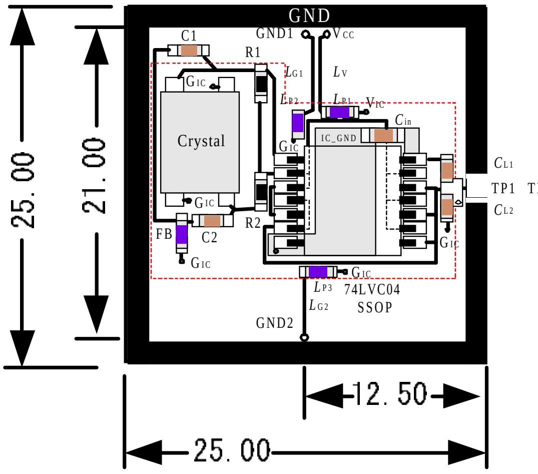


Fig. 2. Configurations of an evaluation module.

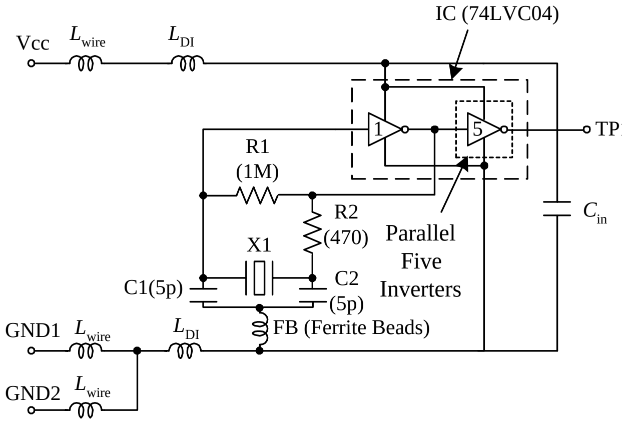


Fig. 3. Equivalent circuit of the evaluation module.

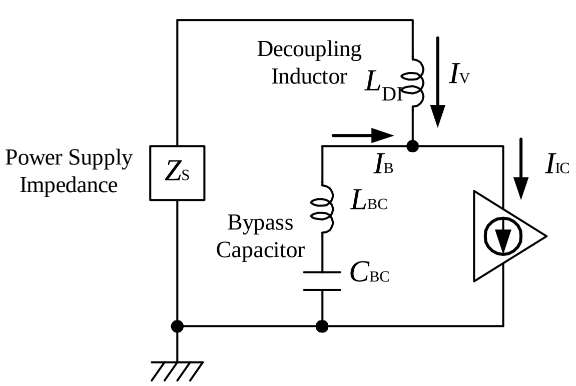


Fig. 4. Power decoupling scheme.

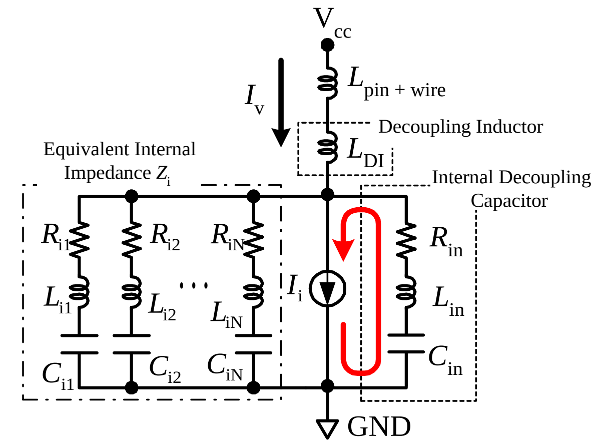


Fig. 5. Internal decoupling in package.

To validate the macro-model, we designed an evaluation module, here we call “IC module”, as shown in Fig. 2 and 3. The module consists of a CMOS 6-inverter IC and a crystal oscillator on a 1-inch square four-layer PCB with some passive components [9]. It is designed to evaluate internal power decoupling technique on package. As shown in Fig. 4, the operation current of IC is supplied from either DC power supply or the bypass capacitor mounted close to the IC. The high-frequency (RF) component of power current drives the power and ground planes in PCB and causes EMI. If we bypass the RF current by an internal decoupling capacitor, the EMI can be reduced. Moreover, if we add some inductance in series with a power-pin connection as shown in Fig. 5, it also suppresses the RF current. On the IC module, pads for the internal decoupling capacitor, C_{in}, and the internal decoupling inductor, L_{DI}, are prepared. Table 1 shows the equivalent circuit parameters of the IC module without C_{in} and L_{DI}.

POWER-BUS EMI SIMULATION

Radiated emission from a power bus in multi-layer PCB was simulated with the PCB power bus model and the device model. The power bus model treats the power/ground planes in a PCB as a parallel-plate resonator and a full cavity-mode expansion model is adopted to obtain the frequency characteristics as an EMI antenna [3][4]. The characteristics are expressed in an impedance Z-matrix, so that the simulation with some active and passive devices can be treated as a circuit analysis. The IC module and a battery module are mounted on an evaluation board shown in Fig. 6, and radiated emission in a semi-anechoic chamber is measured and simulated; the horizontal distance between the board and the antenna is 3 m, the height of the antenna is 1.5 m, and the height of the board is 1 m. Peak values are recorded while the board rotating on a turntable through 360°. Fig. 7 shows the results with no internal decoupling.

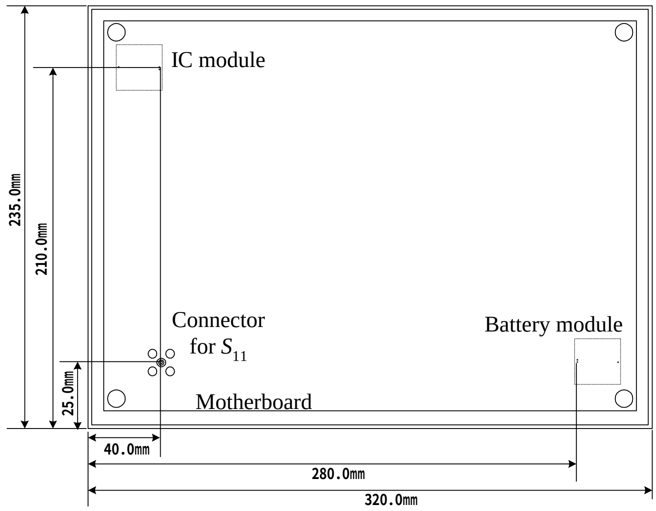


Fig. 6. Evaluation board; two layer FR4, with rectangular Power and ground planes.

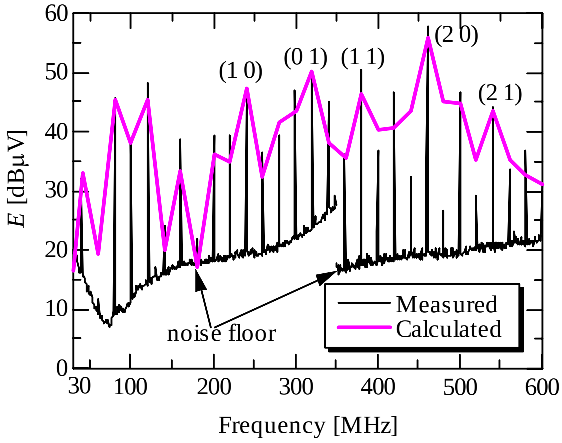
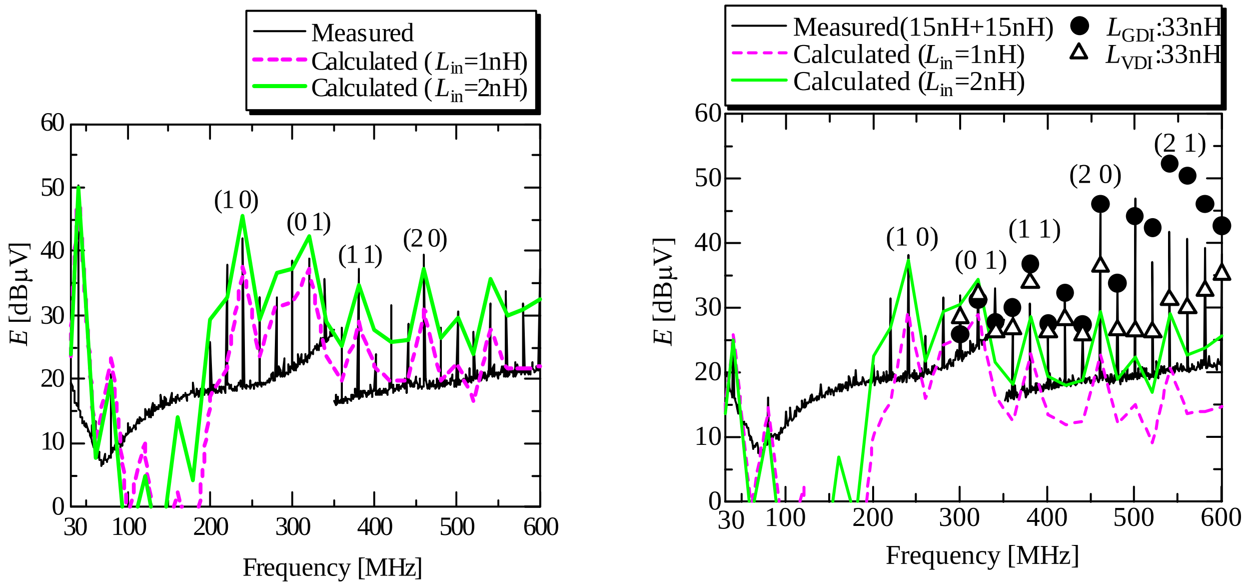


Fig. 7. Simulated and measured far-field EMI with no internal decoupling.



(a) C_{in} = 1000 pF.

(b) C_{in} = 1000 pF, L_{DI} = 30nH(33nH).

Fig. 8. Far-field EMI with an internal decoupling capacitor and internal decoupling inductor.

Internal bypass capacitance of 100 or 1000 pF and/or internal decoupling inductances are tested. In low frequency region up to about 350 MHz, the linear equivalent circuit model is quite accurate and effective; the simulated EMI spectra correspond with the experimental results within 6 dB as shown in Fig. 7, 8. However, even in this region we can also see that very small parasitic inductance, such as trace inductance of 1 nH, can affect the results and makes few dB of difference. In higher frequency range above 350 MHz, the situation comes to be more critical; few pF of stray capacitance can affect the results. Fig. 8 (b) is one example we see the effect of stray capacitance.

FAST SIMULATION OF POWER/GROUND RESONANCE WITH SEGMENTATION METHOD

We extend the power-bus model for a single rectangular PCB to a general shape consisting of some rectangular segments [8]. The resonant characteristics of the power/ground planes in PCBs are simulated, using the so-called segmentation method. For example the structure of Fig. 9 is decomposed into two rectangular segments. The Z-matrix

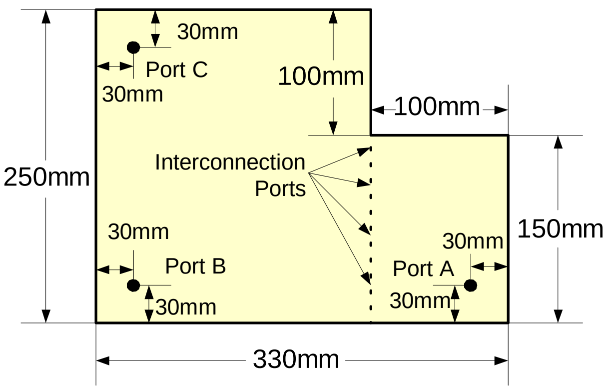


Fig. 9. Evaluation PCB for Segmentation of power/ground planes.

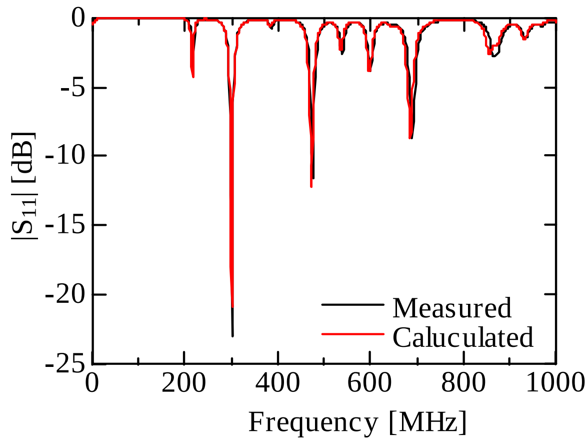


Fig. 10. Resonance characteristics.

elements in each of the rectangle is expressed with the full cavity-mode expansion, and are connected on the common edge with some virtual interconnection ports. We can put excitation ports and component ports at any position, and calculate the overall Z-matrix easily for the ports together with the virtual ports. We do not need any other elements for calculation, so the order of the matrix can be smaller than that in other numerical simulation method.

Fig. 10 shows an example of calculated and measured input reflection characteristics $|S_{11}|$ observed at the port B in Fig. 9, with the number of interconnection ports $N = 20$, which demonstrates the usefulness and accuracy of our fast algorithm and the segmentation method.

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