EMI Prediction Methodology for PCB Excited by Switching Noise of IC

Hyun Ho Park[#1], Jin-Hwan Jung[*2], Tae-Sun Jang[#3], Sang-Tae Han[#4], Soo-Jeong Woo[*5], Seung-Hyun Song[+6], Hark-Byeong Park[#7]

[#]*Mechatronics & Manufacturing Technology Center, SAMSUNG ELECTRONICS Co., LTD.*
Suwon, Korea

[*]*CS Managerment Center, SAMSUNG ELECTRONICS Co., LTD.*
Suwon, Korea

[+]*SYSTEM LSI Department, SAMSUNG ELECTRONICS Co., LTD.*
Yongin, Korea

{[1]hyunh.park, [2]world.jung, [3]taesun.jang, [4]sangtae.han, [5]soojeong.woo, [6]seunghyun.song, [7]hb111.park}@samsung.com

***Abstract* — This paper describes a methodology to predict radiated emission from the printed circuit boards (PCBs) excited by switching noise of integrated circuits (ICs). Radiation characteristics of PCBs were simulated by using commercial 3D full-wave softwares. IC's switching noise was obtained by measurement. The radiated emission can be calculated by these two factors. To verify the calculation, test PCBs composed of power and ground plane were designed and measured in a 3 m semi-anechoic chamber. The calculated radiated emission showed a good agreement with the measured results.**

Key words: electromagnetic interference, radiated emission, switching power noise, radiation efficiency.

I. Introduction

Recently, as a number of integrated circuits (ICs) and printed circuit boards (PCBs) are operated speedily and packed densely, it is getting difficult to solve electromagnetic interference (EMI) problems. In order to solve these problems, PCB engineers started to consider EMI characteristic of chip as well as of PCB when they design high-speed PCB and digital devices. Power noise on PCB generated by chip switching is primary one of EMI sources. To calculate accurate power noise, it is necessary to model both chip and PCB together through simulation.

As far as this matter is concerned, some researches are published: EMI modeling method at IC level [1] [2], calculation method by modeling of PCB and components including chip and package together in order to calculate PCB power noise generated by chip switching [3], and prediction method for radiated emission due to IC's power noise by simulation and measurement recently [4] [5] [6]. If there is a certain method to predict EMI at an early stage of IC and PCB designs, it is really useful to reduce design time and cost.

This paper, based on the proposed method of Sudo in [5], presents a specific procedure by simulation to predict radiated EMI at PCB level if measured chip noise is given. Our procedure was verified by test PCBs. Verification result showed a good agreement between the prediction by simulation and the measurement.

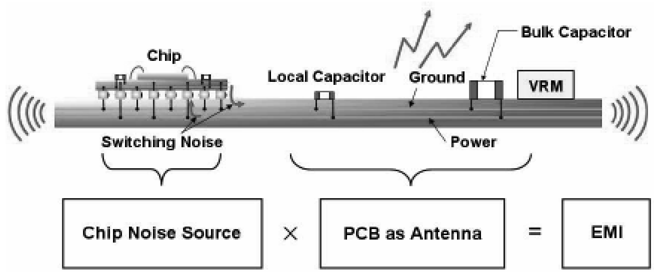


Fig. 1 Mechanism of radiated EMI from PCB with IC

II. Methodology for EMI Prediction

In general, radiated EMI from PCBs can be characterized by noise source and PCB antenna as shown in Fig. 1. Although ICs themselves are not typically efficient radiator due to their small size, ICs are often the EMI source when they meet antenna such as PCB traces, power/ground planes, or cables. In this paper, power bus structure is only antenna we considered.

When ICs are switching at high speed, voltage fluctuations occurred on power distribution network of PCB. This kind of power noise radiates through PCB edge due to resonance of power bus structure. To put it simply, therefore, IC's switching noise and PCB radiation efficiency are regard as an input function and an EMI transfer function, respectively. Once these two factors are well defined, it is possible to predict the radiated emission from the PCB effectively. This paper presents prediction methodology of radiated EMI by using PCB radiation characteristics derived from measured switching noise source. This methodology is verified by measured result of test PCBs.

A. *Configuration of Test PCB*

Test PCB consist of only two layers with power and ground planes with a copper conductivity of 5.76×10^{7} S/m as shown in Fig. 2. It is 140 mm on each side and 1.6 mm thickness bet-

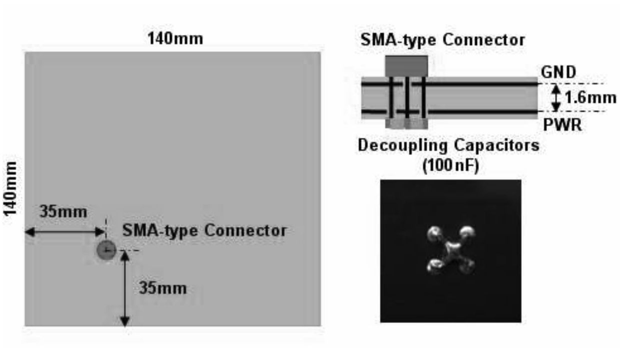


Fig. 2 Configuration of test PCB

ween planes. It has a dielectric constant of 4.3 and a loss tangent of 0.02. One SMA-type connector, to excite voltage source from signal generator or arbitrary waveform and function generator (AWG), was attached on upper ground plane at (35 mm, 35 mm) from the edge of PCB. Decoupling capacitors (decaps) of 100 nF were mounted on bottom plane to change impedance of power bus. We made two kinds of PCB; one has one decap and the other has four decaps.

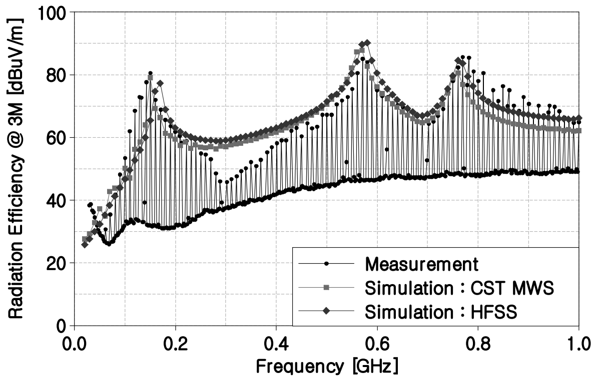
B. Simulation of Radiation Efficiency

To simulate radiation efficiencies of test PCBs, the commercial 3D full-wave tools such as Ansoft HFSS and CST MWS were used. Although 3D full-wave simulations need to take long time to solve, they can calculate the radiation characteristic of arbitrarily shaped PCB accurately.

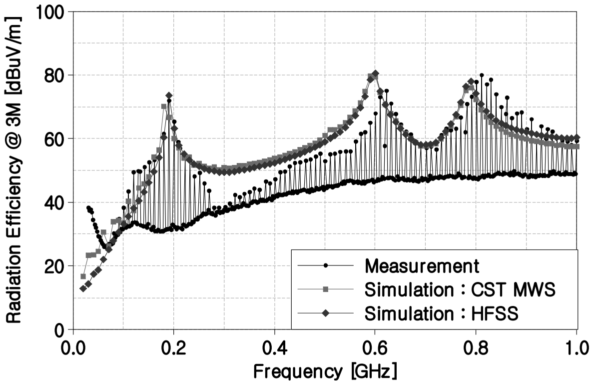
To verify the simulation, far-field emission of test PCB was measured in a 3m semi-anechoic chamber. The antenna located at 1 m height horizontally and vertically. The test PCB placed on 0.8 m height table. Peak values were observed by using a spectrum analyzer up to 1 GHz while the test PCB on table was turned around by 360^{o} rotation. 10 MHz frequency sweep signal with 0 dBm power from signal generator excited test PCB.

The test result of comparison is shown in Fig. 3. According to the results of test PCBs with one decap and with four decaps, the comparison between simulation and measurement has a good agreement in terms of both amplitude and resonance frequencies. Simulation results of Ansoft HFSS and CST MWS also have a fairly good agreement each other.

When test PCB had one decap, radiated emission peaks occurred at near resonance frequencies of 160, 560, and 760 MHz which caused by parallel plate structure of PCB with decoupling capacitors. When test PCB had four decaps, the resonances occurred at 180, 600, and 800 MHz. Due to adding decoupling capacitor, resonance frequencies were slightly moved to higher frequencies. This result can be confirmed by considering impedance change by decoupling capacitors as shown in Fig. 4. Moreover, radiated emission level in the case of four decaps is 10 dB lower than that in the case of one decap due to the impedance change. Simulated radiated emissions are overestimated about 10 dB around 300 MHz and also underestimated above 800 MHz compared with measured results. The reason may be that the reflection effect on the ground floor in chamber did not take into account in the



(a) Test PCB with one decap



(b) Test PCB with four decaps

Fig. 3 Radiation efficiency of test PCBs

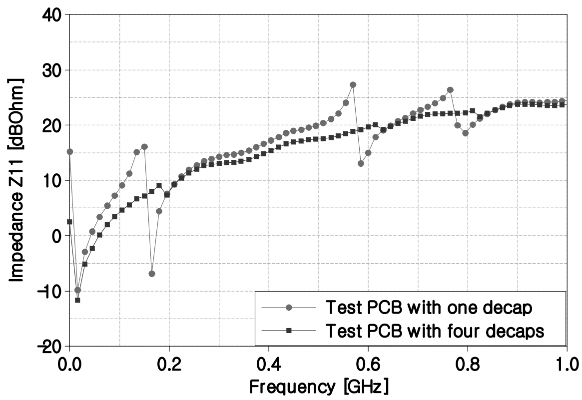


Fig. 4 Measured impedance profiles of test PCBs

simulation. These differences will affect the accuracy of prediction of radiated EMI in the latter.

C. Determination of Noise Source

Switching chip mounted on power distribution network of PCB represents an equivalent circuit as shown in Fig. 5. Internal activities of chip can be modeled by both internal current source and equivalent internal impedance through the Norton equivalent circuit. It is critical to decide the internal noise source accurately for EMI prediction.

Normally, chip designers can calculate internal noise source by IC level simulation because internal circuit inside of

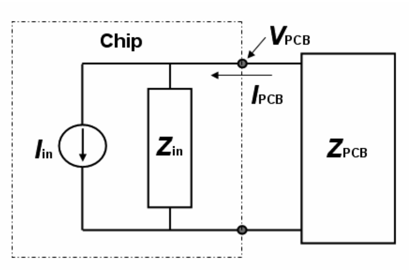


Fig. 5 Equivalent circuit to decide noise source

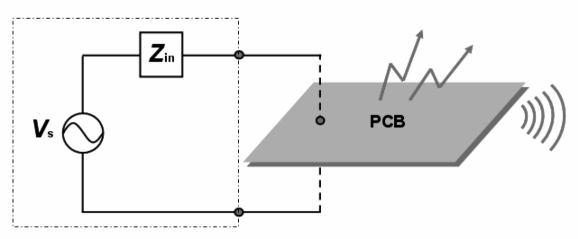


Fig. 6 Equivalent circuit to predict radiated EMI from PCB

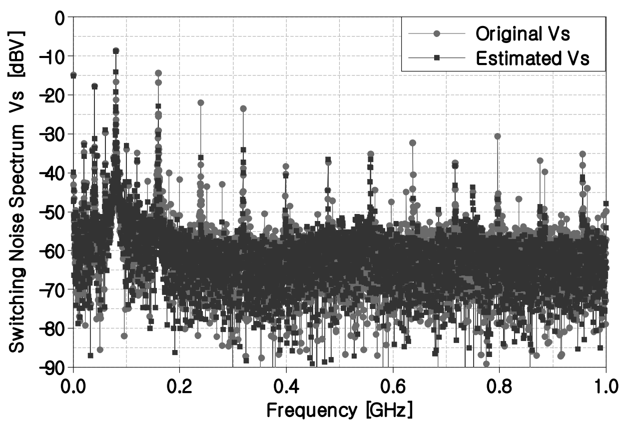


Fig. 7 Switching noise sources

chip is available. However, PCB designers can hardly calculate internal noise source of chip. So when PCB designers require the internal noise source, first of all, V_{PCB} is obtained by measuring PCB with IC as depicted in Fig. 5. Then internal current source I_{in} can be estimated by equation (1) which is induced by using equivalent internal impedance of chip and impedance of PCB.

$$I_{in} = \frac{Z_{in} + Z_{PCB}}{Z_{in} \cdot Z_{PCB}} \cdot V_{PCB} \qquad (1)$$

Internal current source I_{in} can be converted into equivalent voltage source V_S by using Thevenin equivalent circuit as shown in Fig. 6.

$$V_s = I_{in} \cdot Z_{in} = \left[1 + \frac{Z_{in}}{Z_{PCB}}\right] \cdot V_{PCB} \qquad (2)$$

We would like to examine how accurate noise source V_S can be estimated by using measured V_{PCB}. In case that certain V_S was already given, V_{PCB} was measured when V_S excited to test PCB through AWG. By using the V_{PCB}, V_S was recalculated through equations (1) and (2) as estimated V_S.

In this paper, switching power noise, which was measured from 80 MHz clock driven timing controller (T-CON) chip on actual complex PCB to control Liquid Crystal Display (LCD), was used as internal noise source V_S.

In Fig. 7, there is comparison between noise source V_S which is originally given and calculated V_S which was obtained by measured V_{PCB}. Amplitude of harmonics match well between original V_S and estimated V_S at 80, 400, 480, 560, 720 MHz but estimated V_S is 10~15 dB lower than original V_S at 240, 320, 640, 800, 880 MHz. This may be caused by three factors: the observation error of V_{PCB}, the singularities of Z_{PCB} due to resonances [2], and the estimation error of internal equivalent impedance. Because of these factors, there may be limitation to estimate accurate V_S by measurement. In near future, therefore, simulation method is being considered to calculate internal noise source of chip.

D. Prediction of Radiated EMI

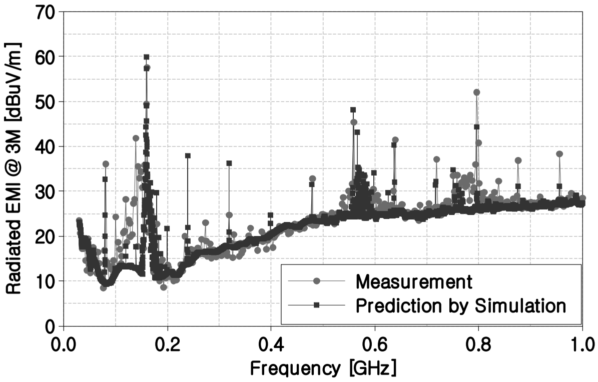
As long as the radiation characteristics of PCB and the noise source are obtained, radiated EMI can be calculated by following procedure.

- Step #1. Add chip's internal noise spectrum and PCB's radiated efficiency spectrum in dB scale
- Step #2. Compare the spectrum with background noise of chamber
- Step #3. Choose the greater between the spectrum and background noise to be estimated EMI spectrum.

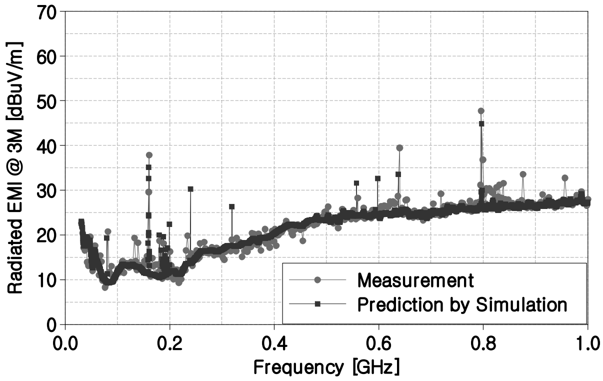
To validate the prediction of EMI, radiated emission was measured by using test PCB which was excited with original V_S from AWG. When using original V_S for prediction, comparison between predicted EMI and measured results indicates a good agreement over all frequency as shown in Fig. 8. The differences of predicted and measured results are within 10 dB at most of harmonics of 80 MHz. However, the predicted EMI results at 240 and 320 MHz are 10~15 dB higher than measured results. It's because simulated radiation efficiency of test PCB at those frequencies was higher than actual radiation efficiency as shown Fig. 3. Therefore, if accurate PCB radiation characteristic is obtained from simulation, radiated EMI can be predicted more accurately through implementing procedure proposed above.

From Fig. 8 (a), it is found that radiated EMI is magnified at 160 and 560 MHz when noise source meet PCB resonance frequency. It is important for PCB designers that the resonance frequencies of power bus structure avoid to meet noise source harmonics to reduce radiated EMI.

In case of using the estimated V_S, predicted EMI and measured EMI show in Fig. 9. When comparing Fig. 9 to Fig 8, predicted result was lower because estimated V_S was lower than original V_S in Fig. 7. In case of test PCB with one decap, predicted EMI and measured result were corresponded within 7 dB at 80, 160, 240, 320, 480, and 560 MHz as shown in Fig.

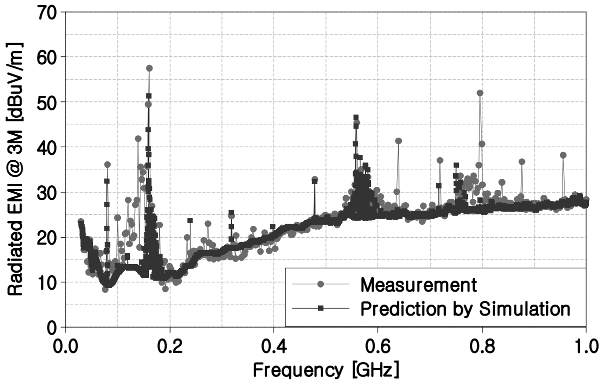


(a) Test PCB with one decap

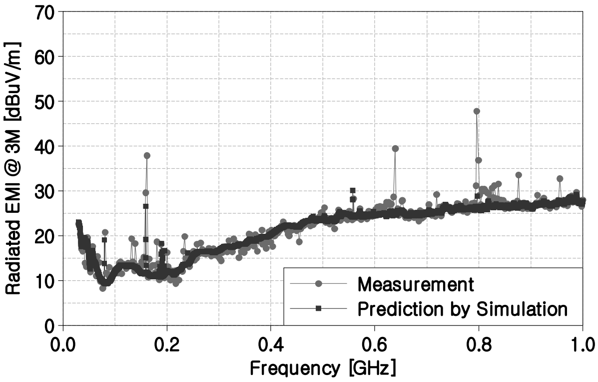


(b) Test PCB with four decaps

Fig. 8 Comparison of radiated EMI from prediction by original V_S and measurement



(a) Test PCB with one decap



(b) Test PCB with four decaps

Fig. 9 Comparison of radiated EMI from prediction by estimated V_S and measurement

9 (a). However, no radiated EMI was predicated at 640 and 800 MHz. The reason is that estimated V_S was about 15 dB lower than original V_S at those frequencies in Fig 7. In case of test PCB with four decaps in Fig 9 (b), there is no calculated EMI except 80, 160, and 560 MHz. According to these results, we can find that noise source should be obtained accurately to predict radiated EMI correctly. As mentioned previously, therefore, it is necessary to estimate internal noise source of ICs by simulation.

III. Conclusions and Future work

In this paper, a methodology for the prediction of radiated emission by using simulation with measured chip power noise was presented. The simulation result which was obtained by proposed procedure was able to provide proper estimation compared to the measurement result. Our results also indicated that obtaining both radiation efficiency of PCB and internal noise source of ICs accurately was important to predict EMI correctly.

In the future, a methodology which uses only simulation to predict radiated emission without measuring chip noise will be performed. This methodology requires an accurate simulation with chip power model (CPM) such as ICEM [1] and LECCS [4]. Chip noise can be calculated properly with the models. Furthermore, simulation including CPM and power bus structure will be fully conducted. To validate this result, it will be necessary to compare the simulation with the measurement of test PCB with ICs.

References

[1] C. Labussiere-Dorgan, S. Bendhia, E. Sicard, Tao Junwu, H.J. Quaresma, C. Lochot, and B. Vrignon, "Modeling the electromagnetic emission of a microcontroller using a single model," IEEE Trans. Electromagn. Compat., vol. 50, no. 1, pp.22-34, Feb. 2008.

[2] Y. Fukumoto, T. Matsuishi, T. Kinoshita, O. Wada, Y. Toyota, and R. Koga, "Power current model of LSI and parameter identification for EMI simulation of digital PCBs," in Proc. 2001 IEEE Int. Symp. on Electromagn. Compat., Aug. 2001, vol.2, pp. 1185-1190.

[3] S. Li, H. Bishnoi, J. Whiles, P. Ng, H. Weng, D. Pommerenke, and D. G. Beetner, "Development and validation of a microcontroller model for EMC," in Proc. Int. Symp. on Electromagn. Compat. (EMC Europe 2008), Step. 2008, pp. 125-130.

[4] Y. Toyota, M. Nishida, K. Iokibe, R. Koga, and O. Wada, "EMI simulation based on cavity-mode model for power-bus radiation calculation of power/ground planes with IC/LSI," in Proc. 2008 Asia-Pacific Symp. on Electromagn. Compat. (19th Int. Zurich Symp. on Electromagn. Compat.), May 2008, pp. 427-430.

[5] T. Sudo, "Predicting common mode radiation of power bus structure excited by IC's switching current," in Proc. 2008 Asia-Pacific Symp. on Electromagn. Compat. (19th Int. Zurich Symp. on Electromagn. Compat.), May. 2008, pp. 160-163.

[6] D. Shaowei, T.H. Hubing, and D.G. Beetner, "Using TEM cell measurements to estimate the maximum radiation from PCBs with cables due to magnetic field coupling," IEEE Trans. Electromagn. Compat., vol. 50, no. 2, pp.419-423, May 2008.