EMI Modeling and Correlation in a Highly Integrated Package Design

Sayed Mobin, Gokul Kumar
MemTech Application Engineering, Advanced Mfg Engr
SanDisk, a Western Digital Brand
Milpitas, CA, USA

Daniel N. de Araujo, Steve McKinney
System Design Division
Mentor Graphics Corporation
Austin, TX, US

***Abstract*— Electromagnetic emission must be properly addressed in complex multi-chip packages (MCM) due to highly miniaturized form-factor requirements. Such modules induce electric and magnetic fields due to high frequency current paths, and if not contained within a susceptible limit, can cause other electronic components to malfunction or compliance failure. Testing for electromagnetic interference (EMI) in the lab after the system is built could be too late. This paper presents an approach to understand the possible EMI sources in a highly integrated complex package system. An EMI simulation methodology has been developed and correlation to near-field measurements is used to establish the accuracy of the simulation. A full wave 3D solver was used to perform the EMI simulation in frequency domain. The emissions were also measured using near-field probes within a shielded chamber. Good correlation was achieved between the measurements and simulations, suggesting benefits of the proposed methodology**

Keywords—Electromagnetic modeling, correlation, near-field measurements, simulation, full-wave extraction, multi-chip package, signal integrity.

I. Introduction

Electromagnetic Interference (EMI) modeling is a critical aspect of commercial product design. While high performance, fast signaling and aggressive designs in low cost environments are challenging, a product cannot be commercially sold until it passes certification for EMI compliance. Higher data signaling speeds leading to faster edge rates increase the harmonic content of high frequency signals on a system resulting in more EMI issues [1]. EMI compliance testing and validation is typically done at the end of the design cycle leaving little to no time for changes without affecting product schedule. These factors are aggravated in miniaturized multi-chip packages, which can impact the system performance due to radiated coupling. Therefore, detecting EMI issues, design trade-off impacts on radiation, is critical for closure of EMI compliance. The focus is traditionally on system level performance where the sum of the parts contribute to an overall spectral profile [2]. To address these challenges, in this paper, we evaluate the EMI emissions for highly complex multi-chip packages, and compare it with measured near-field measurements. The near-field analysis is used as an indicator for package contribution to overall far-field performance required for compliance [3]. The spatial location of emission hot spots as well as impact of design changes and shielding effectiveness is evaluated, and design guidelines for effective package design are proposed.

II. EMI Simulation Methodology

Properly simulating EMI effect in a highly integrated package system involves the accurate characterization of a signal that has a dominant frequency component in the same range of the package and system resonance. These resonances will act as potential EMI sources, leading to distortions in the signal quality. To simulate the EMI effect correctly for the entire system, all the signal and power interconnects should be included in the analysis.

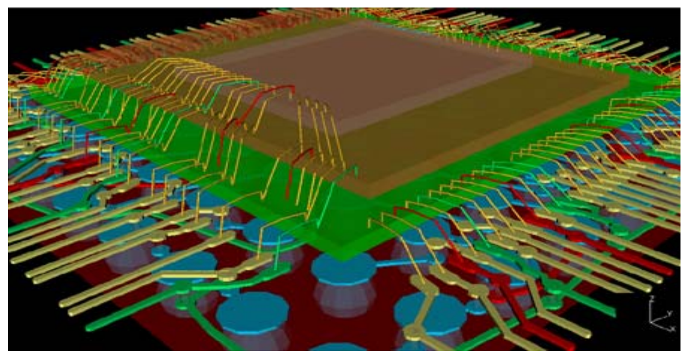

Fig. 1. Simple 3D view of Highly Integrated PKG

The EMI simulation was performed using a full 3D EM boundary element solver (BEM), HyperLynx Advanced Solver by Mentor Graphic (HLAS). The highly complex package with imperfect ground referencing is extracted from the layout data. Since the entire package is studied for EMI emission patterns, package structure and dimensions are critical for proper meshing. The ground plane perforations, vias, pads, anti-pads, and shield stubs were found to play a critical role for EMI performance and simulation meshing [4]. A simple structure of a highly integrated package is shown is Figure 1.

It is extremely critical to set up the mesh options adequately for the problem being solved in any 3D EM solver. Inadequate meshing of the 3D structure will produce inaccurate EMI results. During EMI simulation methodology development it was found out that explicit meshing of every ground plane perforation was important to the accuracy of the EMI extraction. While holes can have little effect in the signal and power integrity when located far from the signal nets, they are important for EMI simulation. Every hole was meshed explicitly providing a better correction between measurement and simulation. The implementation of default and advanced mesh options is shown in Figure 2.

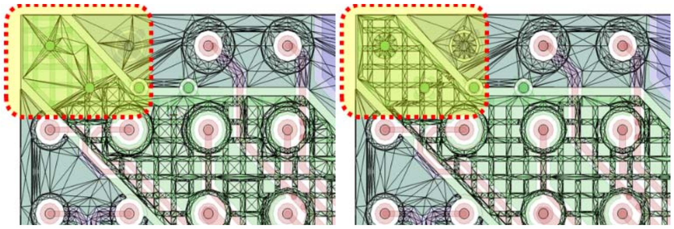

Fig. 2. Meshing complex structures in MCM packages – default mesh (left), Advanced Accurate mesh (right)

Ports were defined at the die pins and a normalized current source were used as an excitation. A sinusoidal/impulse response source was used. The E-field and H-Field patterns were simulated and observed at the desired reference plane above the package surface. The simulation frequency of interest was determined based on the current profile of the primary signal interface, and the harmonics of the input signal across the frequency spectrum.

A. Simulation Flow

The EMI simulation methodology can be viewed analogous to 3D signal integrity simulation flow in 3D EM solvers. The simulation flow is shown Figure 3.

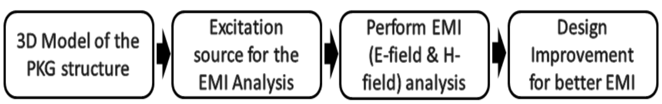

Fig. 3. Simulation Flow for EMI methodology

B. 3D Model of the PKG structure

In a highly integrated embedded MCM system, both the Host (transmitter) and the Device (receiver) are on a same package connected through wirebonds. The design complexity increases dramatically by allowing multiple stacked die on the same substrate. In addition, the multiple stacked dies increase the overall package current flow, and create non-linear switching loads across the planes. Multiple bondwire interconnections also contribute to field radiation due to inductive mismatch. A fully distributed 3D model of the entire PKG should be created to identify the package resonance including wirebonds, signals and power discontinuities, transition vias and the substrate. Since lumped element models do not radiate, a full wave S-parameter model is essential for the EMI analysis.

C. Time / Frequency domain excitations

Excitations for EMI analysis are typically extracted in the time domain using the extracted layout s-parameters and transistor-level transceiver models with appropriate excitation patterns. Figure 4 shows the driver output currents using PRBS7 pattern as an excitation source at 200MHz. EMI analysis is done in the frequency domain with current sources. HLAS can import time domain current excitations and do the appropriate frequency domain conversion using FFT [5]. The frequency domain conversation of the time domain currents in Figure 4 is shown in Figure 5. For time domain to frequency domain conversion, fundamental digital signal processing principle (Nyquist Criterion) should apply. Smaller sampling interval in time domain would increase the bandwidth and more samples in frequency domain would increase the spectral resolution.

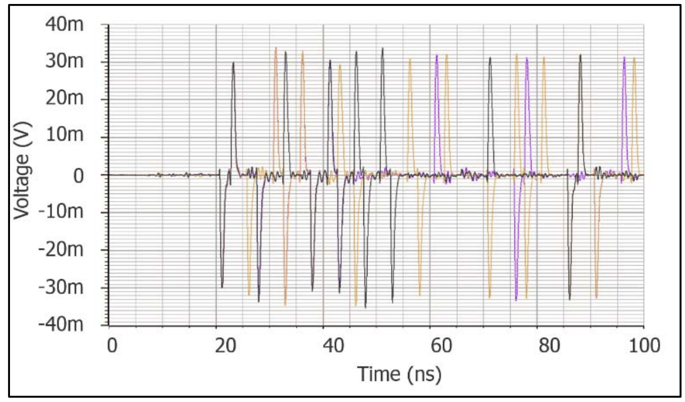

Fig. 4. Time domain transistor-level driver current into transmission line

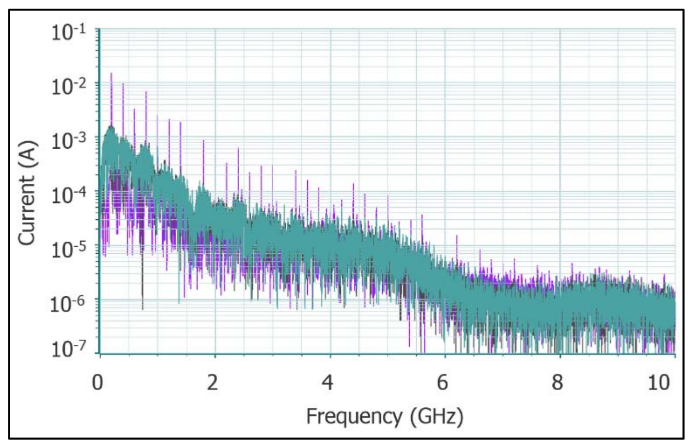

Fig. 5. Frequency domain transistor-level driver current into transmission line

III. EMI NEAR FIELD MEASUREMENT SETUP

To validate the simulations, a near-field measurement was performed in a shielded room based on H-field radiation [6]. In order to measure the near field emission, the device under test (DUT) is contained in a fully shielded chamber. The field emissions were captured using a loop probe. The DUT is placed on a specifically designed test board that would provide power and test control signals to the device. The probe was positioned automatically to measure the H-field across the PCB, package and multiple dies [7]. The measurement setup is illustrated in Figure 6.

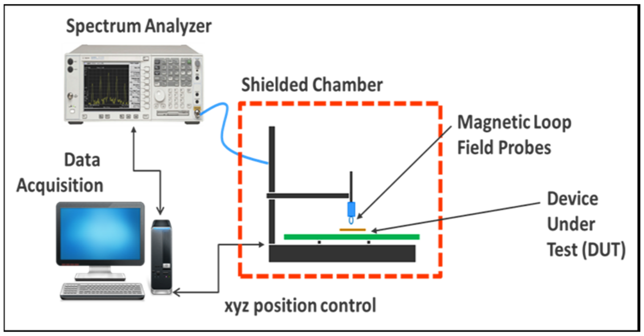

Fig. 6. Near Field Laboratory Measurement Setup

A test sequence was pre-programmed within the device to simulate the actual system switching performance during measurement. A magnetic loop field probe is used to capture the emission pattern along the X and Y direction of the PKG at the same reference height as the simulations. The Data is captured through spectrum analyzer and transferred to a computer for analysis.

IV. Measurement & Simulation Correlation

In this section, two real-world scenarios were examined, to demonstrate the effectiveness of the proposed simulation methodology. First, the native “unshielded” package mcm is modeled and measured to determine the hotspots intrinsic to the package structure. This structure does not have any metallic enclosure or attenuation between the source and measurement plane. This simulation and measurement correlation is established in Figure 7. The outline of the package on the PCB is shown to demarcate the package position. The near-field measurement provided mapping of field hot spots for correlation and provided baseline for design improvements. Initial qualitative comparison of the measured vs. simulated near field pattern matched author’s expectations. The emission pattern was almost identical, indicating the emission along the interconnect signal traces (the diagonal of the PKG) and the power plane transitions (on the top and bottom of the PKG).

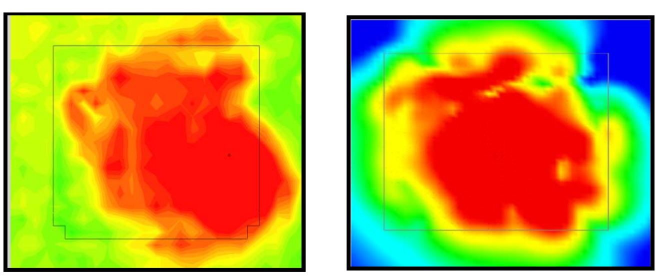

Fig. 7. Unshielded multi-die package near field measurements (left) and simulation (right)

The second scenario examines the use of a metallic enclosure to reduce the excessive emission of the unshielded module. In this structure, the package was entirely shielded with a metallic enclosure fully encased the top of the package as well as four sides connecting to the ground planes on the package. Near-field measurement showed around 15-20dB reduction along the diagonal, as shown in Figure 8. The hot spot around the lower right corner was due to the presence of a power ball at that location. Further, the simulations showed around 15-20dB reduction in emission along the diagonal and also predicted the high emission area at the power ball location.

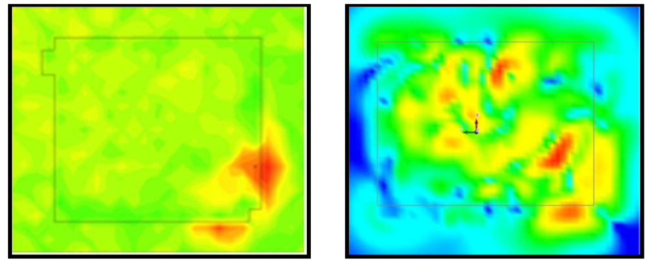

Fig. 8. Shielded multi-die package near field measurements (left) and simulation (right)

One aspect being investigated is the modeling of the metallization of the die interconnects which is present in the measurement but absent in the model. This would provide additional shielding of the package emissions under the memory die.

V. Conclusion

In summary, this paper describes the methodology for modeling, simulation of highly integrated multi-die package designs as well measurement and correlation of an unshielded and package integrated shielded design. Significant improvements in the order of 15-20dB were achieved by optimizing the package design based on the proposed simulation technique. Therefore, integrating the EMI simulations can help catch potential EMI challenges early in the design cycle and evaluate trade-offs in package design, routing, and emissions.

Acknowledgment

The authors would like to thank Pranav Balachander for the simulation flow development and Ye-Bai for near field measurement support.

References

[1] E. Bogatin, “Signal and Power Integrity Simplified”, 2nd Edition, 1.5, Prentice Hall

[2] Shai Sayfan-Altman and Vladimir Vulfin, "PCB EMI Simulation", 2014 IEEE 28-th Convention of Electrical and Electronics Engineers in Israel

[3] R.C. Johnson, H.A. Ecker, J.S Hollis, “Determination of Far-Field Antenna Patterns from Near-Field Measurements”, IEEE Proceedings, Vol 61, No. 12, Dec. 1973.

[4] W.Pan, D.Pommerenke, S.Xu, J.Jia, “PCB ground fill design guidelines for radiated EMI,” IEEE EMC Symp. Detroit 2008.

[5] Ramirez, Robert W., “The FFT, Fundamentals and Concepts.” Prentice Hall, NewJersey, 1985

[6] Yaghjian, A.D.: “An Overview of Near-Field Antenna Measurements”, IEEE Transactions on Antenna and Propagation Vol. AP-34, January, 1986

[7] T. Harada, N.Masua, and M. Yamaguchi, “Near-field magnetic measurements and their application to EMC of digital equipment,” IEICE Trans. Electron. Vol. E89-C, No. 1, pp. 9-15, Jan. 20