EMI/EMC Modeling of Packaged Electronics: Challenges and Opportunities

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Abstract

The complexity of EMI/EMC modeling at the package, board and system level of multifunctional electronic designs necessitates the use of approximations in the development of a manageable computer model. Such approximations can be interpreted in terms of geometric, material, and layout variability. This variability, which is also relevant to uncertainties in floor-planning, layout and operating conditions, calls for methodologies and tools for predictive component and system EM performance and functionality assessment in the presence of uncertainty. Such modeling capability is not available today. This paper explores the opportunities for and potential benefits from the development of such modeling capability in support of EMI/EMC modeling for noise-aware computer-aided integration of multi-functional electronic systems.

1. Introduction

Thanks to significant advances in the modeling sophistication, numerical algorithms, numerical robustness and computation capacity of electromagnetic (EM) field solvers over the past two decades, the IC signal integrity community has at its disposal today a powerful arsenal of CAD tools for noise-aware design and routing of the signal and power distribution networks at all levels of circuit and system integration. As a result, the multi-conductor transmission-line models commonly used in the latter part of the past decade for high-speed link design are now giving way to three-dimensional (3D) full-wave models of the interconnects so that the impact of 3D effects, associated with via transitions and other types of discontinuities, are accounted for in a physically-consistent manner in the prediction of interconnect-induced signal degradation. Similarly, 3D full-wave field solvers are now relied upon for noise-aware design optimization of multi-pin connectors and related non-planar transitions of the signal distribution network. As far as power grid design goes, the most popular, commercially-available tools pride themselves in their ability to account for the distributed EM nature of the field in their prediction on power voltage fluctuations during high-speed switching.

The benefits from such enhanced sophistication of EM field modeling tools for signal integrity cannot be overstated. Today's highly-compact, portable computing and communication devices rely heavily on the use of these tools for their reliable functionality and performance. However, as mixed-signal functionality integration continues to escalate, and switching speeds and signal bandwidths continue to increase, the designer's demand for EM CAD at the system level quickly pushes state-of-the-art field solvers to their limits. An example for such system-level EM modeling is the investigation of reliability challenges resulting from such integration. More specifically, the electromagnetic interference (EMI) between densely integrated components and circuits stands out as a major hurdle in robust mixed-signal IC design. While integration complexity is one of the major obstacles in the use of EM field solvers for the development of rules and guidelines for noise-aware, functional integration, the uncertainty in layout and operating conditions looms as another hindrance of reliable functionality.

Interestingly enough, even in those cases where the comprehensive data is available for the geometric and material attributes of the electronic system, its multi-scale nature makes its brute-force electromagnetic modeling comprehensively prohibitive. Thus, it is often the case that approximations are introduced in the development of the numerical model used for EMI/EMC analysis. Such approximations could be described in terms of geometric/material/layout variability. This variability, which is also relevant to uncertainties in floor-planning, layout and operating conditions, calls for methodologies and tools for predictive component and system EM performance and functionality assessment in the presence of uncertainty. Such modeling capability is not available today.

In the following, we discuss the impact of such modeling approximations on the accuracy of the electromagnetic modeling of emissions from integrated electronics at the platform level. The purpose of this discussion is to motivate a proposal for system-level electromagnetic modeling of packaged electronics in the presence of geometric, material, and layout variability resulting from simplifications in the numerical model used for computer-aided investigations of

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electromagnetic interference and electromagnetic coupling effects and their consequences on system functionality and electromagnetic compliance with its operating environment.

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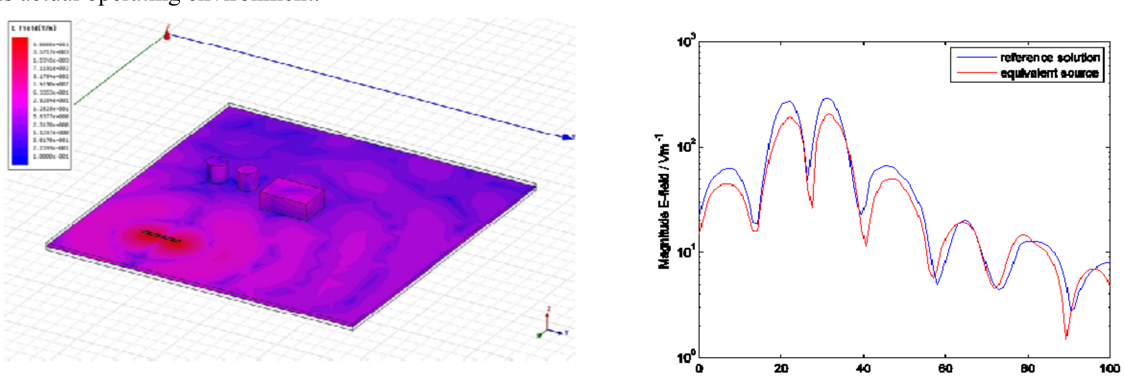
2. Approximations in the Modeling of Radiated Emissions

One of the most challenging tasks in EMI/EMC modeling at the board level is the correct modeling of the radiating source. The source is typically a functional block (e.g., a packaged IC), the accurate modeling of which, for the purposes of board-level EMI analysis, would require the detailed description of all the electronics devices and the interconnect wiring contributing to the radiated fields. The multi-scale complexity of such modeling is apparent. Therefore, an efficient alternative would be to make use of electromagnetic equivalence principles toward the description of such radiation in terms of an appropriately selected spatial distribution of equivalent currents. The merits and accuracy of such an approach have been investigated and presented in the open literature (see, for example, [1]). Spatial near-field data, obtained through measurements, provide one of the possible ways of computing the equivalent currents when the aforementioned detailed modeling is not feasible.

A simple test of this possibility is provided in the following example where we consider the problem of a horizontal dipole radiating in the presence of a copper plate. The copper plate is a 10 cm by 10 cm square and the dipole is placed 1 mm above the copper plate as depicted in Fig. 1a below. The topography of the plate is altered by three conducting blocks. The length of the dipole is 1.214 cm and the operating frequency is taken to be 10 GHz. Given that the wavelength in air at this frequency is 3 cm, the length of the dipole is slightly less than one-half wavelength. The center of the dipole is at point (x = 8 cm, y = 2.6 cm). Ansoft's HFSS was used to calculate the radiated fields generated by the dipole. In order to represent the radiating dipole in terms of an equivalent current distribution, the computed magnetic field in the aforementioned simulation was sampled over a plane placed 1 mm above the radiating dipole and parallel to the copper plate. The distance above the radiating dipole amounts to 1/30 of the wavelength at the operating frequency. This distance is consistent with typical distances above the source that near-field scanning equipment is used to sample the near field. The magnetic field was sampled over a 6 mm x 16 mm rectangle, divided into a 2 mm x 2mm square grid. The sampling step was dictated by the desired level of accuracy in the calculation of the field when the equivalent sources are used in place of the dipole.

Depicted in Fig. 1b is the comparison of the magnitude of the electric field along y on the x = 60 mm plane for the two cases, when the actual dipole is radiating and when the equivalent surface current density is being used in its place. The approximation being made here is evident, namely, the equivalent currents are obtained in terms of sampled fields over only a portion of the surface enclosing the radiating source. Nevertheless, the results of Fig. 1b support the possibility of using near-field measurements of radiated emissions from components on the board for the development of equivalent source representations of these components. Furthermore, given that the sampled field is in the immediate vicinity of the radiating block, the conjecture is made that the field is dominated by the block emissions only, with any fields due to scattering of the primary radiation from neighboring components amounting to a secondary, less influential contribution. Under this assumption, the generation of these equivalent source representations for the electromagentic emissions from a functional block can be made through near-field measurement of the block on a test board rather than its actual operating environment.

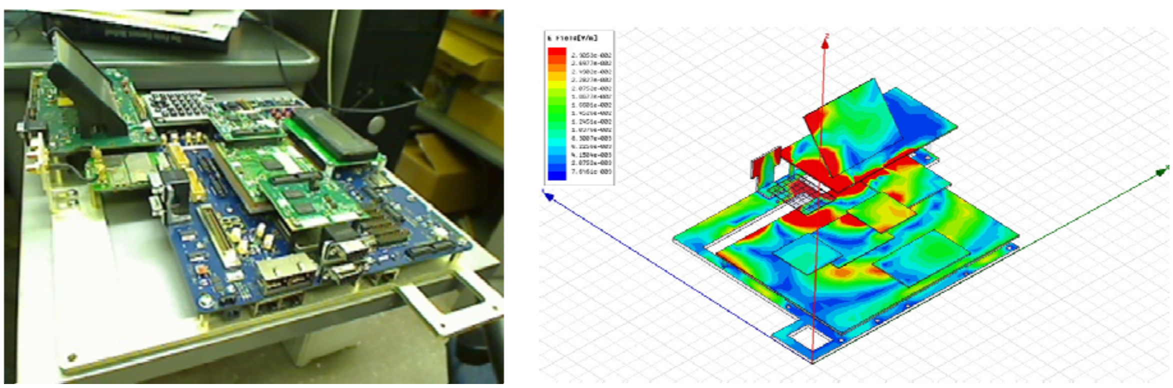


(a) (b)

Figure 1. (a) Horizontal dipole radiating in the presence of a conducting plate of finite extent. (b) Electric field intensity due to the equivalent surface current density over the sampling plate, used in place of the actual dipole source.

3. Approximations in the Modeling of Electromagnetic Coupling

The task of modeling of the radiated emissions coupling mechanisms is complicated by both the multi-scale complexity of the integrating substrate and the uncertainty of the specifics of the layout and floor planning, which are not fully determined during the design stage. One way of tackling the multi-scale complexity of the integrating platform is through the intentional introduction of approximations in its geometric and material properties. An example of such approximations in depicted in Fig. 2 below. Figure 2a shows the test board used for the experimental investigation of electromagnetic compliance of the various functional blocks integrated in a cell phone. The multi-scale complexity involved in the development of a numerical model for a computer-aided analysis of such compliance is obvious. Figure 2b depicts a reduced model of this board that made possible the application of Ansoft's HFSS for numerical modeling of such electromagnetic compliance. Clearly, the majority of surface mounted components have not been included in this reduced model. Once an initial reduced model has been established and its validity assessed through comparisons with near-field measurements for the calculated fields, small components that were originally neglected may be gradually introduced into the model if further refinement is warranted. Pin connectors on top of the circuit board, with arrays of vertical copper pins, are being modeled by a solid copper. More complex mounts can be reduced to their basic geometry by considering which features will have the strongest impact on the EM fields. For example, for our purposes, LCD screens or keypads on the board have been modeled using conducting plates, an approximation that was also used for the PCB itself, given the fact that its power/ground plane metallization is expected to dominate the scattering of the primary incident fields at the frequency of interest given the electrically small thickness of the insulating layer at the top of the board. Alternatively, for improved accuracy, surface impedance boundary conditions can be developed to describe the electromagnetic attributes of the board in a macroscopic manner accounting for the material and geometric attributes of the stackup.



(a) (b)

Figure 2. (a) Picture of test board used for compliance testing of wireless device functional blocks. (b) Reduced model of the board used for HFSS modeling of electromagnetic field coupling due to radiation from one of the functional blocks.

In developing the reduced model the following two, physics-motivated assumptions were made. First, it was assumed that any secondary radiation by components of size less than 1/20 of the wavelength at the operating frequency is negligible. Hence, such features were not included in the model. A quantitative justification for this principle is provided by the fact that the total time-average power reradiated by a conducting sphere of diameter much smaller than the wavelength of the incident radiation is proportional to $|E|^2a^6/\lambda^6$, where $|E|$ is the magnitude of the incident radiation, a is the radius of the sphere, and λ is the wavelength of the incident radiation. Thus, the magnitude of the re-radiated electric field by a metallic sphere of $a = \lambda/20$, is in the order of 10^{-4} of the magnitude of the incident electric field. The second assumption was that composite, inhomogeneous components of characteristic size that is comparable to wavelength but for which the feature size of their spatial variation in material properties is much smaller than the wavelength, can be replaced by homogeneous blocks of a material with electromagnetic parameters decided by the material that dominates the electromagnetic behavior of the component.

There is no doubt that such approximations introduce an error that is difficult to quantify with high confidence. However, for the purposes of noise-aware design iteration, the simplicity of the reduced model is very attractive and enabling. It is for this reason that we argue that implementing such approximations makes good engineering sense and we seek to establish a systematic framework for such approximate modeling in the EMI/EMC modeling of packaged electronics.

Toward this objective, we have embarked on the development of modeling methodologies where the uncertainty introduced by geometric and material approximations are described in terms of a set of properly chosen random variables. The multi-dimensional random space thus introduced needs to be properly comprehended in the development of our numerical model for EMI/EMC compliance analysis. While such modeling may be carry out in a brute-force way through standard Monte Carlo techniques, the framework of polynomial chaos expansion and stochastic collocation offer a computationally more efficient alternative [2-4]. Specific applications in the context of the aforementioned modeling for system-level EMI/EMC are currently under investigation.

4. Concluding Remarks

In summary, in this paper we argue that the multi-scale modeling challenges associated with computer-aided investigation of system-level EMI/EMC of packaged electronics calls for the adoption of new approaches in the way the radiating sources and the interacting blocks and associated coupling mechanisms are represented in the model. For those cases where such modeling is used for the purpose of expedient iteration in layout and floor planning decisions during the design phase, the proposition is made to allow for approximations in the model development that enable significant reduction in model complexity. Given that such approximations amount to a user-introduced uncertainty in the model, the possibility of describing such approximations in terms of properly selected random variables is entertained. In this manner, use can be made of ideas from polynomial chaos and stochastic collocation for the computationally efficient description of the introduced uncertainty and the expedient modeling of the resulting stochastic electromagnetic model.

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