Practical and Accurate EMC Simulation

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INTRODUCTION

New EMC compliance standards are coming into full force in Europe and this is causing repercussions worldwide as manufacturers adjust to new design procedures. Nevertheless, there are individuals who disregard EMI/EMC regulations. One industry expert believes that the motivation for this behavior stems from either economics or ignorance.[1]

It is mistaken economy to disregard design practice when proper design costs no more and does not expose the supplier to litigation. Exporters to Europe are now sensitized to the risk of having their equipment returned. There is clearly no economy to this and it won't take long to learn this lesson.

The other motivation is ignorance of control standards. This ignorance (or disdain) may be the result of the inability of individuals to correlate the law with the physics of their experience. To acquire experience in the laboratory, design office or test chamber takes many years. Even then, it is hard to understand what the impact of changes could be without extensive test experience.

For instance, what would happen if the power cable encircled the enclosure differently? What would be the effect of moving the printed circuit board 1 cm closer to the enclosure ventilation slot? Would the situation be improved (or exacerbated) if the board is inverted or reversed within the enclosure? How can one tell where the EMC hot spots on the board are? How can we understand the contribution of a via towards electromagnetic radiation? How can we learn to redesign a printed circuit board in order to reduce these problems?

Issues that are fundamentally electromagnetic in nature have been compelling to some but are repelling to most. Those who have taught electromagnetic courses in college have had to use their most innovative techniques to keep the students in the classroom. The problem is the complexity of Maxwell's (and other) field equations and the difficulty of relating all this theory with what happens in practice. It is very difficult for the instructor to devise examples that are at once practical and amenable to mathematical solutions. The problems that can be easily solved are of interest to nobody.

It is helpful to have good simulation tools available to solve difficult problems. Simulation tools are useful in two obvious ways: to assist in the design process in order to avoid errors and to optimize designs; and to impart physical insight to the designer so that he or she can anticipate system response.

GOALS OF EMC/EMI SIMULATORS

Because of the complexity of the issues involved, EMC/EMI design issues must be dealt with at various levels.

Williams[2] reviews several practical problems which need to be overcome in the development of practical software EMC tools. He makes the point that several goals to be achieved have nothing to do with electromagnetic modeling:

- EMC design aspects do not respect the demarcation common in design labs between circuit, layout and mechanical disciplines. Considerable interaction between disciplines is needed, which presupposes a common body of EMC knowledge among the different fields, which is unlikely to exist.
- To overcome this demarcation, the CAD package must integrate these aspects and must therefore accept input on all fronts. Few integrated CAD environments are installed which can provide such input automatically, but manual input is not realistic given the time constraints facing a typical design department.
- The output of the package must also be in a form which is usable and comprehensible by designers. It must be structured to be of maximum assistance at the most appropriate phase(s) of the design process. Some re-training of the users may be required so that they can actually use the output.

One class of software tools are design advisors. These are not simulators but rather a compilation of rules derived from rather simplified analysis and experience. They can prove to be useful although restrictive in scope. However, they frequently embody EMC knowledge from the circuitry layout and mechanical disciplines. Certainly, they are helpful to electronic designers facing compliance issues in the design process.

A full-system EMC simulator must be designed around an extendible algorithm that does not make explosive computer demands with increasing system complexity. It must not use methods that would prematurely restrict its applicability. For example, a general simulator must not be based upon imaging methods that would preclude accounting for enclosures, cables and multi-board radiation.

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A full system-level simulator must have the ability to handle multi-board configurations, cables and enclosures. Its technology has to be designed in so comprehensive a fashion that other quicker and simpler modules result from it that are used early in the design cycle, e.g., for screening PCB nets in the course of component placement and track layout, and for the design of enclosures for EMC compliance prior to completion of the electronic subsystem design. These designers' tools have to be rapid and intuitive while at the same time they must be based upon correct electromagnetic and mathematical principles rather than upon heuristics (e.g., rules-based advisors).

FUNCTIONALITY OF A SYSTEM SIMULATOR

Because of standards requirements, a practical EMC simulator has to allow the engineer to compare simulated maximum field strength at points in space as a function of frequency. To do this, the tool has to provide easy access to a variety of test standards (including in-house standards) in graphical form in order to locate violations easily. At the least, standards must include FCC, IEC (Europe) and VCCI (Japan). In addition, the simulator must:

- Perform the mathematics in the background to allow the engineer to concentrate on the task and not be concerned with algorithmic details;
- Permit convenient selection of the appropriate EMC standard against which the simulation is to be compared;
- Automatically access circuit schematic, PCB layout and mechanical design files; and
- Locate PCB tracks that are the likely sources of EMC violations so that corrective action can be taken with the aid of board-level simulation tools and by repositioning the PCBs and cables relative to the enclosure.

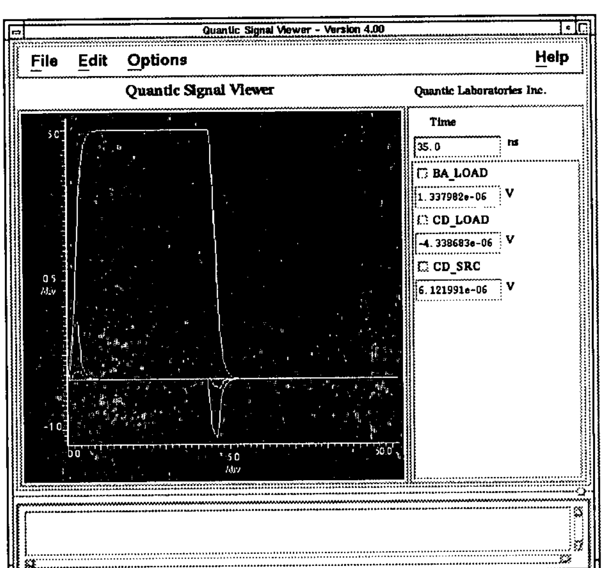

***Figure 1.** Signal and Crosstalk Viewed With a Software Signal Viewer.*

Simulation of signal and crosstalk waveforms on cables and printed circuit boards is essential to the solution of radiation problems. Therefore, circuit simulation is essential and the ability to view simulated waveforms (Figure 1) is a great convenience in order to identify excessive ringing and signal degradation.

Signal integrity issues are part of the problem. In addition, attached cables draw energy from the electronics circuitry through the launching of common-mode waves. Differential-mode currents produce only a minor part of the total radiation, with common-mode currents being the major contributor. Furthermore, it is understood that enclosures usually diminish but could (surprisingly) enhance the electromagnetic radiation that originates from printed circuit board systems and attached cables.

To effectively manage boards, cables and enclosures, the relevant design data must be available in a convenient manner. Current practice is to develop appropriate graphical user interfaces under the Motif format as demonstrated in Figure 2. Figure 3 shows an example of a PC enclosure and board.

COMPUTATIONAL COMPLEXITY

Several numerical techniques for calculating radiation are in vogue. Finite Difference Time Domain (FDTD) subdivides space and time into discrete steps in order to solve the wave equation. It handles transient (time-domain) situations directly and is easy to implement for rather simple shapes, such as an aircraft fuselage subjected to an incoming wave. However, this technique has difficulty accommodating systems with objects of greatly differing sizes, such as PCB traces over grounds in the vicinity of enclosures.

The Finite Element Method (FEM) - which, like the FDTD, is a partial differential equation (PDE) solver - has been very successful in the analysis of nonlinear magnetic problems such as power transformers and rotating machinery. To solve field problems, it subdivides the space into sub-regions (frequently triangles in two dimensions and tetrahedra or cubes in three dimensions) allowing for convenient modeling of complex shapes. Sparse matrices (matrices with many zero elements) are the result. These are manipulated very efficiently and go some way towards handling the very large number of variables generated by the distribution of nodes throughout three-dimensional space. However, the FEM is unable to accommodate the open region (infinite-space region) without the aid of impedance boundary conditions which approximately emulate the truncated infinite space.

The Boundary Element Method (BEM) subdivides surfaces in space (rather than volumes), effectively reducing three dimensions to two. Basically, it solves for currents on surfaces rather than fields throughout space

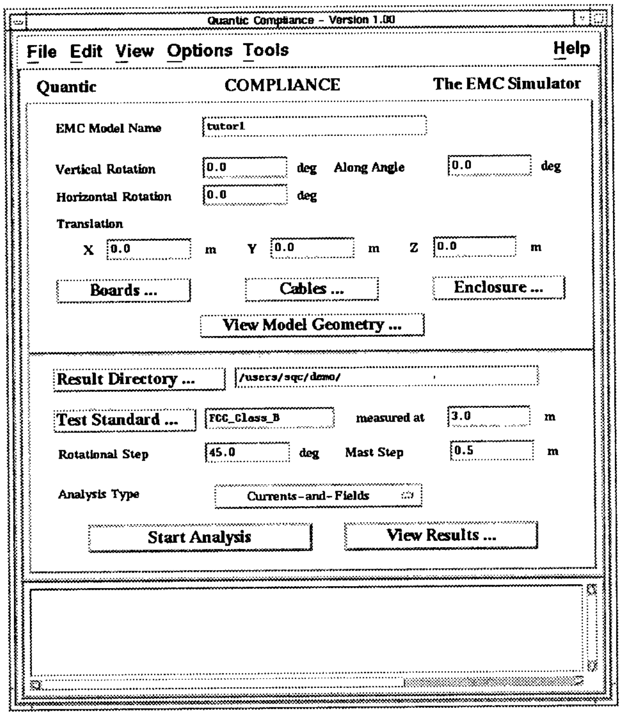

Figure 2. A Simulator Main Interface.

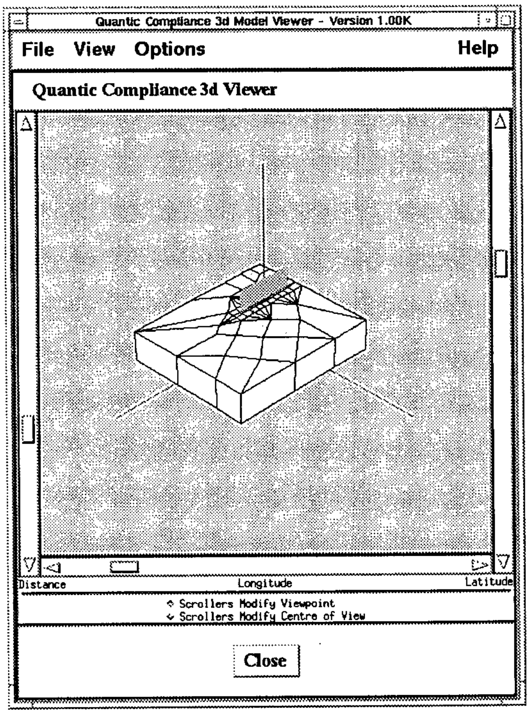

Figure 3. Board Attached to an Extender Card on a Test Module.

and does this by solving the integral equation formulation of the electromagnetic field problem. It embodies open-region boundary conditions within the elementary source solution (known as Green's function). Thus, methods such as those needed for the FEM to artificially truncate space are directly determined and so these are obtained with a very high degree of accuracy. Typically, matrices are dense but rather small in size.

Electronic systems are characterized by large feature-magnitude contrasts, i.e., many tracks of small transverse dimensions on PCBs, comparatively large ground planes and still larger enclosures. It is this broad scale of topologies that make associated, realistic EMC computations a daunting challenge.

Attempting to accommodate this wide spectrum of spatial features for a large number of tracks (and to include the time domain as well) by scaling the spatial grid size (and, for stability, the time step), results in a great number of unknowns and time steps. The computer memory and CPU demands are impossible to satisfy for realistic problems.

For example, the FEM and FDTD methods (being PDE solvers with nodes distributed throughout three-dimensional space) are particularly subject to scaling demands. Furthermore, these methods cannot conveniently and accurately handle open-region problems, especially problems involving exterior cables. This is attested to by virtue of the fact that antenna analyses are invariably performed using integral equation/boundary element methods.

OPEN-ENDED ALGORITHMS

For the reasons outlined above, the BEM is frequently preferred. It deals with surfaces rather than three-dimensional volumes and caters naturally to open-region problems. Especially for this latter reason, it is the natural choice of those solving electromagnetic scattering problems.

When solving electromagnetic scattering problems, the surface node distributions are spaced at a minimum number of surface nodes per square wavelength. Typically, this number is 10 nodes per wavelength (or 100 nodes per square wavelength) with a finer distribution where rapid surface variation warrants it (e.g., near edges). Given that $f\lambda = c$ (where $c = 3\times10^8$m/s, the velocity of electromagnetic radiation in free space), we see nodes spaced about .03 m apart over the surface at $f = 1$ GHz. This spacing is considerably greater than that of the transverse dimension of a track. If one attempts to solve for the currents on the tracks by a direct moment method, the density of track surface nodes, and that on the adjacent ground plane in the vicinity, must conform to the track dimensions. We would then be faced with an immense number of unknowns (although still less than the number needed by the FEM and FDTD methods).

An appropriate algorithm solves for transmission-line differential-mode currents in the time domain while taking into account nonlinear driver and receiver characteristics if necessary. Back-radiation may alter the track-current values calculated by transmission-line network methods. This effect has been shown to be very small except sometimes at high frequencies. When required, a perturbation to the currents will be calculated by considering the back-radiation as an incident field. This outer-loop iteration will not increase matrix sizes.

With the transmission-line parasitic information now available per unit length (from the above analysis) for each cross-section, a transmission-line model can be generated. The circuit created by connecting all these transmission lines forms a model of the entire PCB layout. Appropriate drivers, receivers and loads are then attached to the transmission-line models of the traces. These devices can be modeled by behavioral driver and receiver circuits synthesized from data sheet information supplied by chip manufacturers, or from SPICE models if available. The final step is a time-domain analysis to determine signal integrity parameters and crosstalk. Through this algorithm, the currents needed to simulate radiation from the PCB traces are directly available.

Consider radiation from tracks directly. Track currents over ground planes may be viewed to radiate by virtue of the track and negatively-directed imaged track currents. Intuitively, because of the small enclosed loop areas - between each track and its companion image - and the tendency toward cancellation of the effects of these currents due to their proximity, this direct contribution to radiation would be modest in comparison to enclosure and cable common-mode radiation. Note, however, that the track current is the source of the common-mode currents that radiate strongly.

Generally, common-mode currents are the major contributor to electromagnetic radiation due, in part, to the large surfaces on which they exist, such as ground planes, enclosures and cable lengths. Additionally, cables are excited within the enclosure, and conduct waves to the outside of the enclosure whereupon the large outer surface is excited, with significant radiation resulting.

Vias are spaced relatively far from one another. A vertically-directed via current may be far from another via whose current is oppositely directed at the same moment. Consequently, there is little tendency for cancellation - as there is for track currents - and vias are strong radiators. This tendency to radiate is augmented by their ground plane images whose currents are in the same (rather than opposite) directions.

Once all surface currents are known, electric and magnetic fields are calculated by vectorially summing the contributions at desired points in space due to all differential and common-mode currents. Typically, fields are calculated at locations specified for measurement by relevant EMC standards.

SUMMARY

Several needs have to be met for a system-level EMC simulator to be effective. These needs are met if the algorithm has the following capabilities:

- Employs boundary element solution of the integral equation
- Handles open-region problems efficiently and accurately
- Handles problems with structure of great size ratios without fine mesh grading
- Features open-ended algorithm in which computer demands increase linearly (rather than exponentially) with problem complexity
- Calculates track currents by transmission-line network analysis methods, with provision for perturbation due to back-radiation effects, rather than by a costly direct-moment method
- Integrates with signal integrity tools and handles nonlinear components
- Boundary element size not governed by the size and/or number of tracks
- Uses the minimum number of patches that match the criteria set by wavelength and geometry for meshing algorithm
- Handles multi-board systems with cables and enclosures
- Integrates with EDA files and mechanical design files
- Identifies tracks that are the major contributor to radiation
- Compares with EMC standards
- Emulates test laboratory environment

REFERENCES

1. R.D. Goldblum, "Laws Governing EMI," *ITEM* 95, p. 12.

2. Tim Williams, *EMC for Product Designers* (Oxford: Newnes/Butterworth-Heinemann Ltd.) 1992.

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