Fast Frequency Domain Tools for System Analysis of EMI/EMC Topologies

E. S. Siah¹, K. Sertel², R. W. Kindt¹, J. L. Volakis¹² and V. V. Liepa¹

¹Radiation Laboratory, EECS Dept., University of Michigan, 1301 Beal Ave, Ann Arbor, MI 48109-2122, USA
²ElectroScience Lab, Ohio State University, OH 43212, USA

e-mail: esiah@eecs.umich.edu, volakis@eecs.umich.edu

Abstract: With the increased use of wireless devices and applications, coupling and interference in electronic devices due to either intentional or un-intentional electromagnetic sources is of increased concern. Such sources can cause sufficient disruption to the circuit or chip logic to the point where the functionality and logic state of the electronic device can be altered due to such extraneous sources. In this paper, we employ fast EM algorithms such as the multilevel fast multipole moment method (MLFMM) and the hybrid finite-element boundary-integral (FE-BI) method for the analysis of coupling from external sources into realistic geometries. Specifically, the MLFMM is employed to analyze large scale problems such as vehicular structures whereas the FE-BI method is used to analyze volumetric structures with dielectric media such as printed circuit boards. In this paper, the Method of Moments (MoM) accelerated by MLFMM is employed to analyze for the fields within an automobile chassis in the presence or absence of a wire harness and for different aperture sizes. The employed FE-BI method focuses on the analysis of plane wave illumination onto passive circuit geometries such as the microstrip interdigital filter and active circuit topologies like an active microstrip low noise amplifier.

Keywords: Finite Element-Boundary Integral, Multilevel Fast Multipole Method, Method of Moments, EMC/EMI, Harmonic Balance Method

Introduction
With the increased availability and abundance of computational resources, use of computational EM tools is an attractive alternative for computing EMI/EMC as opposed to measurements, which are costly and time consuming. The availability of O(NlogN) computational speed ups provided by the multilevel fast multipole moment method (MLFMM) [1-5] along with the generality of the hybrid finite-element boundary integral (FE-BI) method [7-8] allows for the analysis of realistic complex geometries. The employed analysis methods incorporate the finite element-boundary integral method and the fast multipole methods to characterize rather arbitrary sets of geometries which may include printed circuit boards, absorbers and lumped loads within surface enclosures such as cavities and automobiles.

The generality and formulation of MLFMM makes it ideal for analysis applied onto a finite, large-scaled geometry. As such, we apply MLFMM over MoM primarily to the analysis of electrically large PEC structures such as automobile chassis and large cavities. On the other hand, the FE-BI method is particularly attractive for the analysis of finite volumetric structures such as printed circuit boards. In this paper, this method is applied to the analysis of plane wave illumination onto passive circuits such as the microstrip interdigital filter. In addition, the FE-BI is interfaced with a single tone harmonic balance method utilizing FET transistor SPICE models. This is applied to the analysis of plane wave illumination on a microstrip low noise amplifier circuit. The strengths of both methods can be harnessed concurrently by employing a hybrid surface integral equation and volumetric finite element method to analyze system level simulations of EMI/EMC. The latter is useful for the treatment of inhomogeneous dielectric objects such as active or passive circuit boards within the vicinity of an electrically PEC large structure which can be modeled as surface elements.

Validation of MLFMM and FE-BI
In this section, we discuss the techniques used for the above mentioned analysis. The MLFMM method is particularly attractive for analyzing vehicular structures and large cavities due to its large saving in both storage and computational speed. In our implementation, we employ a spherical (multipole) wave expansion of the free-space Green’s function to carry out the matrix-vector products in an iterative solution of the electric field integral equation (EFIE). The associated details of the implementation are given in the literature [1-5]. The multilevel aspect of the MLFMM algorithm is implemented using a multilevel nested group strategy and clustering of the basis functions with the oct-tree algorithm. Typically, the conjugate gradient squared iterative method is used to solve for the unknowns. Of particular importance in our implementation is the use of curvilinear elements to discretize the geometry surfaces [6]. This increases the accuracy of modeling curved surface geometries and alleviates the need for higher spatial sampling. In our case, curved quadrilateral biquadratic surface elements are used to model complicated geometries.

The hybrid FE-BI approach [7-8] is a further extension of the FEM method and it is particularly useful for the treatment of printed circuit elements enclosed within the structure. In the volumetric system, the passive circuit element is solved with the traditional FEM method and the surface equivalence principle is used to form a boundary integral equation to rigorously terminate the finite element mesh. This avoids the need of using Absorbing Boundary Conditions (ABC) which are less accurate and increase the computational domain. On the other hand, the employed BI leads to dense matrices requiring MLFMM to speed up the solution. In our implementation, a single layer of air can be placed above a thin layer of PCB to form the boundary integral. Again, curvilinear hexagonal elements are chosen to model the three dimensional geometry.

A plot showing the validation of the MLFMM and the FE-BI method for computing the field at the center of the rectangular cavity is shown in Figure 1. This result shows an excellent
agreement between the MLFMM, the FE-BI methods and the measured data.

System Analysis of EMI problems

The application of the MLFMM to system level coupling within an automobile is shown in Figures 2 and 3. In Figure 2, a circularly polarized crossed slot antenna is placed at the rear of the automobile, resonating at the DAB frequencies of 1.475 GHz, in the presence of a simple wire harness placed within the automobile. The wire transverses the passenger compartment and then penetrates into the vehicle’s engine compartment. At this frequency, the prescribed problem was modeled using 40,000 unknowns, requiring 430 Mbytes of RAM storage. The solution was solved in 14765 seconds on a SGI workstation. Two plots are shown, one of which refers to the lateral (x) axis close to the wire and the other showing the lateral (y) axis at some distance away from the wire harness. It is seen that the presence of a wire harness within the automobile causes the electric shielding factor (ESF) to decrease by a factor of 4 to 5 dB at observation points close to the wire and is almost the same for observation points further away from the wire. Figure 3 shows a similar analysis with the wire harness removed and the aperture at the dashboard replaced by a rectangular aperture.

The same study is conducted at two different frequencies: 0.7 GHz, where the slot resonates, and at 1.1 GHz, where the rectangular slot is non-resonant. The presence of the resonant slot increases the coupling factor within the engine compartment by as much as 5 to 15 dB for observation points along the lateral axis. This tool is important for the design of car sensor tolerances. In Figure 4, the FE-BI technique is employed to compute the magnitude of the induced voltage at the 50 Ω load at the ends of the interdigital coupled line microstrip filter due to an incident plane wave normal to the microstrip board. The applied plane wave has an amplitude of 1 V/m from 1.5 to 2.5 GHz (white spectrum source). As can be seen, the magnitude of the induced voltage shows a maximum induced strength of 3.6 mV per 1V/m of plane wave incidence at 2 GHz, viz at the filter resonance frequency. It is observed that a plane wave incident upon a passive element can result in additional spurious induced voltages at the output of the device that may cause interference at other cascaded devices. More specifically, an incident wave with an intensity of 100V/m can induce a spurious voltage of 0.35 V at the output port which may be sufficient to cause a change of state at the input of an active device.

This analytical study is further extended to a low noise amplifier operating with a gain of 11 to 12 dB from 8 to 12 GHz. Within the volumetric finite element domain, the dimensions of the FET metal regions are much smaller than a wavelength. Thus, the input impedances looking into the gate and drain terminals of the FET are modeled as lumped loads attached to the gate and drain terminals of the LNA. The geometry of the LNA is shown in Figure 5 and in this case, a plane wave is illuminated normal to the surface of the LNA circuit, polarized in the x direction, with various amplitude levels within the operational bandwidth of the LNA. The LNA is fabricated on a Gallium Nitride (GaN) substrate with a permittivity of 9.7. The gain of the LNA is defined as the ratio of the voltage measured at the output port to the input port, which is fixed at 10 mV.

\[ Gain = \frac{V_{out}}{10mV} \]

Induced voltages at the gate and drain terminals of the FET are computed with the FE-BI method at various amplitudes of plane wave illumination. Next, these voltages are modeled as extraneous sources in a single tone harmonic balance simulation to evaluate the effect on the LNA gain due to plane wave illumination. Implicitly, in this example, the values of input driving voltages and amplitudes of the external plane wave are chosen such that the LNA operates within the linear region, which is fairly typical of most LNA circuits. For large values of incident field amplitudes, the harmonics of each frequency point within the bandwidth of the LNA is utilized by the harmonic balance method to perform an accurate simulation. From Figure 5, as the amplitude of the plane wave is increased, the distortion in the gain of the LNA is increased. The LNA gain is increased at lower frequencies and subsequently decreases at higher frequencies. This deviation of the LNA gain from the designed gain is due to coherent constructive and destructive addition of the induced voltages on the driving signal at the gate and the drain of the LNA and not in the FET operating in the saturation region. When the LNA is connected to digital circuits, such EM interference may result in bit errors at the output terminal leading to improper functionality of the digital circuit.

Conclusion

In this paper, we employed fast frequency domain EM tools to analyze realistic EMI/EMC problems. We demonstrate that complex structures can be analyzed with modern surface and volumetric fast computational tools. Also, an integration of full wave methods with SPICE models via the harmonic balance method is introduced for modeling of EMI effects on active circuit devices. It can be seen that the hybridization of surface integral techniques with volumetric finite element method would utilize the strengths of both techniques. This allows the analysis of more complicated problems such as circuit board geometries within surface enclosures more efficiently and quickly.

References

\[ EFS = -20 \log \left( \frac{E_{\text{total}}}{E_{\text{inc}}} \right) dB \]

Fig 1: Validation of the MLFMM and the hybrid FE-BI analysis with measured data using the EFS parameter defined above.

Fig 4: Induced voltage at the end of the interdigital filter due to a 1V/m incident plane wave normal to the microstrip line filter.

Fig 5: Effect of the overall gain due to the plane wave illumination of the low noise amplifier circuit. The Plane wave is polarized in the x axis and is directed into the LNA.
Fig 2: Effect on electric shielding factor (EFS) in the engine compartment due to a simple wire harness transversing between the passenger and engine compartments.

A circularly Polarized crossed slot antenna is used as the excitation. (Freq = 1.475 GHz DAB)

Fig 3: EFS response evaluated within the engine compartment, due to an antenna excitation at the rear of the car, through a slot resonant at 0.7 GHz on the car’s dashboard.