FDTD Applications to Electromagnetic Interference and Shielding

M. Hussein and A. Sebak
Electrical and Computer Engineering Department, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6

Abstract— **The finite difference time domain method (FDTD) is applied to two electromagnetic interference (EMI) problems. The technique is used to simulate fields to wire coupling. Two types of excitation are used in this simulation: a plane wave excitation and dipole antenna. The effect of the shield (enclosure) presence on the strength of penetrated field is studied via the calculation of the shielding effect. The results obtained confirm the capability of the FDTD technique on modeling EMI problems.**

I. Introduction

Many environments have high levels of electromagnetic radiation due to a concentration of transmitting devices. Coupling of high level RF signals into electrical equipment occurs via power and interface cables, and via direct entry through cabinet or enclosure apertures. Other types of electrical equipment generate leakage of electromagnetic radiation during operation even though it is not their function to radiate. Time varying magnetic fields generated by rotating machinery could influence and degrade the performance of a nearby high resolution color monitor. Unwanted radiation from such sources can interfere with the operation of many electrical equipment.

The immunity of electrical equipment against any electromagnetic interference is known as the susceptibility of the system. It is thus important to test electrical equipment to determine how well it functions when subjected to unwanted electromagnetic radiation, and how will is it shielded against unintentional electromagnetic interference (EMI).

Another victim of the EMI is printed circuit boards (PCB). The EMI emission source that most modern digital electronic devices have in common is the direct current (DC) bus that supplies and distributes necessary electric power to integrated circuits. DC buses are used in almost all digital electronic devices, including satellite transmitters and receivers, electronic tools for medical research and care, personal computers, cellular and cordless telephones, and electronic games and toys. The DC bus becomes an unintentional radiating antenna when switching signals are emitted from the ICs. The simultaneous switching current at $200 MHz$ or at higher rates will induce on the DC bus a considerable current fluctuation at the clock frequency rate. Therefore, the DC bus plays a crucial role in coupling EMI from switching solid-state devices to both conducted and radiated paths. Predicting EMI from DC buses in digital equipment is a vast topic, a literature review on EMI in printed circuit boards was reported by Gravelle and Wilson [1]. The study provides a very good discussion on the EMI sources and the measures needed to insure voltage and current waveform integrity throughout the interconnecting paths. The suppression of conducted and radiated emission, and hardening against susceptibility failure are also discussed.

Thus, the problem of EMI can be classified into two classes, intrasystem problem, for which the EMI may come from within the system. The causes of such EMI may be owed to printed circuits, clock, and switching transients. The second class of EMI is the intersystem problem, which may come from outside causes and applications such as radio transmitters, microwave relay, air craft, local oscillator, radar transmitters, power lines and generators, and lightning strokes.

There is a great deal of complexity in the shape, interconnections and details of actual real life equipment and systems. Modeling such equipment is not an easy task. Some of the features necessary in the modeling method suitable for EMI studies and discussed in [2] and [3] are,

- it must be capable of modeling complex shapes,
- it must permit simultaneously the modeling of regions inside and outside a shield,
- it must be capable of modeling wire like structures,
- it must be suitable for modeling space with inhomogeneous properties,

IEEE CAT. NO. 95CH3581-6/0-7803-2741-1/95/$3.00

- it must be capable of dealing with open boundary problems,
- its application and interpretation must retain as much physical meaning as possible, to allow the user some feel of the nature of simplifications and assumptions necessary in any exercise of such complexity.

No numerical method can score the maximum in all items in the list above, however, some methods are better suited to EMI problems, *i.e.* method of moments, finite difference time domain and transmission line modeling.

II. Field to Wire Coupling

A generic EMI problem can be described as an equipment shield, which may consist of metallic or carbon-fiber composite parts and open slits (apertures). Part of the EM energy penetrates through parts of the shield and couples into the system (device) wiring, often, other penetration of the shield such as power cables, add further paths where EM radiation can couple into equipment.

An ideal EMI problem is given in Fig. 1, the goal here is to study the field coupling to a wire placed inside a shielded enclosure, such a problem required simultaneous modeling of the regions internal and external to the enclosure, apertures and wires.

The FDTD is used to model the box and the wire. The FDTD is a numerical technique developed by Yee [4]. It was nearly one decade before it was used to any great extent for actual applications. This is due to the lack of the necessary computer hardware capabilities. The FDTD technique offers many advantages as an electromagnetic modeling, simulation, and analysis tool. Its capabilities include,

- Arbitrary three-dimensional (3-D) modeling.
- Simulation of electromagnetic field interaction with objects of arbitrary conductivity and frequency-dependent material.
- Predicting the response of a system such as, scattered field, radiation pattern, radar cross-section (RCS), currents, penetration and interior coupling, and scattering parameters for a given excitation.

The basis of the FDTD code is the two Maxwell's curl equations in time-domain. These equations are expressed in a linearized form by means of central finite differencing. Only nearest-neighbor interactions need to be considered as the fields are advanced temporally in discrete time steps over spatial cells of rectangular shape. For more details on the technique the readers can refer to [5] and [6].

Two examples are considered for this application, in the first example a perfectly conducting box of dimensions $0.36 \times 0.6 \times 0.4$ meters is placed on a perfectly conducting ground. The box has an opening of dimensions $8 \times 12cm$ and a conducting wire of a radius $r = 1mm$ is placed at the center of the box with the upper end short-circuited to the box and the lower end terminated with a 50Ω. A pulsed plane wave with the electric field polarized parallel to the wire is incident on this box. The transient current in the 50Ω resistance is observed and recorded in Fig. 2. Results obtained using the FDTD simulation are in good agreement with the experimental result produced by [2].

The second example of the application of FDTD to this type of problem is considered for the configuration shown in Fig. 1. A perfectly conducting box of dimensions $0.546 \times 0.546 \times 0.546$ meters is placed in free space. A center fed dipole antenna of length 0.156 meter is placed a distance of 1 meter form the center of the conducting box, a wire of the same length as the dipole antenna is placed at the center of the box with its center loaded by a 50Ω resistor. The wire and the dipole antenna both are assumed to have a radius of $2.6mm$. The box has an opening in the $x-z$ plane of dimensions $13 \times 7.8cm$. The wire and the space surrounding it are modeled using FDTD. The space cell dimensions used in the modeling of the problem are $2.6 \times 2.6 \times 2.6cm$, and the box is modeled by assuming the surface tangential components of the electric field to be zero. The small radius wires, the dipole antenna and the wire, are modeled using the contour integral approximation. A Gaussian pulse is used to excite the dipole antenna, and the time step $\Delta t = \Delta/2c$ is used.

In order to get a good understanding of the EMI/EMC relation three different simulations will be implemented . The first simulation is to model the configuration in Fig. 1 without the box. The separation between the antenna and the wire is kept the same as described above. The effect of the dipole antenna presence on the wire is observed in Fig. 3, where the current through the 50Ω resistance is recorded. The shielding effect of the conducting box is recorded in Fig. 4, again the current through the 50Ω resistance is recorded, and it is clear that the box has reduced the EMI generated by the dipole antenna. Lastly, the slot in the conducting box is covered with a lossy absorbing material. The material has a permittivity $\varepsilon_r = 2.5$ and a conductivity $\sigma = 0.04$. It is evident from Fig. 5 that the absorbing material placed at the slot has reduced the coupling effect substantially.

The effect of the shield presence on the degree of electromagnetic interference is needed, this will help in the design of a proper enclosures and cabinets. To illustrate this effect, the structure in Fig. 1 is modeled without the wire. The same space increments and time stepping are used, then the field, in this case the E_z component, is observed at a position near the center of the box, for two simulations. In the first simulation the box is removed and the time-domain field response is recorded, see Fig. 6. Then the same field component is observed at the same position in the presence of the box, Fig. 7. It is clear from the two figures that the presence of the metallic box has reduced the interference generated from the external source. The frequency response of the two observations are recorded in Fig. 8 and Fig. 9, respectively. The effect of the shield presence is demonstrated by taking the ratio of $E_z(f)$ with shield and $E_z(f)$ with no shield, the results obtained are provided in Fig. 10.

IV. Conclusions

The FDTD technique was applied successfully to two important EMI/EMC problems. Field to wire coupling has been investigated and the results obtained are in very good agreement with measurements data available in literature. The shielding effect of a slotted metallic box has been calculated. One can conclude that the metallic box did provide a good shield except at selected frequencies, the resonance frequencies of the box, thus the designer should avoid having any of these frequencies as the operating frequency in the equipment needed to be enclosed by this specific enclosure. The capability of the FDTD to model EMI/EMC problem makes it a potential substitute to the available expensive EMC testing equipment.

Acknowledgement

The authors wish to acknowledge the financial assistance of the Natural Sciences and Engineering Research Council of Canada.

References

[1] L. B. Gravelle and P. F. Wilson. "EMI/EMC in printed circuit boards- a literature review". *IEEE Trans. Electromagn. Compat.*, 34:109–116, 1992.

[2] J. Herring, P. Naylor, and C. Christopoulos. "Transmission-line modeling in electromagnetic compatibility studies". *Int. J. Num. Mod.*, 4:143–152, 1991.

[3] B. Keiser. *"Principles of electromagnetic compatibility"*. Artech House, MA USA, 1987.

[4] K. Yee. "Numerical solution of initial value problems involving Maxwell's equations in isotropic media". *IEEE Trans. Antennas Propagat.*, vol. 14, pp. 302–307, 1966.

[5] A. Taflove and K. Umashankar. "The finite-difference time-domain method for numerical modeling of electromagnetic wave interactions". *Electromagn.*, vol. 10, pp. 105–126, 1990.

[6] M. Hussein and A. Sebak. "Application of the Finite-Difference Time-Domain Method to the Analysis of Mobile Antennas". *Accepted for publication at IEEE Trans. Vehicular Technology*, 1995.

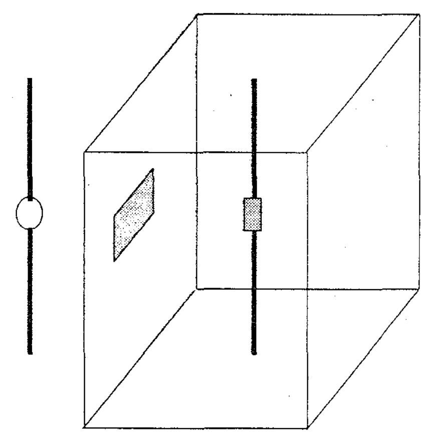

Fig. 1 Generic EMC problem geometry.

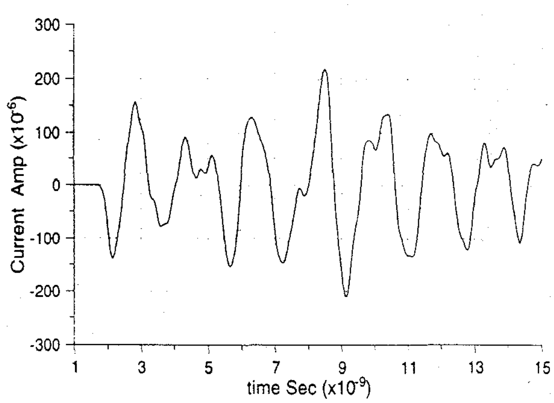

Fig. 2 Current in the 50Ω resistance due to coupling with the field due to plane wave excitation.

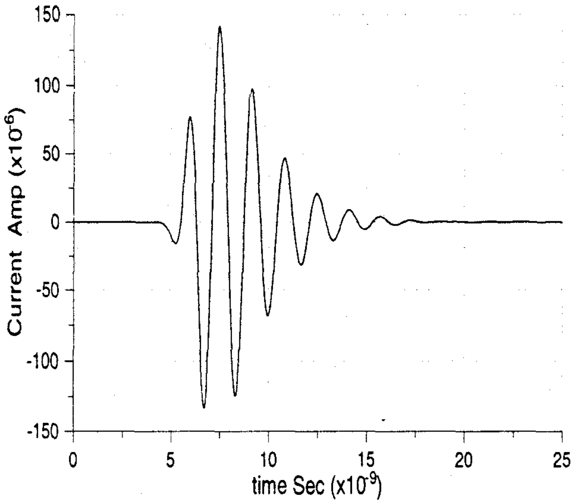

Fig. 3 Current in the 50Ω resistance due to coupling with the dipole field, with no box.

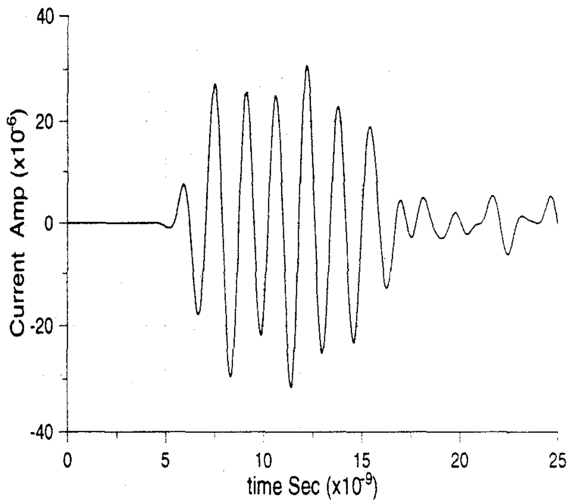

Fig. 5 Current in the 50Ω resistance due to coupling with the dipole field, with box and slot covered with absorbing material.

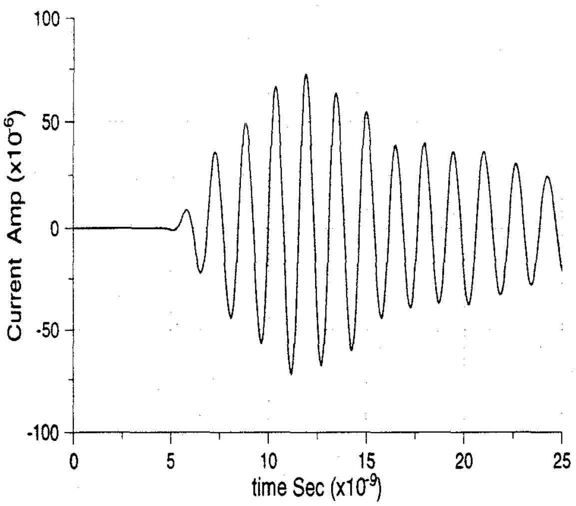

Fig. 4 Current in the 50Ω resistance due to coupling with the dipole field, with box and slot.

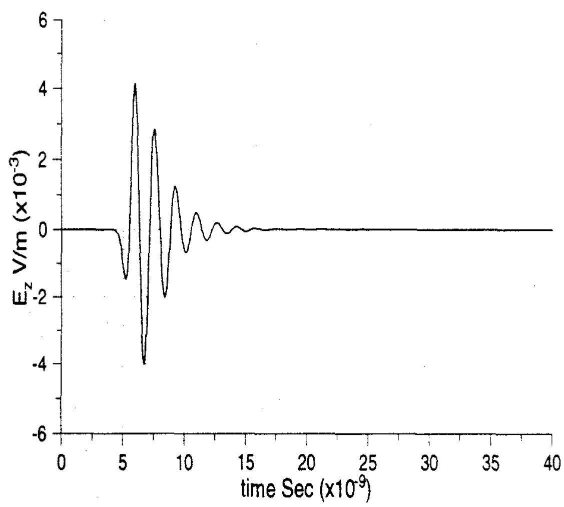

Fig. 6 Time-domain E_z response near the center of the box position, with no box present.

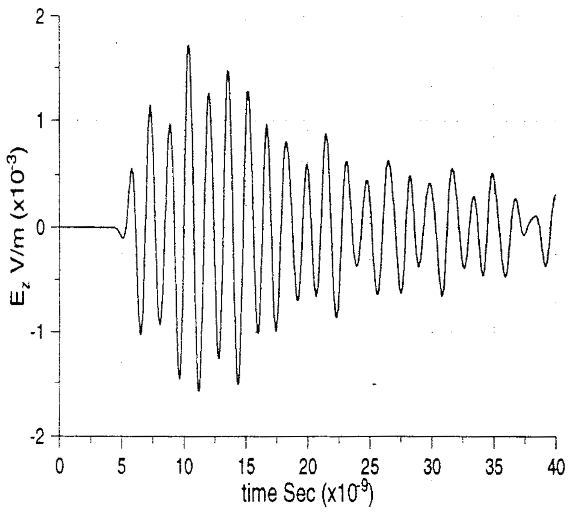

Fig. 7 Time-domain E_z response near the center inside the box.

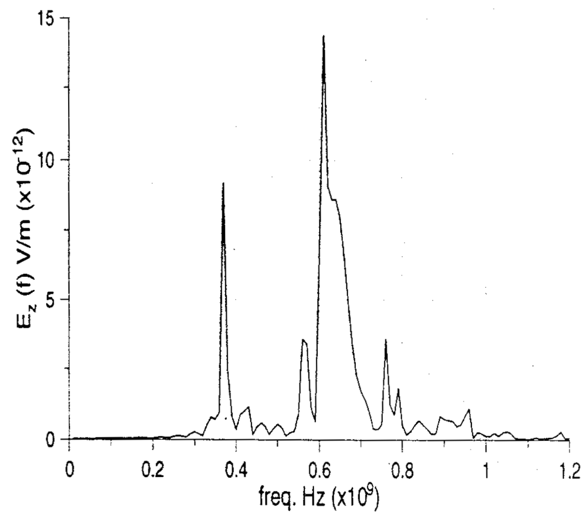

Fig. 9 Frequency response of the field near the center inside the box.

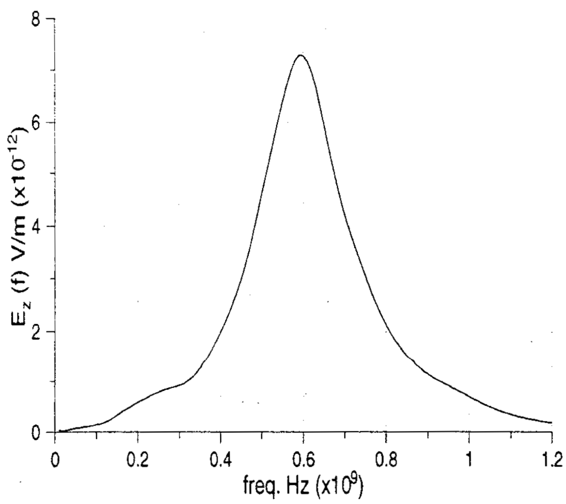

Fig. 8 Frequency response of the field near the center of the box position, with no box present .

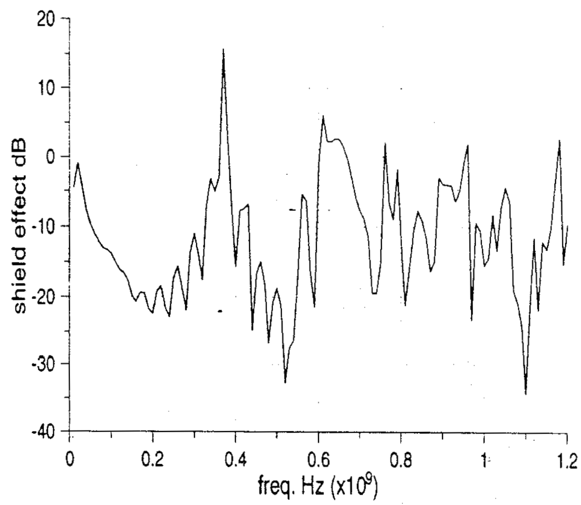

Fig. 10 Shielding effect of the conducting box with a slot.