Modeling Experiences With Full-Wave Time-Domain Modeling Software

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Abstract—**When evaluating electromagnetic modeling software, there is usually a significant focus on the "accuracy" of the software. Differences between the results generated by the software and the "correct" solution are the result of several potential sources of error including: approximations made in order to represent the actual configuration as a structure that the software can understand; approximations made during the discretization and solution of Maxwell's equations; and differences between what the modeler wants to analyze and what the software is actually modeling. Of these three potential error sources, the last one is usually the greatest source of error even when the analysis is being done by experienced modelers. In this paper, three full-wave time-domain EM modeling codes are evaluated by analyzing three simple canonical problems. These codes employ the three most common time-domain modeling techniques: the Transmission Line Matrix method (TLM), the Finite Integration Technique (FIT) and the Finite Difference Time Domain technique (FDTD). The three canonical problems are a center-driven dipole, a circuit board power-bus structure, and a power-bus structure with a cable attached. All of the codes are capable of yielding accurate results, but the differences in the specific technique employed and the user interface have a significant effect on the simulation time and the likelihood of getting the correct answer.**

Keywords—**Full-wave, numerical modeling, TLM method, FIT method, FDTD method**

I. Introduction

Full-wave electromagnetic modeling software is widely used to analyze antenna and microwave circuit configurations. It also has many applications related to the analysis of unintentional RF transmitters or receivers where electromagnetic interference (EMI) or susceptibility to electromagnetic fields is a concern. There are many commercial EM modeling tools available [1] ranging in price from a few hundred dollars to tens of thousands of dollars. There are also several free codes available [2]. Most of these tools are capable of analyzing a wide range of configurations that are relevant to EMC engineers.

In this paper, three full-wave time-domain EM modeling codes are evaluated by analyzing three simple canonical problems. These codes employ the three most common time-domain modeling techniques; the Transmission Line Matrix method (TLM), the Finite Integration Technique (FIT) and the Finite Difference Time Domain technique (FDTD). The three canonical problems are a center-driven dipole, a circuit board power-bus structure, and a power-bus structure with a cable attached. A companion paper, [3], analyzes these same three canonical problems using frequency-domain software.

II. Time-Domain EM Modeling Software

Time domain codes, in general, are well suited to the analysis of very large problems because they do not require the solution of very large matrices and they adapt well to massively parallel computation platforms. They are usually much better at calculating the response to time-domain excitations than frequency-domain codes; and, using a band-limited impulse as the excitation, they are capable of yielding broad-band results in the frequency domain relatively efficiently. Another advantage of time-domain codes is that complex and nonlinear materials can be relatively easy to incorporate in the analysis.

However, time-domain methods have their own disadvantages. For example, when using FDTD software, the fineness of the grid is generally determined by the dimensions of the smallest features in the whole structure being modeled [4]. Since changing the grid density introduces potential errors and significantly increases the amount of computation required, large structures with areas of fine detail are not modeled efficiently. The Finite Integration Technique is more efficient than FDTD when modeling structures that require a variable grid density; however, this technique has more difficulty modeling complex structures that have multiple or inhomogeneous materials [5]. The transmission line matrix method also overcomes some of the disadvantages of FDTD, but it requires significantly more computer memory per node [6].

Nevertheless, TLM, FIT and FDTD techniques are very powerful and widely used. Many modeling experts prefer the FDTD method because it is a relatively simple and direct approach to solve Maxwell's field equations. Those who are more familiar with circuit and transmission line theory may find it more intuitive and easier to work with the TLM method. Others may select the FIT method for its ability to

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work with flexible grid structures. For any given problem, there is probably one technique that is better suited than the other two; however the differences in the implementation of the technique are often much greater than the differences in the techniques themselves. For this reason, in most cases it is best not to select EM modeling software solely on the basis of which time-domain technique it uses to do the analysis.

III. CANONICAL PROBLEMS

In this paper three commercial time-domain codes were used to model three different canonical problems. Code A employs a TLM solver, Code B employs an FIT solver and Code C is an FDTD code. The canonical problems evaluated are a 1-meter center-driven thin wire dipole, a parallel plate structure resembling a circuit board power bus, and the same parallel plate structure with a 1-meter wire attached over an infinite ground plane.

These problems are generally simpler than the canonical structures described on the website of the IEEE EMC Society TC-9 committee [7]. The reason for choosing the simpler structures was to reduce the number of possible interpretations of the structure and ensure that there was only one well defined solution to each problem.

A. 1-meter center-driven dipole

The geometry of the center-driven dipole is shown in Fig.1. The dipole has a length, l = 1 meter and a radius, a = 0.5 mm. The half-wavelength resonant frequency is 150 MHz and the corresponding input impedance for an infinitely thin dipole would be 73 + j42.5 ohms at this frequency [8]. A more accurate impedance that accounts for the radius of the wire is closer to 83 + j45 ohms [3]. The user interface for each code allows the user to model the wire in different ways. The wire can be modeled by gridding throughout its volume with very small elements (Case 1); it can be modeled as a flat ribbon with a width equal to 4 times the wire radius (case 2); or it can be modeled using a thin-wire approximation that essentially places the wire along the corner of grid elements (Case 3). The accuracy and the efficiency of the model are greatly affected by this choice, but the user interface provides no guidance to the user. In most cases, the default choice was not the most efficient.

For these simulations, the gap between two antenna parts was 1 mm in Case 1 and Case 2. It was unspecified in Case 3. A 1-volt voltage source with a 50-ohm resistor in series was used to excite the antenna. Table 1 lists the simulation results obtained using the three codes. The input impedance was calculated at 150 MHz and the resonant frequency (lowest frequency where the reactance is zero) was also obtained. The results show that the resonant frequency and the impedance at 150 MHz using a flat ribbon (Case 2) are nearly the same as those obtained using the cylinder structure (Case 1); however, the time required to analyze the ribbon structure was less than half the time required to analyze the cylinder. The simulation time decreased greatly when the thin wire approximation Code A and Code C was employed. Code B took the shortest amount of time to model the center-driven dipole.

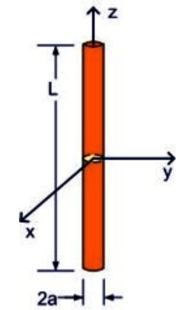

Fig.1. Geometry of center-driven dipole antenna.

Table 1. Results for cylindrical dipole from three different codes

		Code A	Code B	Code C
Case 1	Input impedance (Ohm)	79.7 + j46.1	85.1 + j34.7	81.1 + j52.3
	Resonant frequency (MHz)	144.3	145.2	143.6
	Simulation time (Min)	677	< 1	167
Case 2	Input impedance (Ohm)	79.5 + j46.2	84.6 + j34.2	81.3 + j52.0
	Resonant frequency (MHz)	144.0	145.4	143.6
	Simulation time (Min)	326	<1	51
Case 3	Input impedance (Ohm)	76.6 + j24.1		82.2 + j53.6
	Resonant frequency (MHz)	147.0		143.1
	Simulation time (Min)	5		4

B. Modeling a power-bus structure

Fig. 2 shows the circuit board power-bus structure. This canonical geometry is basically a pair of perfectly conducting planes with a slightly lossy dielectric material between them. The structure has dimensions of 125 mm × 100 mm × 1 mm. The dielectric material has a relative electric permittivity of 4.5 and loss tangent of 0.015. A voltage source (1 volt, 50 ohms) is located in the middle of the short edge. The input impedance and radiated electric field were obtained in the frequency range from 5 MHz to 2 GHz. In this frequency range, with this source position, the following cavity resonances are excited: TM_{10}@566MHz, TM_{20}@1.13GHz, TM_{02}@1.41GHz, TM_{12}@1.52GHz, TM_{30}@1.7GHz, and TM_{22}@1.81GHz.

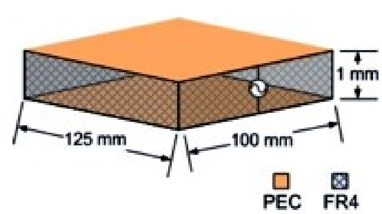

Fig.2. Geometry of the power-bus structure.

A constant loss tangent cannot be specified for the time domain codes used in this paper. In fact, strictly speaking, constant loss tangent materials do not exist. One approach for modeling the loss was to set the conductivity of the dielectric to 0.005 S/m, which corresponds to a loss tangent of 0.015 at 1 GHz. This results in slightly more loss at low frequencies and slightly less loss at high frequencies than specified in the statement of the problem. Another (less efficient) approach was to adjusted the conductivity to match the loss tangent at each frequency of interest and re-run the analysis. Fig. 3 show the results obtained from Code A when the conductivity was set to match a loss tangent of 0.015 at each of the resonant frequencies. The peak impedances obtained at the resonant frequencies closely match the results obtained using a frequency domain (finite element) modeling code.

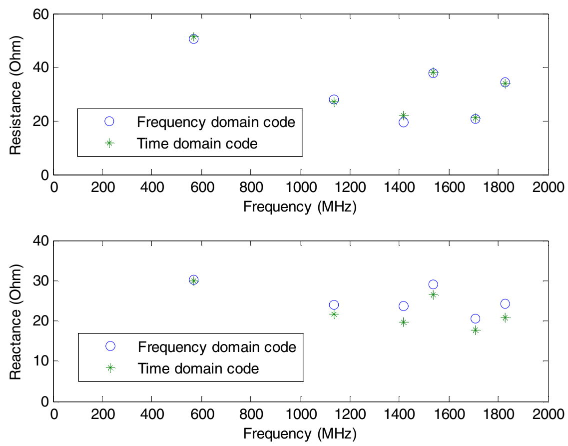

Fig.3. Comparison of the peak values of the input impedance obtained using a frequency domain code and the time domain Code A.

A nearly constant loss tangent can be simulated using Debye parameters. In this case, the frequency dependent permittivity is given by [9].

$$\varepsilon(j\omega) = \varepsilon' - j\varepsilon'' = \varepsilon' - j\varepsilon' \tan\delta \qquad (1)$$

where $\varepsilon' = \varepsilon_\infty + \dfrac{\varepsilon_s - \varepsilon_\infty}{1+\omega^2\tau^2}$ and $\varepsilon'' = \dfrac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{1+\omega^2\tau^2}$. These parameters are obtained by setting the derivative of the loss tangent to zero at a given frequency ω_0. Then, the relaxation time τ, the infinite frequency relative permittivity ε_∞, and the static relative permittivity ε_s can be computed as follows:

$$\tau = \frac{\tan\delta + \sqrt{1+\tan^2\delta}}{\omega_0} \qquad (2)$$

$$\varepsilon_\infty = \frac{1+\omega_0^2\tau^2}{2\omega_0^2\tau^2} \cdot \varepsilon_r \qquad (3)$$

$$\varepsilon_s = \frac{1+\omega_0^2\tau^2}{2} \cdot \varepsilon_r \qquad (4)$$

Fig.4 shows the input impedance obtained by modeling the loss with Debye parameters using Code B and Code C. The derivative of the loss tangent was set to zero at 1 GHz, which is the middle of the frequency range of interest. The radiated electric field 3 meters away from the rectangular power-bus structure was calculated using all three codes and the results are shown in Fig.5. The results from the three codes generally agree with each other. The simulation time for each code is listed in Table 2. For Code C, a very long simulation time was required due to a very high grid density.

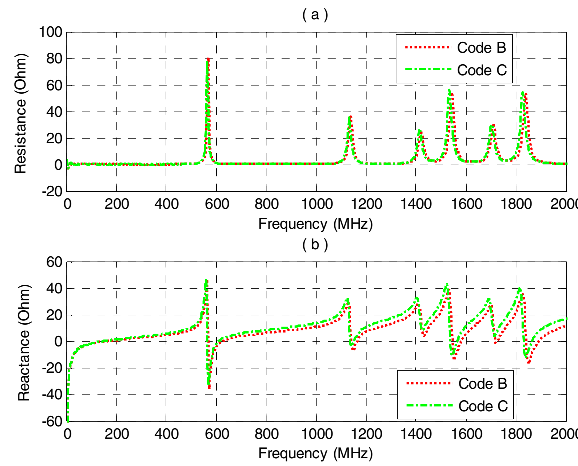

Fig.4. Input impedance of a rectangular power-bus structure obtained using two selected codes utilizing a dispersion dielectric material option.

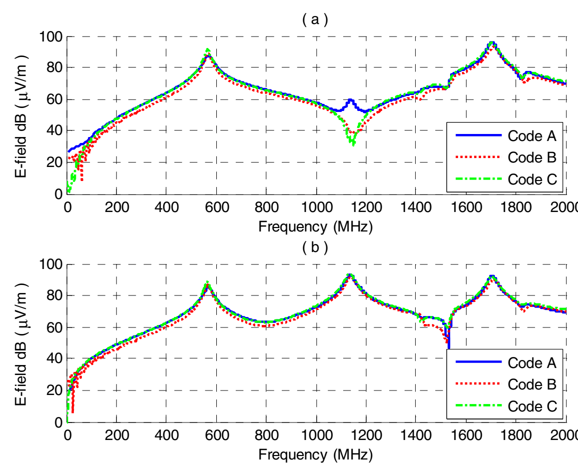

Fig.5. Radiated electric field from a rectangular power-bus structure for r = 3 m, θ = 0°, φ = 0°; (b) r = 3 m, θ = 90°, φ = 0°

Table 2. Time required to analyze the power-bus structure.

Code	Code A	Code B	Code C
Simulation time (Min)	30	39	540

C. Modeling a power-bus structure with a cable attached

Adding a cable and a ground plane to the previous structure significantly complicates the modeling process. Some codes are not capable of modeling this geometry and most codes have difficulty with it due to the large differences in scale (i.e. the thin dielectric and the long cable). The geometry of this canonical problem is shown in Fig.6 (not to scale). The wire is 1-meter long and has a circular cross section with a 2-mm radius.

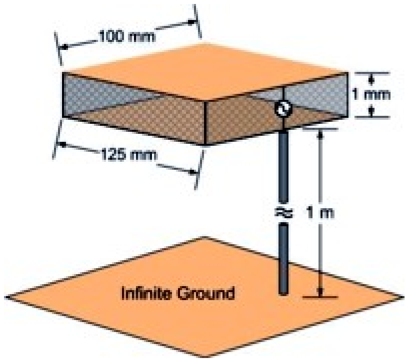

Fig.6. Geometry of a power-bus structure with a cable attached.

Fig.7 shows the radiated electric field 10 meters away from this structure calculated using Code A with the cable modeled as a round wire and a flat, 8-mm wide ribbon. The results using both cable models are consistent with each other. Code B and Code C generate similar results. The simulation times are listed in Table 3. Both Code B and Code C require a longer simulation time than Code A.

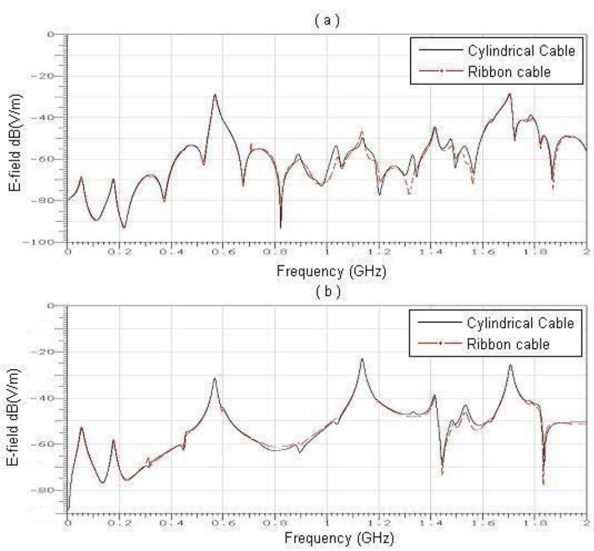

Fig.7. Radiated electric field from a rectangular power-bus structure with a cable attached calculated using Code A for (a) r = 10 m, θ = 0°, φ = 0°; (b) r = 10 m, θ = 90°, φ = 0°

Table 3. Time required to analyze the power-bus structure with a cable attached

		Code A	Code B	Code C
Simulation time (Hour)	Cylindrical cable	6	14	20
	Ribbon cable	4.5	10	14

IV. CONCLUSION

In this paper, TLM, FIT, and FDTD codes were evaluated by analyzing selected canonical problems. The results show that all three codes were capable of generating reasonably accurate solutions. For the problems considered, the FIT code was more efficient for modeling the wire dipole and the TLM code took the shortest time to get a reasonably accurate result for the power-bus structure with a cable attached. However, the differences in accuracy and efficiency were not due to inherent advantages of the techniques. It was the specific implementation of the technique and the user-interface that made the greatest difference.

More often than not the initial results obtained from the software were incorrect. The user interface allows the user to model configurations even when there are problems with the input or the mesh that prevent an accurate analysis. It is important that people using EM modeling software be very familiar with the limitations of the software and the modeling technique it employs. It is also important to have a pretty good idea of what the output should look like and to model several variations of the configuration under study before relying on the simulation results.

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