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Comparison of TLM and FDTD Methods in RCS Estimation

[1]R. Srinivasa Rao and [2]P.V. Subbaiah

[1]Professor, Dept of ECE, Sree Vidyanikethan Engineering College, Sree Sainatha Nagar, Tirupathi, India
[2]Principal, Amrita Sai Institute of Science and Technology, Paritala, Krishna Dist., India

Abstract

The two time domain methods, Finite Difference Time Domain (FDTD) and Transmission Line Matrix (TLM), are discussed and applied to typical but complex electromagnetic problems. Three dimensional (3D) TLM and FDTD algorithms are built in rectangular coordinates and are used in Radar Cross-Section (RCS) calculations. Mono- and bi-static RCS patterns of canonical structures are simulated via both techniques from low frequency (Rayleigh and resonance) region to high frequency (quasi-optical) region. Near fields are obtained via the two techniques and far fields, necessary for RCS calculations, are extrapolated via a time domain near-to-far field (NTFF) transformation based on the calculation of the equivalent currents over a closed virtual surface enclosing the object under investigation. Off-line frequency analysis is done with discrete Fourier transform (DFT) followed by cartesian-polar transformation to obtain frequency domain behaviors. Good agreement between TLM and FDTD results are obtained and are presented for RCS.

Introduction

Transmission-Line-Matrix (TLM) [1] and Finite-Difference Time-Domain (FDTD) [2] methods have become almost the most important time-domain simulation techniques used in almost all kinds of electromagnetic (EM) problems. Since their first introduction, they both have found wide application areas in engineering problems. The advantage of the techniques is not just because they allow time-domain transient analysis (where broad band frequency responses can be obtained) but also because they allow the visualization of electromagnetic behaviors (such as propagation, scattering, coupling etc.). They have the ability to handle complex structures with arbitrary geometries where no analytical solutions have been found yet. The aim of this study is therefore to apply both techniques to some complex EM problems and to compare their results. These problems are chosen to be RCS calculations and antenna analysis.

The radar signature calculations play an essential role in designing today's surface and air targets with low RCS behaviors. The complete RCS signature is described by the frequency response of the target illuminated by plane waves from all possible angles. Practical RCS problems involve interaction of EM waves with complex propagation and scattering environments, where analytical solutions can hardly be derived. With today's fast and high capacity computers, it has become possible to investigate EM problems directly in time domain by either discretizing Maxwell's equations (FDTD technique) or by using the analogy between network and EM theories (TLM technique). These techniques have gained great priority in the last decade after the introduction of effective absorbing boundary conditions (ABCs) and near-to-far field (NTFF) transformations [4]. In TLM and FDTD algorithms both total and scattered field representations are used, where broad band RCS signature of a complex target can be calculated and antenna characteristics of various structures can be obtained. With the RCS algorithm, mono- and bi-static RCS modeling of discrete targets may be investigated in broad frequency regions. Symmetrical Condensed Node (SCN) structure is chosen for the TLM method [5]. Unit cells of SCN-TLM and FDTD are explained in detail and precautions those should be taken during the calculations and afterward comparisons are listed in [5] (therefore they are not repeated here). One should remember that SCN-TLM and FDTD techniques are based on different parameterizations; while voltages are being used in the former, electric and magnetic fields are handled in the latter. In Sec.II, brief information related to RCS simulations is given. Numerical applications are presented in Sec.III, where comparisons of TLM and FDTD simulations are discussed. Finally, the conclusions are outlined in Sec.IV.

RCS Analysis

TLM and FDTD can simulate near fields inside a finite discrete rectangular volume. Two additional simulations must be used to perform RCS and antenna calculations: Free-space simulation and far field extrapolation. The first one is essential to overcome artificial reflections introduced by the finite nature of the simulation volume. The finite rectangular volume is enclosed by effective ABCs (Higdon in TLM [5] and PML in FDTD [6]) to simulate free-space. The second one is essential for RCS simulations and for some of antenna parameter calculations, such as radiation patterns. A time-domain near-to-far field (NTFF) transformation technique based on equivalence principle is used in both techniques [4]. The object under investigation is located within the computation volume and illuminated by a broad band pulsed plane wave from any given direction with any polarization. The incident field is a plane wave of the first derivative of the Gaussian wave shape in time domain and is analytically specified at each point at each time step, as if it were propagating in free-space. Since both methods have different parameterization, obtaining the scattered fields show quite differences in the algorithms. In TLM algorithm, calculation of scattered field components is different, because this method uses voltage pulses. Each unit cell in TLM is represented with a scattering matrix, S (12×12 for free space), and reflected voltage pulses (V_r) are equal to the multiplication of S with incident voltage pulses (V_i). That is, $V_r = S \times V_i$. The scattering matrix for PEC bodies is diagonal with the elements equal to –1. So, one can easily see that $V_r = -V_i$ on PEC boundaries. Since electric and magnetic fields are defined in terms of 12 voltage pulses in TLM, the scattered fields are automatically obtained in the observation space when analytical incident plane wave illuminates PEC geometries. The purpose of this approach is to reduce the computation time and to simplify complexity of the algorithm. In literature [7], scattered fields are separated from total fields by implementing a connecting boundary routine in TLM algorithm, which requires more memory and increases computation time.

Numerical Implementations

Two different versions of RCS algorithms are built to perform RCS calculations. These are *Sn-RCS* and *Bi-RCS*. In Sn-RCS, RCS versus frequency of a target along a single direction for a mono or bi-static case may be obtained. In Bi- RCS, bi-static RCS behavior of the target at a chosen plane may be obtained at various frequencies [8].

First, a PEC rectangular plate is taken into account. It is a 10cm×10cm×0.5cm plate and is represented by 40×40×2 cells, where the unit cell size is $\Delta x=\Delta y=\Delta z=\Delta l=0.25$cm. Its frequency characteristics of back-scatter RCS is plotted in Fig.1 for two different illuminations. The bandwidth of the incident pulse is 9GHz, which satisfies the numerical dispersion conditions. The two illuminations represent two extreme cases; specular reflection and edge-diffraction. The results presented in the figure show good agreement between TLM and FDTD calculations. The discrepancy between the results is because of the spatial discretization. It is clearly observed that good agreement between the results needs at least 20 cells per minimum wavelength.

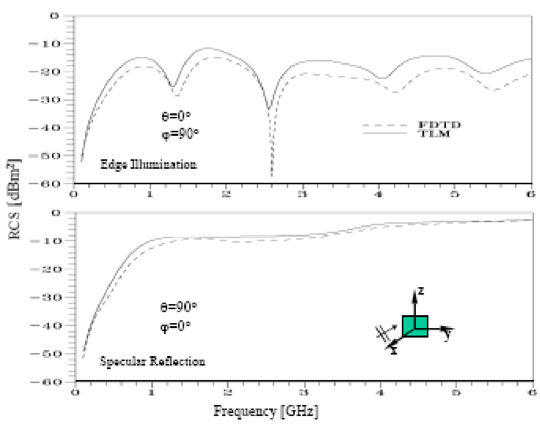

Figure 1: Mono-static RCS versus frequency at a chosen observation point.

Then, a PEC cube is used as the target and its bi-static RCS simulations are obtained with the two techniques. The results are given in Fig.2. Here, the two techniques are used once and broad band RCS behaviors are obtained for θθ case. Six of them are plotted in the figure, representing the Rayleigh and resonance regimes. The results are normalized to their maxima, which are mentioned on right top of the plots. The dynamic range of the plots are same (i.e., 30dB), which means a 6dB difference between concentric dashed circles.

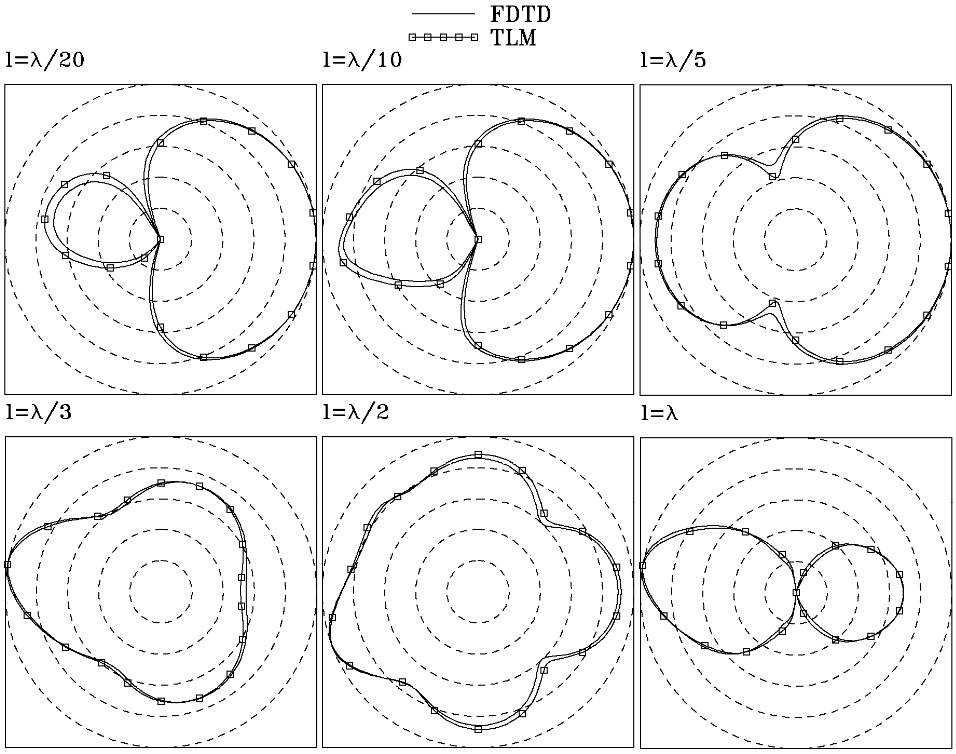

Figure 2: Bi-static RCS patterns at a chosen plane.

Conclusions

In this study, important EM problems are handled via powerful time-domain techniques. The aim is to present how powerful numerical techniques should be used in dealing with these complex problems. Since analytical reference solutions are rarely available for these kinds of problems, attention should be paid to interpreting the results obtained via these numerical simulation techniques. The results should be supported either with measurements or be compared against each other in order to gain confidence. The results presented here show the effectiveness of TLM and FDTD techniques. It should be noted that computation time and memory requirements are as important as numerical agreement. TLM needs more computation time and memory, but seems less sensitive to numerical dispersion. Similar comparisons should be done for lossy structures, since only PEC bodies are of interest in this study.

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