Time Adaptive Time-Domain Techniques for the Design of Microwave Circuits

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Abstract

The recently developed MRTD schemes are used for the development of a time adaptive time-domain technique for circuit design. The new technique exhibits considerable savings in memory and computational times in comparison to the conventional FDTD scheme.

I Introduction

Significant attention is being devoted now-a-days to the analysis and design of various types of microwave circuits. The finite-difference-time-domain (FDTD) scheme is one of the most powerful numerical techniques used for numerical simulations. However, despite its simplicity and modeling versatility, the FDTD scheme suffers from serious limitations due to the substantial computer resources required to model electromagnetic problems with medium or large computational volumes. In addition, the FDTD scheme cannot provide the accuracy required for computer simulations of time-dependent electromagnetic interactions in electrically long regions or in regions which contain non-linear materials. Such simulations are very important for integrated device modelling, especially in relation to the design of non-linear photonic devices. To alleviate these problems hybrid combinations of FDTD with other numerical techniques and higher order FDTD schemes based on Yee's grid have been proposed. MRTD (MultiResolution Time Domain Method) [1, 2] has shown unparalled properties in comparison to Yee's FDTD. MRTD is not a new methodology. It is a correct and accurate generalization of the conventional discretization approaches. It provides the correct mathematical frame for solving problems in time domain and allows for the development of time/space adaptive grids.

II Introduction to MRTD

It is well known that the method of moments provides a mathematically correct approach for the discretization of integral and partial differential equations. Since it allows for the use of any complete and orthonormal set, the choice of an appropriate expansion set may lead to different time domain schemes. For example, the expansion of the unknown fields using pulse

0-7803-4178-/3/97/$10.00 © 1997 IEEE

functions leads to Yee's FDTD scheme. In a MRTD scheme the fields are represented by a two-fold expansion in scaling and wavelet functions with respect to time/space. Scaling functions guarantee a correct modelling of smoothly-varying fields. In regions characterized by strong field variations or field singularities, higher resolution is enhanced by incorporating wavelets in the field expansions. Wavelets are introduced only at specific locations, allowing for a time/space adaptive grid capability.

MRTD schemes based on cubic spline Battle-Lemarie scaling and wavelet functions (Fig.1) have been successfully applied to the simulation of 2D and 3D open and shielded problems [1, 2, 3, 4]. The functions of this family do not have compact support, thus the MRTD schemes have to be truncated with respect to space. Localized boundary conditions (PECs, PMCs etc.) and material properties are modelled by use of the image principle and of matrix equations respectively. However, this disadvantage is offset by the low-pass (scaling) and band-pass (wavelets) characteristics in spectral domain, allowing for an a priori estimate of the number of resolution levels necessary for a correct field modelling. In addition, the evaluation of the moment method integrals during the discretization of Maxwell's PDEs is simplified due to the existence of closed form expressions in spectral domain and simple representations in space domain. Dispersion analysis of this MRTD scheme shows the capability of excellent accuracy with up to 2 points/wavelength (Nyquist Limit). However, specific circuit problems may require the use of functions with compact support. For that reason, Haar basis functions have been utilized and have led to [5]. As an extension to this approach, intervalic wavelets of higher order may be incorporated into the solution of SPICE-type circuits. Results from that new technique will be shown at the Conference.

III Time Adaptive MRTD Scheme

The major advantage of the use of Mutiresolution analysis to time domain is the capability to develop time and space adaptive schemes. This is due to the property of the wavelet expansion functions to interact weakly and allow for a spatial sparsity that may vary with time through a thresholding process. The adaptive character of this technique is extremely important for the accurate modelling of sharp field variations of the type encountered in beam focusing in nonlinear optics, etc. The use of the principles of the multiresolution analysis for adaptive grid computations for PDEs has been suggested by Perrier and Basdevant [6]. To understand the fundamental steps of such an adaptive scheme for Maxwell's hyperbolic system, let's consider Maxwell's equations in 2D (1 for space and 1 for time):

$$\frac{\partial \hat{u}}{\partial t} = A\hat{u} = \begin{bmatrix} 0 & -\epsilon(z)^{-1}\frac{\partial}{\partial z} \\ -\mu(z)^{-1}\frac{\partial}{\partial z} & 0 \end{bmatrix} \hat{u}, \quad \hat{u} = (E(z,t), H(z,t))^T \quad , \tag{1}$$

After manipulation, the above equation can be written as

$$\mathbf{M}\hat{u} = \begin{bmatrix} \epsilon T_h^\dagger D_t & T_h^\dagger D_z \\ Z_h^\dagger D_z & \mu Z_h^\dagger D_t \end{bmatrix} \hat{u} = 0 \qquad (2)$$

where Z_h, T_h are half shift operators for space and time coordinates z,t and $Z_h^\dagger, T_h^\dagger$ are their Hermitian conjugates. D_t, D_z are difference operators given by:

$$D_t = \frac{1}{\Delta t}(\sum_{i=-9}^{8} a_{\phi t}(i)T^{-i} + \sum_{i=-9}^{9} a_{\psi t}(i)T^{-i}), \quad D_z = \frac{1}{\Delta z}(\sum_{i=-9}^{8} a_{\phi z}(i)Z^{-i} + \sum_{i=-9}^{9} a_{\psi z}(i)Z^{-i}) \quad , (3)$$

where a_ϕ, a_ψ are the coefficients associated with the scalar and the wavelet functions respectively. At each time step we keep both the wavelet field values that are larger than a given threshold as well as the adjacent values. An adjacent wavelet field value is defined on the basis of the wavelet resolution level(s) incorporated in the solution. Recently, an efficient space/time adaptive meshing prosedure was proposed [7] for Battle-Lemarie expansion functions. In this paper, intervalic wavelets are used for the expansion of the fields (Fig.2). The adaptive mesh will be applied to a variety of circuit problems and results will be discussed during the presentation.

IV Conclusion

A Time Adaptive Time-Domain Technique based on intervalic wavelets has been proposed and applied to various types of circuits problems with lumped and distributed elements. This scheme exhibits significant savings in execution time and memory requirements while maintaining a similar accuracy with conventional circuit simulators.

V Acknowledgments

This work has been partially funded by NSF.

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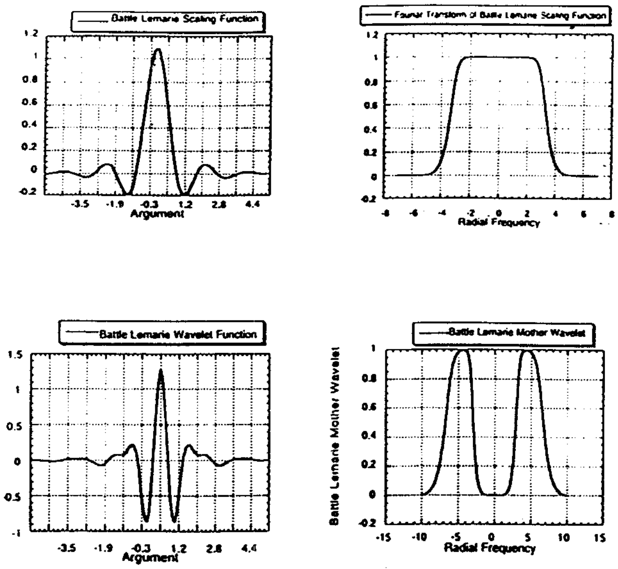

Figure 1: Battle-Lemarie Scaling and Wavelet Functions.

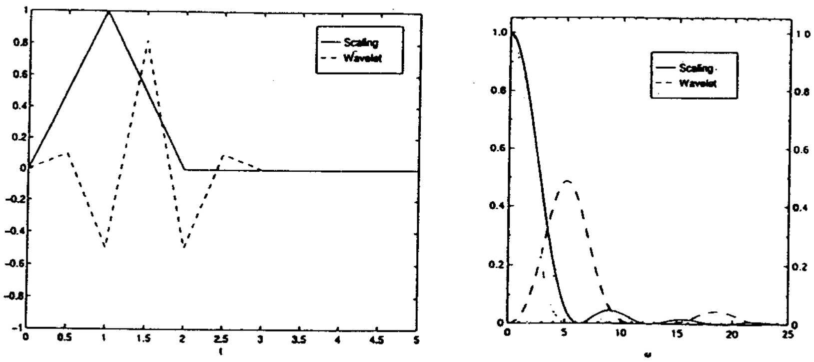

Figure 2: Intervalic Wavelets (Linear - Order 1).