INTRODUCTION & OBJECTIVES

One drawback of the conventional FDTD method, e.g., in [1], is that the smallest spatial step limits the maximal stable time step. Therefore, spatially highly discretized electromagnetic simulations are generally inefficient. In particular, EM simulations at low frequencies requiring detailed structures embedded within large environments would thus require tremendous runtime requirements. Typical applications include EMI and compliance of implanted devices for patients within MRI systems or general exposures to intermediate frequencies from 0.1 to 10 MHz.

To increase the time step, implicit time integration schemes, which are unconditionally stable, can be used. In 3-D the alternating direction implicit (ADI) FDTD method is an numerically efficient possibility [2,3,4]. ADI-FDTD is an approximate factorization of the Crank-Nicholson scheme (CN) applied to Yee discretization. On the other hand, conformal PEC FDTD models, reducing staircasing errors, may get a time step reduction to obtain the best accuracy. The objectives of this study were thus the development and implementation of a conformal ADI-FDTD solver in 3-D.

METHODS

All implementations and comparisons were performed within the framework of the 3-D EM TCAD platform SEMCAD X [5]. In contrast to published C-FDTD schemes, the C-ADI-FDTD model presented here uses the conventional ADI-FDTD algorithm but with locally modified update coefficients (no splitting of curl coefficients). Therefore, the original ADI-FDTD update equations are used, while the coefficients calculation is conformally enhanced.

Instead of the well known C-FDTD schemes, a new conformal PEC model [7] using modified but conventional update coefficients was adapted to the ADI-FDTD method. The derived stability criterion was used to favor either speed or accuracy depending on the controlling parameter CFL, the time step reduction. The conformal dielectric model uses effective electromagnetic properties calculated in the area perpendicular to the dielectric edge. In detail, arithmetic averaging weighted with the conformal area fraction defines the effective electromagnetic properties. Furthermore, no additional memory or CPU time is needed for the C-ADI-FDTD algorithm compared to the conventional ADI-FDTD method. The proposed conformal PEC scheme is similar to the very recently (May 2006) published ADI-CFDTD implementation of a conformal ADI-FDTD solver in 3-D.

CONFORMAL ADI-FDTD THEORY

The proposed C-ADI-FDTD scheme uses the conventional ADI-FDTD updating equations but enhances the way of determining the updating coefficients with the geometrical details of the model. Therefore, the description of the method is organized by firstly explaining the connection between the conventional FDTD coefficients and the ADI-FDTD coefficients and secondly by the modifications to the FDTD coefficient functions due to the conformal enhancements.

The well known conventional Yee FDTD update scheme can be written as

$$E^{n+1} = \alpha E^n + \beta E^n$$

where $E$ and $H$ denote the electric and magnetic field, $\Delta t$ is the time step, $\alpha$ and $\beta$ are the conventional FDTD update coefficients, and $n$ indicates the time $n \times \Delta t$.

The derivation of the ADI-FDTD algorithm starts with the same spatial discretization but with electric and magnetic fields coalesced in time. With a similar notation as in [3] the two subiterations of the ADI-FDTD scheme for the $E_{(x)}$ field reads

1. Subiteration $E_{(x)} \left[ \frac{\partial H}{\partial y} + \frac{\partial H}{\partial z} \right] = \beta \left[ \frac{\partial H}{\partial y} + \frac{\partial H}{\partial z} \right]$

2. Subiteration $E_{(x)} \left[ \frac{\partial H}{\partial y} + \frac{\partial H}{\partial z} \right] = \alpha \left[ \frac{\partial H}{\partial y} + \frac{\partial H}{\partial z} \right]$

where $\hat{E}$ and $\hat{H}$ denote intermediate but non-physical field values.

RESULTS & BENCHMARKS

Starting with canonical validations, the versatile usage of the proposed C-ADI-FDTD method is demonstrated on real applications with increased complexity.

CONFORMAL DIELECTRIC SCHEME

The dielectric model is based on the widely used effective material properties. For the electric permittivity, the formula reads.

$$\varepsilon_{\text{eff}} = \varepsilon_{\infty} + \frac{\varepsilon_{\text{rel}} - 1}{2}$$

Again, the conformal enhancement for the C-ADI-FDTD method is formulated with the conventional ADI-FDTD coefficients, but with modified material parameters.

BENCHMARK 1: VALIDATION WITH MIE SCATTERING

As canonical benchmark example, the scattering of a metal sphere was investigated on the near and scattered field. The total field, scattered field technique [13] adapted to ADI-FDTD was used to irradiate the sphere by an incident plane wave at a frequency of 100MHz. Mie series served as analytical reference solution. The boundary was terminated with 10 layers of UPML. The simulation was performed at 100MHz with a uniform grid resolution of 8mm, which gives oversampled 375 grid points per wavelength. The discrete norm $\| \|_{d} = \sqrt{\sum_{k=1}^{K} \left( \sum_{n=1}^{N} |X_{kn}|^2 \right)}$ was used to compare the calculated E field to the analytical solution.

Figure 1 depicts the relative norms of the near field errors of the ADI-FDTD and C-ADI-FDTD methods. With the conventional FDTD time step (CFL = 1), the accuracy of the two ADI algorithms recover the accuracy of the FDTD and C-FDTD methods.
The relative permittivity of the dielectric is 2.7. The coaxial cable is bent 90 degrees with a radius of 2mm of the coaxial center line. The non-uniform grid resolves the inner and outer radius with 4 and 13 cells, respectively.

The two open boundaries are terminated with a 10 layered UPML absorbing boundary. Figure 2 shows the model in the graphical user interface of the simulation platform. Comparisons between C-ADI-FDTD simulations and the FDTD reference simulation bear on E field modules or H field modules corresponding FDTD simulation (used as the reference simulation). For all simulations, PML absorbing boundaries [6] have been run for different time steps and are compared with their reference simulation. The deviations between the FDTD reference simulation and the ADI-FDTD simulations are very small up to a time step of 32CFL as indicated in Table 1. This benchmark shows not only that ADI-FDTD is as robust as FDTD for complex simulations but also that it is significantly more efficient.

CONCLUSIONS

Aside from canonical benchmarks, complex CAD based electromagnetic engineering problems have demonstrated the suitability and benefits of the presented C-ADI-FDTD method compared to the conventional FDTD method. Since the ADI-FDTD scheme decreases accuracy with increasing overtuning of the conventional timestep, a tradeoff between speed and accuracy has to be taken into account. However, the developed C-ADI-FDTD method allows the effective computation of complex CAD derived configurations, in particular for overdisscretized models, which would require unacceptable runtime requirements using conventional FDTD. Furthermore, the proposed conformal ADI-FDTD scheme has neither an impact on the memory consumption nor on the speed compared to the conventional ADI-FDTD method, since both use the conventional ADI-FDTD coefficients. Therefore, the C-ADI-FDTD method improves the accuracy of simulation results without deficiencies and should be favored even over the ADI-FDTD method.

ACKNOWLEDGEMENTS

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REFERENCES

[10] B. H. H. F. and M. K. S. H. D. E. T. C. H. E. N. G. R. E. N. G. I. N. (NRC, Finland) aiming at evaluating to which degree FDTD is capable of accurately simulating an entire CAD derived model (CATIA) of the NOKIA 8310 (Figure 3).

BENCHMARK 3: NOKIA 8310

Our objective was to replicate with the ADI-FDTD solver a previous joint study carried out with the Nokia Research Center (NRC, Finland) aiming at evaluating to which degree FDTD is capable of accurately simulating an entire CAD derived model (CATIA) of the NOKIA 8310 (Figure 3).

An important aspect of this study concerns the near-field analysis in which E-fields (dB normalized to maximum) are compared for the DCS1800 band in two horizontal planes located at 3 mm from either side of the phone. The ADI-FDTD simulations have been run for different time steps and are compared with their corresponding FDTD simulation (used as the reference simulation). For all simulations, PML absorbing boundaries [6] are used. The time steps of the C-ADI-FDTD simulations are specified as multiples of the CFL criteria. Comparisons between C-ADI-FDTD simulations and the FDTD reference simulation bear on E field modules or H field modules and are characterized by their deviation calculated by

Both ADI-FDTD and FDTD simulations show that the energy is mostly radiated out of the back of the phone through the high E-fields located above the antenna (Figure 4). This is desirable because the energy is thus directed away from the user, as intended with the use of an integrated antenna.

Comparing the two conformal schemes reveals, that the ADI-FDTD simulations are very small up to a time step of 32CFL as indicated in Table 1. This benchmark shows not only that ADI-FDTD is as robust as FDTD for complex simulations but also that it is significantly more efficient.

<table>
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Table 1: phone simulations: comparisons of E field deviations from reference FDTD simulation for different time step factors (CFL).

BENCHMARK 2: BENT COAXIAL CABLE

This benchmark shows a bent coaxial cable. The outer and inner radius of the cable are 0.1435mm and 0.6mm, respectively. The relative permittivity of the dielectric is 2.7. The coaxial cable is bent 90 degrees with a radius of 2mm of the coaxial center line. The non-uniform grid resolves the inner and outer radius with 4 and 13 cells, respectively. The two open boundaries are terminated with a 10 layered UPML absorbing boundary. Figure 2 shows the model in the graphical user interface of the simulation platform.

Comparing the two conformal schemes reveals, that the presented C-ADI-FDTD methods needs more than 17 times less time steps to complete the simulation. The immediate benefit of the C-ADI-FDTD scheme proposed in this publication is obvious.