INVESTIGATIONS INTO EIFFICIENT IMPLICIT LOD-FDTD USING ORTHOGONAL AND NON-ORTHOGONAL MESHES

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CERTIFICATE

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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ABSTRACT

In this thesis we aim to develop efficient, enhanced versions of locally one dimensional finite difference time domain (LOD-FDTD) using orthogonal and non-orthogonal meshes with convolutional perfectly matched layered (CPML) absorbing boundary condition (ABC) for solving a range of electromagnetic (EM) and microwave problems. To solve many real world propagation problems related to electrically large structures and compute the EM response from resonant and curved structures both in two dimensional (2-D) and three dimensional (3-D) employing orthogonal and non-orthogonal meshes, novel LOD-FDTD with CPML ABC are presented to render the problem manageable and treatable with available resources within a reasonable time frame and without placing an unrealistic burden on the computational resources.

In the first part of the thesis, a segmented (S)-LOD-FDTD method has been developed for EM propagation modelling in electrically large symmetric structures. After modifying 3-D symmetric structures to two dimensional (2-D) structures, the segmentation approach is applied. The developed S-LOD-FDTD method has been validated through propagation prediction inside large straight, branched and curved tunnels. The predictions on path loss agree reasonably well with the results obtained using segmented alternating direction implicit finite difference time domain (S-ADI-FDTD) method as well as with published measured data. The results indicate higher signal attenuation for the junction/transition regions as compared to regions away from such abrupt transitions. A performance comparison of the proposed method has also been described in terms of CPU time and memory. It was found that by dividing the domain into more segments, both execution time and memory usage can be reduced.

Subsequently, a non-orthogonal LOD-FDTD (LOD-NFDTD) method is presented for EM scattering from 2-D structures. Formulations of scattered field and CPML ABC in generalised non-orthogonal curvilinear grids for 2-D LOD-NFDTD are also presented. The non-orthogonal grids are used to fully mesh the computational domain, which leads to efficient computation. Moreover, the proposed technique requires fewer arithmetic operations than the nonorthogonal ADI-FDTD (ADI-NFDTD) method, leading to a reduction of CPU time. The numerical dispersion of the proposed method as a function of Courant-Friedrich-Lewy (CFL) number (CFLN) is also discussed. Computational

results for EM scattering from 2-D conducting, dielectric, and coated cylinders are presented. The proposed method is unconditionally stable and the numerical results agree reasonably well with the results in the literature, as well as with the ADI-NFDTD results. Compared to ADI-NFDTD, the proposed method is characterised by a lighter calculation burden and higher accuracy.

We also propose a dispersion controlled rotationally symmetric LOD-FDTD (D-RS-LOD-FDTD) method for analysing rotationally symmetric (RS) microwave structures and antennas. First, the formulation for conventional RS-LOD-FDTD with CPML ABC is presented. Then D-RS-LOD-FDTD algorithm with CPML is derived and utilised to reduce the dispersion that may result from modelling RS microwave structures. As a preliminary calculation, the open tip monopole (OTM) antenna has been analysed. The dispersion control parameters contribute to the improvement in accuracy even with a large time step beyond the CFL limit. Computational results for the return loss and specific absorption rate from OTM and expanded tip wire (ETW) antennas embedded inside a tissue-like phantom media are presented. The use of the dispersion control parameters not only reduces the resultant dispersion effectively but also enables us to employ a large time step for efficient computations, so that the computation time can be reduced to about half of that required for its explicit counterpart (RS-FDTD).

We also present a two sub-step CPML ABC for the conventional (C)-LOD-FDTD method for both orthogonal and non-orthogonal curvilinear meshes for analysing 3-D microwave structures. Numerical results on three dimensional (3-D) microwave structures using the proposed methods are also presented. A fundamental scheme based LOD-FDTD (F-LOD-FDTD) for both orthogonal and non-orthogonal meshes are proposed to minimise the resultant computational load for solving 3-D microwave structures, in addition to freeing the right-hand side of the resultant update equations of matrix operations. Numerical stability of the F-LOD-FDTD for both orthogonal and non-orthogonal meshes is also presented to demonstrate the unconditional stability of the proposed methods. Numerical results are presented to illustrate the significance of the proposed approaches. A comparison with the C-LOD-FDTD-CPML in terms of CPU time and memory requirements reveals the merits of the proposed F-LOD-FDTD CPML method for both orthogonal and non-orthogonal curvilinear meshes in terms of lighter calculation burden and higher efficiency.

DEDICATION

To my parents, wife, and family

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List of Symbols

E	vector electric field intensity (volts/meters)
$E_{x,y,z}$	electric field intensity in x, y, z directions (volts/meter)
E^{inc}	incident electric field intensity (volts/meter)
E^{scat}	scattered electric field intensity (volts/meter)
E^{tot}	total electric field intensity (volts/meter)
H	vector magnetic field intensity (amperes/meters)
$H_{x,y,z}$	magnetic field intensity in x, y, z directions (amperes/meter)
H^{inc}	incident magnetic field intensity (amperes /meter)
H^{scat}	scattered magnetic field intensity (amperes /meter)
H^{tot}	total magnetic field intensity (amperes /meter)
Δx, Δy, Δz	space increment in x, y, z directions (meters)
i, j, k	mesh index in x, y, z directions
Δt	time increment (seconds)
ε	permittivity (farads/meters)
ε_0	free space permittivity (farads/meters)
ε_r	relative permittivity (farads/meters)
$\varepsilon_{x,y,z}$	permittivity components in in x, y, z directions defined in stretched coordinate method (farads/meters)
$\varepsilon_{xt,yt,zt}$	permittivity components in in x, y, z directions defined in traditionally (farads/meters)
μ	permeability (henries/meters)
μ_0	free space permeability (henries /meters)
μ_r	relative permeability (henries /meters)

$\mu_{x,y,z}$ permeability components in in x, y, z directions defined in stretched coordinate method (henries /meters)

σ electrical conductivity (siemens/meters)

$\sigma_{x,y,z}$ electrical conductivity components in in x, y, z directions defined in stretched coordinate method (siemens/meters)

$\sigma_{xt,yt,zt}$ electrical conductivity components in x, y, z directions defined in traditionally (siemens/meters)

σ^* magnetic conductivity

$\sigma^*_{x,\,y,\,z}$ magnetic conductivity components in in x, y, z directions defined in stretched coordinate method

$\sigma^*_{xt,\,yt,\,zt}$ magnetic conductivity components in in x, y, z directions defined in traditionally

k vector wave propagation constant (radian/meter)

$k_{x,y,z}$ wave propagation constant components in x, y, z directions defined in

η electromagnetic wave impedance (ohm)

η_0 free space electromagnetic wave impedance (ohm)

c_0 free space electromagnetic wave velocities (meter/second)

f frequency (1/second)

ω angular frequency (radians/second)

J_s equivalent tangential electric currents density (amperes/meter)

M_s equivalent tangential magnetic currents density (volts/meter)

R normal reflection coefficient of PML region backed by a perfect conducting wall

r φ radius and angles in cylindrical coordinate

Acronyms and Abbreviations

1-D, 2-D	one dimensional, two dimensional
3D	three dimensional
ABC	absorbing boundary condition
ADI	alternating direction implicit
BOR	body of revolution
CPML	convolutional perfectly matched layer
C	conventional
DFT	direct Fourier transform
EM	electromagnetic
FDTD	finite difference time domain
F	fundamental scheme
FFT	fast Fourier transform
LOD	locally one dimensional
MoM	Method of moment
NF-FF	near field to far field
PEC	perfect electric conductor
PMC	perfect magnetic conductor
PML	perfectly matched layer
RS	rotationally symmetry
SF	scattered field
TEM	transverse electromagnetic
TE	transverse electric
TM	transverse magnetic