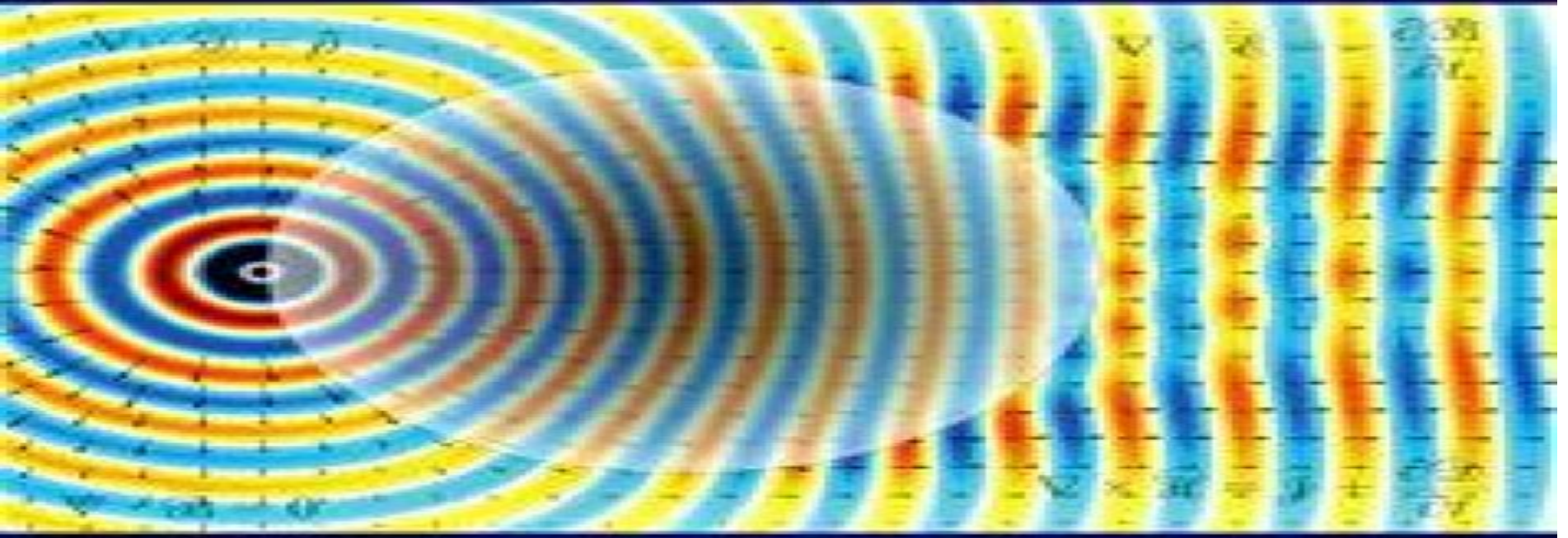
Numerical Electromagnetics

The FDTD Method



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Numerical Electromagnetics Umran S. Inan,Robert A. Marshall,2014-05-14 An introduction to the FDTD method for students and engineers without prior modeling experience *Numerical Electromagnetics* Umran S. Inan,Robert A. Marshall,2011-04-07 Beginning with the development of finite difference equations and leading to the complete FDTD algorithm this is a coherent introduction to the FDTD method the method of choice for modeling Maxwell s equations It provides students and professional engineers with everything they need to know to begin writing FDTD simulations from scratch and to develop a thorough understanding of the inner workings of commercial FDTD software Stability numerical dispersion sources and boundary conditions are all discussed in detail as are dispersive and anisotropic materials A comparative introduction of the finite volume and finite element methods is also provided All concepts are introduced from first principles so no prior modeling experience is required and they are made easier to understand through numerous illustrative examples and the inclusion of both intuitive explanations and mathematical derivations *Higher-Order FDTD Schemes for Waveguides and Antenna Structures* Nikolaos V. Kantartzis,Theodoros D. Tsiboukis,2006-12-01 This publication provides a comprehensive and systematically organized coverage of higher order finite difference time domain or FDTD schemes demonstrating their potential role as a powerful modeling tool in computational electromagnetics Special emphasis is drawn on the analysis of contemporary waveguide and antenna structures Acknowledged as a significant breakthrough in the evolution of the original Yee s algorithm the higher order FDTD operators remain the subject of an ongoing scientific research Among their indisputable merits one can distinguish the enhanced levels of accuracy even for coarse grid resolutions the fast convergence rates and the adjustable stability In fact as the fabrication standards of modern systems get stricter it is apparent that such properties become very appealing for the accomplishment of elaborate and credible designs

Adaptive Mesh Refinement in Time-Domain Numerical Electromagnetics Costas D. Sarris,2022-05-31 This monograph is a comprehensive presentation of state of the art methodologies that can dramatically enhance the efficiency of the finite difference time domain FDTD technique the most popular electromagnetic field solver of the time domain form of Maxwell s equations These methodologies are aimed at optimally tailoring the computational resources needed for the wideband simulation of microwave and optical structures to their geometry as well as the nature of the field solutions they support That is achieved by the development of robust adaptive meshing approaches which amount to varying the total number of unknown field quantities in the course of the simulation to adapt to temporally or spatially localized field features While mesh adaptation is an extremely desirable FDTD feature known to reduce simulation times by orders of magnitude it is not always robust The specific techniques presented in this book are characterized by stability and robustness Therefore they are excellent computer analysis and design CAD tools The book starts by introducing the FDTD technique along with challenges related to its application to the analysis of real life microwave and optical structures It then proceeds to developing an

adaptive mesh refinement method based on the use of multiresolution analysis and more specifically the Haar wavelet basis Furthermore a new method to embed a moving adaptive mesh in FDTD the dynamically adaptive mesh refinement AMR FDTD technique is introduced and explained in detail To highlight the properties of the theoretical tools developed in the text a number of applications are presented including Microwave integrated circuits microstrip filters couplers spiral inductors cavities Optical power splitters Y junctions and couplers Optical ring resonators Nonlinear optical waveguides Building on first principles of time domain electromagnetic simulations this book presents advanced concepts and cutting edge modeling techniques in an intuitive way for programmers engineers and graduate students It is designed to provide a solid reference for highly efficient time domain solvers employed in a wide range of exciting applications in microwave millimeter wave and optical engineering Adaptive Mesh Refinement in Time-Domain Numerical Electromagnetics Costas D. Sarris,2006-12-01 This monograph is a comprehensive presentation of state of the art methodologies that can dramatically enhance the efficiency of the finite difference time domain FDTD technique the most popular electromagnetic field solver of the time domain form of Maxwell s equations These methodologies are aimed at optimally tailoring the computational resources needed for the wideband simulation of microwave and optical structures to their geometry as well as the nature of the field solutions they support That is achieved by the development of robust adaptive meshing approaches which amount to varying the total number of unknown field quantities in the course of the simulation to adapt to temporally or spatially localized field features While mesh adaptation is an extremely desirable FDTD feature known to reduce simulation times by orders of magnitude it is not always robust The specific techniques presented in this book are characterized by stability and robustness Therefore they are excellent computer analysis and design CAD tools The book starts by introducing the FDTD technique along with challenges related to its application to the analysis of real life microwave and optical structures It then proceeds to developing an adaptive mesh refinement method based on the use of multiresolution analysis and more specifically the Haar wavelet basis Furthermore a new method to embed a moving adaptive mesh in FDTD the dynamically adaptive mesh refinement AMR FDTD technique is introduced and explained in detail To highlight the properties of the theoretical tools developed in the text a number of applications are presented including Microwave integrated circuits microstrip filters couplers spiral inductors cavities Optical power splitters Y junctions and couplers Optical ring resonators Nonlinear optical waveguides Building on first principles of time domain electromagnetic simulations this book presents advanced concepts and cutting edge modeling techniques in an intuitive way for programmers engineers and graduate students It is designed to provide a solid reference for highly efficient time domain solvers employed in a wide range of exciting applications in microwave millimeter wave and optical engineering **Time Domain Techniques in Computational Electromagnetics** Dragan Poljak,2004 A state of the art review from invited contributors Subjects covered include time domain analysis of electromagnetic wave fields by boundary integral equation method and transient analysis of thin wires and related time

domain energy measures **Numerical Techniques in Electromagnetics, Second Edition** Matthew N.O. Sadiku,2000-07-12 As the availability of powerful computer resources has grown over the last three decades the art of computation of electromagnetic EM problems has also grown exponentially Despite this dramatic growth however the EM community lacked a comprehensive text on the computational techniques used to solve EM problems The first edition of Numerical Techniques in Electromagnetics filled that gap and became the reference of choice for thousands of engineers researchers and students The Second Edition of this bestselling text reflects the continuing increase in awareness and use of numerical techniques and incorporates advances and refinements made in recent years Most notable among these are the improvements made to the standard algorithm for the finite difference time domain FDTD method and treatment of absorbing boundary conditions in FDTD finite element and transmission line matrix methods The author also added a chapter on the method of lines Numerical Techniques in Electromagnetics continues to teach readers how to pose numerically analyze and solve EM problems give them the ability to expand their problem solving skills using a variety of methods and prepare them for research in electromagnetism Now the Second Edition goes even further toward providing a comprehensive resource that addresses all of the most useful computation methods for EM problems Introduction to the Finite-Difference Time-Domain (FDTD) Method for Electromagnetics Stephen Gedney,2022-05-31 Introduction to the Finite Difference Time Domain FDTD Method for Electromagnetics provides a comprehensive tutorial of the most widely used method for solving Maxwell s equations the Finite Difference Time Domain Method This book is an essential guide for students researchers and professional engineers who want to gain a fundamental knowledge of the FDTD method It can accompany an undergraduate or entry level graduate course or be used for self study The book provides all the background required to either research or apply the FDTD method for the solution of Maxwell s equations to practical problems in engineering and science Introduction to the Finite Difference Time Domain FDTD Method for Electromagnetics guides the reader through the foundational theory of the FDTD method starting with the one dimensional transmission line problem and then progressing to the solution of Maxwell s equations in three dimensions It also provides step by step guides to modeling physical sources lumped circuit components absorbing boundary conditions perfectly matched layer absorbers and sub cell structures Post processing methods such as network parameter extraction and far field transformations are also detailed Efficient implementations of the FDTD method in a high level language are also provided Table of Contents Introduction 1D FDTD Modeling of the Transmission Line Equations Yee Algorithm for Maxwell s Equations Source Excitations Absorbing Boundary Conditions The Perfectly Matched Layer PML Absorbing Medium Subcell Modeling Post Processing **Parallel Finite-difference Time-domain Method** Wenhua Yu,2006 The finite difference time domain FTDT method has revolutionized antenna design and electromagnetics engineering This book raises the FDTD method to the next level by empowering it with the vast capabilities of parallel computing It shows engineers how to exploit the natural parallel

properties of FDTD to improve the existing FDTD method and to efficiently solve more complex and large problem sets Professionals learn how to apply open source software to develop parallel software and hardware to run FDTD in parallel for their projects The book features hands on examples that illustrate th Perfectly Matched Layer (PML) for Computational Electromagnetics Jean-Pierre Bérenger,2022-06-01 This lecture presents the perfectly matched layer PML absorbing boundary condition ABC used to simulate free space when solving the Maxwell equations with such finite methods as the finite difference time domain FDTD method or the finite element method The frequency domain and the time domain equations are derived for the different forms of PML media namely the split PML the CPML the NPML and the uniaxial PML in the cases of PMLs matched to isotropic anisotropic and dispersive media The implementation of the PML ABC in the FDTD method is presented in detail Propagation and reflection of waves in the discretized FDTD space are derived and discussed with a special emphasis on the problem of evanescent waves The optimization of the PML ABC is addressed in two typical applications of the FDTD method first wave structure interaction problems and secondly waveguide problems Finally a review of the literature on the application of the PML ABC to other numerical techniques of electromagnetics and to other partial differential equations of physics is provided In addition a software package for computing the actual reflection from a FDTD PML is provided It is available here The Finite Difference Time Domain Method for Electromagnetics Karl S. Kunz,Raymond J. Luebbers,2018-05-04 The Finite Difference Time domain FDTD method allows you to compute electromagnetic interaction for complex problem geometries with ease The simplicity of the approach coupled with its far reaching usefulness create the powerful popular method presented in The Finite Difference Time Domain Method for Electromagnetics This volume offers timeless applications and formulations you can use to treat virtually any material type and geometry The Finite Difference Time Domain Method for Electromagnetics explores the mathematical foundations of FDTD including stability outer radiation boundary conditions and different coordinate systems It covers derivations of FDTD for use with PEC metal lossy dielectrics gyrotropic materials and anisotropic materials A number of applications are completely worked out with numerous figures to illustrate the results It also includes a printed FORTRAN 77 version of the code that implements the technique in three dimensions for lossy dielectric materials There are many methods for analyzing electromagnetic interactions for problem geometries With The Finite Difference Time Domain Method for Electromagnetics you will learn the simplest most useful of these methods from the basics through to the practical applications

Electromagnetic Simulation Techniques Based on the FDTD Method W. Yu,2009-09-15 Bridges the gap between FDTD theory and the implementation of practical simulation techniques This is the first publication that guides readers step by step through the implementation of electromagnetic simulation techniques based on FDTD methods These simulation techniques serve as an essential bridge between FDTD methods and their applications Moreover the book helps readers better understand the underlying logic of FDTD methods so that they can design FDTD projects using either commercial

electromagnetic software packages or their own codes in order to solve practical engineering problems The book begins with two chapters that introduce the basic concepts of the 3 D Cartesian FDTD method followed by discussions of advanced FDTD methods such as conformal techniques dispersive media circuit elements and near to far field transformation Next the book Presents basic concepts of parallel processing techniques and systems including parallel FDTD techniques and systems Explores simulation techniques based on FDTD methods Illustrates practical simulation techniques using engineering applications Introduces advanced simulation techniques Each chapter concludes with references to help readers investigate particular topics in greater depth Each chapter also includes problem sets that challenge readers to put their new FDTD and simulation skills into practice By bridging the gap between FDTD theory and practical simulation techniques this publication is an invaluable guide for students and engineers who need to solve a wide range of design problems in RF antenna and microwave engineering **Advances in Computational Electrodynamics** Allen Taflove,1998 Finite Difference Time Domain FD TD modeling is arguably the most popular and powerful means available to perform detailed electromagnetic engineering analyses Edited by the pioneer and foremost authority on the subject here is the first book to assemble in one resource the latest techniques and results of the leading theoreticians and practitioners of FD TD computational electromagnetics modeling *Numerical Techniques in Electromagnetics with MATLAB* Matthew N.O. Sadiku,2015-09-11 Despite the dramatic growth in the availability of powerful computer resources the EM community lacks a comprehensive text on the computational techniques used to solve EM problems The first edition of Numerical Techniques in Electromagnetics filled that gap and became the reference of choice for thousands of engineers researchers and students This third edition of the bestselling text reflects the continuing increase in awareness and use of numerical techniques and incorporates advances and refinements made in recent years Most notable among these are the improvements made to the standard algorithm for the finite difference time domain FDTD method and treatment of absorbing boundary conditions in FDTD finite element and transmission line matrix methods The author also has added a chapter on the method of lines Numerical Techniques in Electromagnetics with MATLAB Third Edition continues to teach readers how to pose numerically analyze and solve EM problems to give them the ability to expand their problem solving skills using a variety of methods and to prepare them for research in electromagnetism Now the Third Edition goes even further toward providing a comprehensive resource that addresses all of the most useful computation methods for EM problems and includes MATLAB code instead of FORTRAN **Computational Electrodynamics** Allen Taflove,1995 This work represents a university text and professional research reference on the finite difference time domain computational solution method for Maxwell s equations Sections cover numerical stability numerical dispersion and dispersive nonlinear and gain methods of FD TD and antenna analysis **Advanced FDTD Methods** Wenhua Yu,2011 Advanced FDTD Methods Parallelization Acceleration and Engineering Applications Contents Preface Chapter 1 Computational Electromagnetic Methods 1 1 FDTD METHOD 1 1 1

FDTD Update Equations 1 1 2 Stability Analysis 1 1 3 Boundary Conditions 1 2 METHOD OF MOMENTS 1 3 FINITE ELEMENT METHOD 1 3 1 Scalar Formulation 1 3 2 Vector Formulation 1 4 FINITE INTEGRATION TECHNIQUE References Chapter 2 FDTD Optimization and Acceleration 2 1 INTRODUCTION TO CPU ARCHITECTURE 2 2 SSE INSTRUCTION SET 2 3 CACHE OPTIMIZATION 2 4 TASK PARALLELIZATION AND BUNDLING 2 5 PREFETCH 2 6 READING OR WRITING COMBINATION 2 7 MATERIAL LOOP UP TABLE 2 8 NUMA OPTIMIZATION 2 9 IMPLEMENTATION OF VALU FDTD METHOD References Chapter 3 Parallel FDTD Method and Systems 3 1 PARALLEL FDTD METHOD 3 2 OPENMP FOR MULTICORE PROCESSORS 3 3 MPI TECHNIQUE 3 4 NETWORK CARD SWITCH AND CABLE References Chapter 4 Electromagnetic Simulation Techniques 4 1 MESH GENERATION TECHNIQUES 4 2 BASIC SIMULATION PROCEDURE 4 3 DIPOLE ANTENNA 4 4 VIVALDI ANTENNA SIMULATION 4 5 BANDED MICROWAVE CONNECTOR 4 6 PARALLEL LINES 4 7 TWO PORT ANTENNA 4 8 SLOT COUPLING 4 9 MICROWAVE FILTER 4 10 OPTIMIZATION AND PARAMETER SCAN 4 11 PERIODIC STRUCTURE SIMULATION 4 12 GROUND PENETRATING RADAR MODEL 4 13 MICROWAVE CONNECTOR References Chapter 5 EM Simulation Software Benchmarks 5 1 BASIC STEPS IN EM SIMULATION 5 1 1 HFSS 5 1 2 CST 5 1 3 FEKO 5 1 4 GEMS 5 2 HARDWARE PLATFORMS 5 3 PATCH ANTENNA 5 4 VIVALDI ANTENNA 5 5 SCATTERING OF DIELECTRIC SPHERE 5 6 CELL PHONE ANTENNA 5 7 ELECTROMAGNETIC BANDGAP STRUCTURE 5 8 STANDARD SAR TEST 5 9 WAVEGUIDE FILTER References Chapter 6 Large Multiscale Problem Solving 6 1 RADIO FREQUENCY PROTECTION *Introduction to Time Domain Numerical Methods for Solving Electromagnetic Problems* Shunchuan Yang,Zhizhang (David) Chen,2016-09-15 This book introduces the time domain numerical methods to solve electromagnetic problems including finite difference time domain FDTD method the finite element method FEM and method of moment MOM It also presents emerging methods in the recent ten years for electromagnetics simulations All these methods can be unified under a single mathematic framework This is one of the few books to unify and compare different time domain methods and clarify their respective advantages and disadvantages **Essentials of Computational Electromagnetics** Xin-Qing Sheng,Wei Song,2012-03-22 Essentials of Computational Electromagnetics provides an in depth introduction of the three main full wave numerical methods in computational electromagnetics CEM namely the method of moment MoM the finite element method FEM and the finite difference time domain FDTD method Numerous monographs can be found addressing one of the above three methods However few give a broad general overview of essentials embodied in these methods or were published too early to include recent advances Furthermore many existing monographs only present the final numerical results without specifying practical issues such as how to convert discretized formulations into computer programs and the numerical characteristics of the computer programs In this book the authors elaborate the above three methods in CEM using practical case studies explaining their own research experiences along with a review of current literature A full analysis is provided for typical cases including characteristics of numerical methods helping beginners to develop a quick and

deep understanding of the essentials of CEM Outlines practical issues such as how to convert discretized formulations into computer programs Gives typical computer programs and their numerical characteristics along with line by line explanations of programs Uses practical examples from the authors own work as well as in the current literature Includes exercise problems to give readers a better understanding of the material Introduces the available commercial software and their limitations This book is intended for graduate level students in antennas and propagation microwaves microelectronics and electromagnetics This text can also be used by researchers in electrical and electronic engineering and software developers interested in writing their own code or understanding the detailed workings of code Companion website for the book www wiley com go sheng cem *Advances in FDTD Computational Electrodynamics* Allen Taflove,Ardavan Oskooi,Steven G. Johnson,2013 Advances in photonics and nanotechnology have the potential to revolutionize humanity s ability to communicate and compute This book helps readers understand the developments in computational modeling of nanoscale optical microscopy and microchip lithography as well as nanoscale plasmonics and biophotonics Techniques for Numerically Efficient Analysis of Multi-scale Problems in Computational Electromagnetics Kapil Sharma,2017 Multi scale problems in numerical electromagnetics are becoming increasingly common with the advent and widespread usage of compact mobile phones body area networks small and nano antennas sensors high speed interconnects integrated circuits and complex electronic packaging structures to name just a few commercial applications Numerical electromagnetic modeling and simulation of structures with multi scale features is highly challenging due to the fact that electrically small as well as large features are simultaneously present in the model which demands for discretization of the computational domain such that the number of degrees of freedom is very large thus levying a heavy burden on computational resources The multi scale nature of a given problem also exacerbates the challenge of generating very fine meshes which do not introduce instabilities or ill conditioned behaviors In this work we introduce a hybrid technique which combines frequency domain and time domain techniques in a manner such that the fine features electrically small of the object being modeled are handled by the Method of Moments MoM technique while the electrically large parts of the structure are dealt with by using the Finite Difference Time Domain FDTD technique in order to reduce the computational burden Recently structures with multi scale features have been simulated by using the dipole moment DM approach combined with the FDTD technique to handle fine features in a multi scale geometry However when the size of the scatterer becomes larger in terms of the wavelength and the quasi static assumption becomes invalid extensive modifications of the DM FDTD hybrid approach are needed resulting in a high computational cost The research proposes a novel hybrid FDTD technique which combines the Method of Moments and the Finite Difference Time Domain techniques directly in the time domain circumventing the need to carry out frequency transform calculations as required in the DM approach when the object size is not small size 20 The proposed technique utilizes piecewise sinusoidal basis functions to represent the currents on arbitrarily shaped wires with fine features and

modified RWG basis function for surfaces The fields scattered by the object with fine features in MoM region are computed in the time domain on a planar interface The time domain fields obtained at the planar interface are then combined with the FDTD update equations In contrast to the existing techniques used to handle this type of problems the proposed technique is both efficient as well as stable

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