Mini-symposium A6
Recent Advances in Finite-Difference Time-Domain Method

Organizers:
Ching Eng Png Jason
Institute of High Performance Computing, A*STAR, Singapore
Email: pngce@ihpc.a-star.edu.sg
Yaxin Yu
Institute of High Performance Computing, A*STAR, Singapore
Email: yuy@ihpc.a-star.edu.sg

A6-01 Invite
Fundamental Implicit Finite-Difference Time-Domain Schemes for Computational Physics
Eng Leong Tan*, Ding Yu Heh
School of Electrical and Electronic Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798

This paper presents fundamental implicit finite-difference time-domain (FDTD) schemes for multiple branches of computational physics, which include electromagnetics, thermodynamics and quantum mechanics. The word “fundamental” here refers to the basic form of implicit schemes which cannot be reduced any further on the right hand side (RHS). In electromagnetics, the second-order fundamental locally one dimensional (FLOD) method with conforming divergence is developed, which not only features second-order temporal accuracy, but also conforming to the divergence property of Maxwell’s equation. In thermodynamics, the FLOD method can be further developed for heat transfer equation. The proposed method circumvents the potential instability encountered by the alternating direction implicit (ADI) scheme for full 3-D heat transfer equation in inhomogeneous media. In quantum mechanics, a pentadiagonal fundamental alternating direction implicit (Penta-FADI) method is proposed for solving Schrödinger equation. The complex wave function is separated into real and imaginary parts, which results in pentadiagonal system of equations involving only real operations. These fundamental implicit FDTD schemes all feature operator free RHS with simple and concise update equations. Numerical results exemplify stability beyond the time step limit of explicit schemes and good trade-off between accuracy and efficiency.

A6-02 Invite
Finite Difference Time Domain Method with Nonlinear Circuitries
Mengjing Yuan1, Bo Zhao1, Ma Luo1, Qing Huo Liu1,2,*,+ 1Wave Computation Technologies, Inc. 2 Duke University

Nonlinear circuits are often present in microwave antennas and other high frequency systems, and need to be simulated together with the underlying 3D radiation structures to include their coupling effects. The explicit finite difference time domain method based on the Yee scheme has been the most popular time domain method in computational electromagnetics for the past five decades. However, although it has been used with nonlinear circuits in a number of research papers, only limited applications have been made. In this talk, we will describe our recent work on combining the enlarged cell technique, an improved conformal finite difference time domain method that avoids the staircasing errors near curved conducting objects, with the nonlinear SPICE circuit solver. The developed simulator can simulate arbitrary nonlinear circuits with the help of either a circuit GUI editor or a script input. Large scale problems involving nonlinear circuits, including amplifiers, SQUID and SQUID arrays, will be presented.

A6-03 Invite
Efficient Auxiliary Differential Equation Method for Modeling Dispersive Media
Ya Yan Lu
Department of Mathematics, City University of Hong Kong, Kowloon, Hong Kong

For broadband simulations of dispersive structures, it is convenient to use the auxiliary differential equation (ADE) finite-difference time-domain (FDTD) method with proper dispersion models. Compared with traditional dispersion models based on Drude and Lorentz poles, dispersion models with complex-conjugate pole-residue (CCPR) pairs have advantages in accuracy for the same computer memory requirement. We present a number of new and efficient ADE formulations for CCPR models to speed up the ADE-FDTD method.

A6-04 Invite
FDTD Modeling of Surface Plasmon Polariton Modes in Gold and Graphene
Adam Mock*,+, Sheldon Hewlett
Central Michigan University, School of Engineering and Technology, ET 100, Mount Pleasant MI, 48859, and Central Michigan University, Science of Advanced Materials Program, Mount Pleasant MI, 48859

With the growth of computational science and engineering, the finite-difference time-domain (FDTD) method has emerged as one of the most versatile numerical methods for modeling the behavior of electromagnetic fields. The method itself is well-established, so current research focuses on modeling unique and new devices and materials and on techniques for improving computational efficiency. This presentation will highlight some of our recent work using the FDTD method to model the electromagnetics of surface plasmon polariton (SPP) modes in gold films and in graphene. In both cases the material properties as well as geometry resolution requires special attention. For the case of gold, we are interested in the waveguiding properties of thin gold films deposited inside of glass microcapillary tubes. The targeted application is refractive index sensing. We are also interested in FDTD modeling of the SPP modes of graphene. Graphene is a single-atom-think two-dimensional solid with a high conductivity. With proper doping it supports SPP waveguiding at near-infrared wavelengths. Our work will show the dispersion and propagation loss of these graphene SPP waveguide modes.

A6-05 Invite
Transformation Optics based FDTD method for complex media
Jinjie Liu
Department of Mathematical Sciences, Delaware State University, Dover, DE, USA

Transformation optics is a special coordinate transformation technique that can be applied to create many interesting phenomenon, such as the well-known invisibility cloak. A key feature of TO is to absorb coordinate transformation into material properties so that the transformed Maxwell’s equations is invariant but become anisotropic. Recently, we have developed a TO based FDTD method for solving the Maxwell's equations. The TO-FDTD method applies TO to enlarge multiple small subregions so that they can be resolved using much larger grid cells, then the transformed anisotropic Maxwell's equations can be stably solved by an anisotropic FDTD method. In contrast, other subgridding or adaptive mesh refinement FDTD methods require field interpolations that lead to late-time instability. Furthermore, the TO-FDTD has also been extended to space-time domain for an alternative moving frame FDTD Maxwell solver. In this talk, we will discuss the recent progress on TO based FDTD method, including the extension to moving and complex media and applications to optics and ground penetrating radar simulations in geophysics.

A6-06 Invite
Some Applications of the FDTD Method to the Analysis of Terahertz Devices
Jun Shibayama*,+, Junji Yamauchi, Hisamatsu Nakano
Hosei University/ 3-7-2 Kajino-cho, Koganei, Tokyo 184-8584, Japan

The finite-difference time-domain (FDTD) method has often been used to characterize terahertz (THz) devices, as well as microwave,
millimeter wave and optical devices. In this presentation, we deal with several topics regarding the FDTD analysis of THz devices. First, we discuss the treatment of metal. For the analysis of THz devices, the perfect electric conductor (PEC) approximation has often been adopted. At higher THz frequencies, however, care must be taken to treat metal, since the effect of a metal dispersion cannot be negligible. We discuss the frequency ranges not only for which the PEC approximation is valid, but also for which the metal dispersion should be considered. Next, we show the two ways to propagate THz waves. One is to use metal gratings, on the surface of which the so-called spoof surface plasmon polaritons are guided. The other is to use semiconductor materials, in which the permittivity becomes negative supporting surface plasmon polaritons, as in the case of metal at optical frequencies. Furthermore, we analyze practical THz devices consisting of a frequency selective surface using the periodic FDTD method. Finally, the application of the implicit FDTD method is presented and discussed for the efficient analysis of THz devices.

A6-07 Invite
Weakly conditionally stable and unconditionally stable FDTD methods
Juan Chen
School of Electronic and Information Engineering, Xi’an Jiaotong University, China
The finite-difference time-domain (FDTD) method has been proven to be an effective means that provides accurate predictions of field behaviors for varieties of electromagnetic interaction problems. However, as it is based on explicit finite-difference algorithm, the Courant–Friedrich–Levy condition must be satisfied when this method is used. Therefore, a maximum time step size is limited by minimum cell size in a computational domain, which makes this method inefficient for the problems where fine scale dimensions are used. To overcome the Courant limit on the time step size of the FDTD method, some weakly conditionally and unconditionally stable FDTD methods have been studied extensively. In these methods, the time step sizes are not confined by the fine space discretization. They are very useful for problems which include fine structures. This talk will discuss these new FDTD methods in detail, including their formulations, time stability condition and numerical dispersion error. The numerical performance of these methods are validated by using numerical examples and their computational accuracy, efficiency and memory requirement are compared with those of the conventional FDTD method.

A6-08
Modeling Semiconductor Gain Medium with Finite-Difference Time-Domain Method
Yaxin Yu *, Ching Eng Png
Electronics and Photonics Department, A*STAR Institute of High Performance Computing, 138632 Singapore
We report and discuss in this talk a Finite-Difference Time-Domain (FDTD) computational model for efficient simulation of electromagnetic interactions with semiconductor gain media. A semi-classical approach is adopted in this model, in which the classical electromagnetic wave characterized by Maxwell’s equations is incorporated into a multi-level multi-electron atom system treated quantum-mechanically. Electron transitions between quantized energy levels are governed by coupled differential rate equations, the Pauli Exclusion Principle, and state filling effect. This model permits in principle a much more robust treatment of the overall electron dynamics of a multi-level gain system integrated into virtually arbitrary electromagnetic field confinement geometries, and therefore seeks broad applications in the area of active photonic devices. The technical details and some numerical examples are to be covered and discussed during the presentation.