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14. ABSTRACT

This final report summarizes the activities and results from computational electro-energetic plasma physics research during the contract period. The report summarizes meetings and Help Desk enhancements for the education of the AFOSR MAGIC users performing plasma physics research. MAGIC code system improvements including physics models, user interface upgrades, and execution efficiency made in response to the users' needs are reported. Several open literature and seminar presentations (separately attached documents) present specific plasma research collaborations with the researchers that we have published during the performance period. They record new approaches and techniques developed and deployed in the software and methodologies. Also attached is a copy of the electronic Magic User's Manual. This document covers the basic concepts of finite difference time domain particle-in-cell (FDTD-PIC) modeling, provides an introduction to the concepts necessary for application to a broad range of plasma physics calculations and vacuum circuit design, and describes in detail for the user all of the code improvements.

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Final Technical Report

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Abstract

This final report summarizes the activities and results from computational electro-energetic plasma physics research during the contract period. The report summarizes meetings and Help Desk enhancements for the education of the AFOSR MAGIC users performing plasma physics research. MAGIC code system improvements including physics models, user interface upgrades, and execution efficiency made in response to the users' needs are reported. In addition, there are several open literature and seminar presentations (separately attached open literature Adobe and PowerPoint documents) that present specific plasma research collaborations with the researchers that we have published during the performance period. They record new approaches and techniques developed and deployed in the software and methodologies. Also attached is a copy of the electronic Magic User's Manual. This document covers the basic concepts of finite difference time domain particle-in-cell (FDTD-PIC) modeling, provides an introduction to the concepts necessary for application to a broad range of plasma physics calculations and vacuum circuit design, and describes in detail for the user all of the code improvements made during the contract period. Included are numerous examples illustrating the concepts and techniques for duplicating laboratory and engineering measurements within the simulation and modeling environment.

Introduction

This is the final technical report for the research proposal "Computational Electro-Energetic Plasma Physics Research" under contract F9550-06-C-0148. This report summarizes the activities that were undertaken during the contract period and results. The outline follows that of the original proposal for ease of reference. Several additional documents are provided in the form of attachments serve as ancillary material related to the exercise of this program. In particular, note the "Magic User's Manual", which details much of the model and algorithm material, both historical (for continuity and context) and new efforts under this contract. Conference publications and presentations made during this effort by the authors are also included. In addition, collaborative efforts with our university partners are attached as pdf files along with this document, including conference presentations.

1.0 Setting the Agenda

The MAGIC (MAGnetic Insulation Code) users (AFOSR Electro-Energetic Physics Researchers) were polled at each of the MAGIC User's Group meetings to determine the levels of interest and needs in various electromagnetic particle-in-cell (EM-PIC) computational topics, and to set subsequent meeting agendas and research priorities.

2.0 Meetings and Education

During the course of the program we held three five-day MAGIC Workshops were held in Las Vegas, Nevada as listed below.

- March 12-16, 2007 at the Sahara Hotel
- March 24-28, 2008 at the Tropicana Hotel
- February 23-27, 2009 at the Tropicana Hotel

The focus of these meetings was education in the technology of the MAGIC software and the application of this technology to the specific research issues in play by the university collaborators.

An annual MAGIC User's Group (MUG) meeting was held at one of the annual conferences attended by our university partners. These meetings provided the researchers direct interaction with us and others in the field and opportunities for an informal exchange of research interests and results, as well as provided us an opportunity for focusing our research effort based on current requirements of the user's group. In addition, we found an opportunity to provide information on our own recent developments in a timely fashion. Three one-day MUG meetings were held in conjunction with major conferences during this contract. They are listed below.

- June 19, 2007 at the IEEE Pulsed Power and Plasma Science Conference, Albuquerque, NM.
- April 23, 2008 at the Portola Plaza Hotel during the International Vacuum Electronics Conference, at Monterey, CA.
- June 3, 2009 at the Omni Hotel during the 36th International Conference on Plasma Science and 23rd Symposium on Fusion Engineering, San Diego, CA.

The above-noted events have included distributions of major releases of MAGIC with continually improving quality assurance during this contract period. Extensive debugs and testing enhancements including detailed comparisons of the MAGIC Tool Suite test problem matrix against truth data have been accomplished. Intermediate version MAGIC code releases have been provided in conjunction with specific user needs.

In addition, short visits have been made to individual organizations to collaborate on the application of the MAGIC software technology to specific research interests. During this contract periods visits have been made to the following universities.

- University of Miami, Coral Gables, FL.
- Saint Peter's College, Jersey City, NJ.

3.0 Website and Help desk

ATK Mission Research (ATK) provides the Magic Web site and a MAGIC Helpdesk as permanent fixtures on the Internet for the use of the community of MAGIC Software users. The website provides a forum for broadcasting new features to the MAGIC Technology and supplies links the web-based online MAGIC help desk. The help desk provides a mechanism for supplying new information (via downloads) and a mechanism for tracking MAGIC technology issues as applied to the various researchers. With it we provide rapid feedback and assistance to particular and specific requests or issues that occur in the application of the MAGIC technology. ATK has provided extensive assistance to AFOSR researchers through the help desk. These research collaborations have led to several joint and ATK publications in the open literature, as noted below.

The website and help desk has been maintained and upgraded during this contract period. The MAGIC User's Group homepage is http://www.mrcwdc.com/Magic/Homepage.htm,

and our e-mail address is afosr@magictoolsuite.com. The MAGIC web-site contains instructional material, recent news, how-to tips, and examples. In the following we itemize some of the research collaboration issues that have occurred over the contract period that seem particularly significant.

- University of Nevada, Las Vegas (UNLV): ATK has collaborated with the team at University of Nevada, Las Vegas, on their Secondary Electron Emission (SEE) experiment[1]. MAGIC software technology has been used in the simulation of the experiment. Consequently, a technical paper on the experiment of vacuum tank EM (electro-magnetic) physics has appeared in the open literature[2].

- University of Miami (UMIA), Stanford Linear Accelerator Center (SLAC): ATK has collaborated with UMIA and SLAC researchers by providing Linux installation of the MAGIC Software technology for their clusters. Subsequently in work with the local research groups, performance tests showing the benefits achievable were reported in the open literature based on the in-house ATK and UMIA clusters[3]. Joint research publications on plasma actuator effects have been made[4,5].

- University of Michigan (UMICH): Much collaboration has been provided to researchers on relativistic magnetrons[6,7,8] as well as a convolute and other devices.

- University of Nevada, Reno (UNR): Professor Robert Vidmar has developed a detailed air chemistry package which can be incorporated into MAGIC for the more accurate modeling of long time scale air plasma simulations[9]. ATK has worked toward incorporation of the software technology for modeling of long time-scale applications of air plasma using short-duration simulations in MAGIC. The plasma model in MAGIC2D has been revised[10] to provide greater fidelity to the application of his work, and has also been extended to MAGIC3D[11] in anticipation of user needs.

- Old Dominion University (ODU): ATK has collaborated with the ODU researchers on the simulation of the Prolate Spheroidal Reflector with Radiator project[12], as well as early plasma bullet calculations.[13]

4.0 User Wizards

Users have been significantly aided in MAGIC setup and execution through the development of InputBuilder and the parallel computer interface. Prompts and Help files are provided for the numerous commands and options available in the code system.

5.0 Performance Improvements

ATK has completed implementations of native 64-bit versions of the MAGIC Software technology using the Intel compiler for both Windows and Linux operating systems during this contract period. Both versions have been made available to AFOSR university collaborative researchers in 32-bit double precision and the native 64-bit version most recently available. The Linux version is used exclusively by UMIA to support their clustered supercomputer.

We have reported results of the extensive performance tests on a variety of platforms in conference presentations.[14]

6.0 Boundary Conditions

MAGIC boundary conditions have been upgraded at conductor-vacuum interfaces and at grid terminations using matched and artificial impedance methods. Non-Conformal conductors were implemented in MAGIC3D Cartesian geometry for the electromagnetic solution.[14] The matched impedance port boundary[15,16] and the Convolutional Perfectly Matched Layer method was implemented in MAGIC3D[17] and has been made available in the university researchers.

7.0 Particle Interactions

A problem of particular concern in finite difference time domain (FDTD)-PIC is that of particle noise. For a class of problems that includes high energy electron beams propagating through a gas, we have designed a hybrid model in which the energetic electrons are treated as conventional macro-particles, and the low energy electrons and ions (resulting from the passage of the beam) are treated as inert charged fluids whose principle physical effect is that of introducing gas conductivity which quenches the beam space field. The resultant is a great reduction in the noise by-product. In addition this hybrid model provides a framework which is also well suited to low energy electron ionization associated with the simulation of plasma barrier discharges and consequently the plasma actuator project[4]. Greater detail on this model can be found the MAGIC User's Manual.

8.0 Diagnostics

Several diagnostics have been added to MAGIC during the period in response to user needs. These include the SMATRIX (reflection and transmission of EM power), CHIRP functions for isolating response characteristics, and TRANSFORM options for mapping of the time axis to another variable or scale.

Summary

Collaborative computational electro-energetic plasma physics research has been accomplished during this contract period primarily in response to researchers' emails and (increasingly) through the MAGIC help desk. AFOSR researchers have been trained hands-on to effectively use the MAGIC tool suite through workshops, MUG meetings, and personal visits. Code upgrades have been developed in response to user needs with major efforts in Windows and Linux native 64 bit parallel MAGIC, physical modeling of plasma discharge experiments, electron beam models, and EM tank physics. Significant effort has gone into speeding up the code and providing users with advice and options for efficient large scale EM plasma computing. Research community communication and education have also been accomplished by our open literature publications flowing out of this research, as noted in the references.

We count ourselves privileged to have had this central responsibility in collaborative computational electro-energetic plasma physics research made possible through the sponsorship of the Air Force Office of Scientific Research.

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