UCRL-ID-126406

Extension to 3-D of the Low-Frequency Electromagnetic Plasma Simulation Models

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Co-Investigators:
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Final Report

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Low-frequency electromagnetic simulation models have a wide range of industrial applications. We have built several models, differentiated by slightly different physics approximations or computational solution methods, that have proven quite useful in a variety of applications[1]. Our models been used to investigate beam plasma interactions in ICF targets, antenna plasma coupling in plasma processing, and magnetic implosion drive in Z-pinch pulsed power generators. The common feature of these models is that they retain inductive effects but implicitly ignore computationally intensive, fully electromagnetic effects. However, the preponderance of our work has been limited to only two dimensions.

Most existing 3-D models either ignore inductive effects or try to follow the prohibitive electromagnetic (EM) time scale. Time dependent models that neglect purely EM modes, known as Darwin models, involve strongly coupled differential equations that have been used primarily in 2D because of the complexity of these models in 3-D. In the course of this funding, we have extended our 2-D infrastructure to 3-D, completed the formulation of one of the most useful variants of these models in 3-D, and began to integrate the capabilities of this new model.

While we have not ignored other applications, we concentrated initially on the physics of inductively generated plasmas. Our efforts were in support of tech transfer funding for the study of plasma processing (semiconductor wafer etching) chambers. A major issue in the plasma processing application is the design of antenna structures that can generate the highest density plasmas consistent with uniformity across the wafer surface. The major issue in the plasma processing application is the design of antenna structures that can generate the highest density plasmas consistent with uniformity across the wafer surface. To enhance the utility of our new software, we have also built a mechanism for representing and driving fully 3-D spatial structures in the model.

Key Components of the New Software

A key part of this effort was the development of a physics model that could capture the essential physics. A new model that combines the capabilities of implicit PIC (for kinetic plasma transport modeling on time scales greater than the plasma oscillation period) and the Darwin limit of Maxwell's equations (which neglects the computationally expensive purely electromagnetic modes) was constructed[2,3]. A code based on this model, called DADIPIC for DArwin Direct Implicit Particle In Cell [4], combines direct implicit PIC methods with our new Streamlined Darwin Field EM method, thus providing a new avenue for the simulation of magnetized plasmas. A description of this work has been published in two papers in the Journal of Computational Physics.

In the second year of this research, we extended this two dimensional model to all three dimensions. Not only were the mathematical algorithms extended to higher dimension, but we also extended the infrastructure [5,6] needed to describe the fully three dimensional structure, shown in Fig. 1, and the necessary prescription for the driving fields via generalized boundary condition constructs. We hope to complete this work in the near future and document this progress in the literature.

In the summary, we have made significant progress modeling low-frequency electromagnetic physics with 1) a new model in 2-D that is now capable of modeling antenna structures in 3-D. Although LLNL's interest in plasma processing has diminished, we have certainly added to LLNL's capabilities. Interestingly, we have already found another application, the magnetic behavior of read/write heads in the magnetic storage industry, that can make use of many of the computational methods described here--rewarding us again for maintaining a strong core competency in low-frequency EM plasmas.

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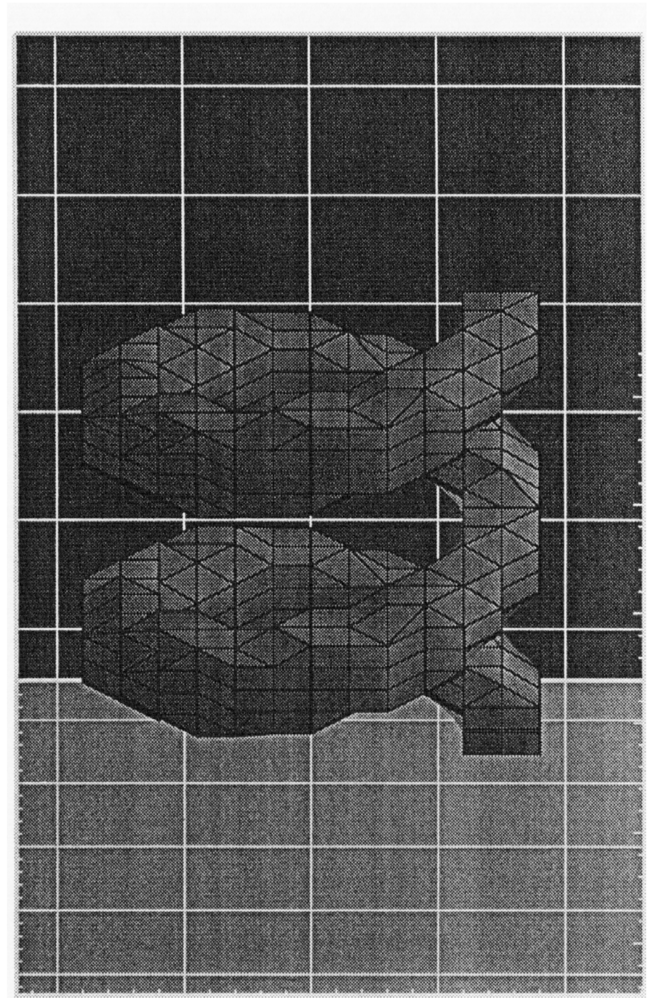
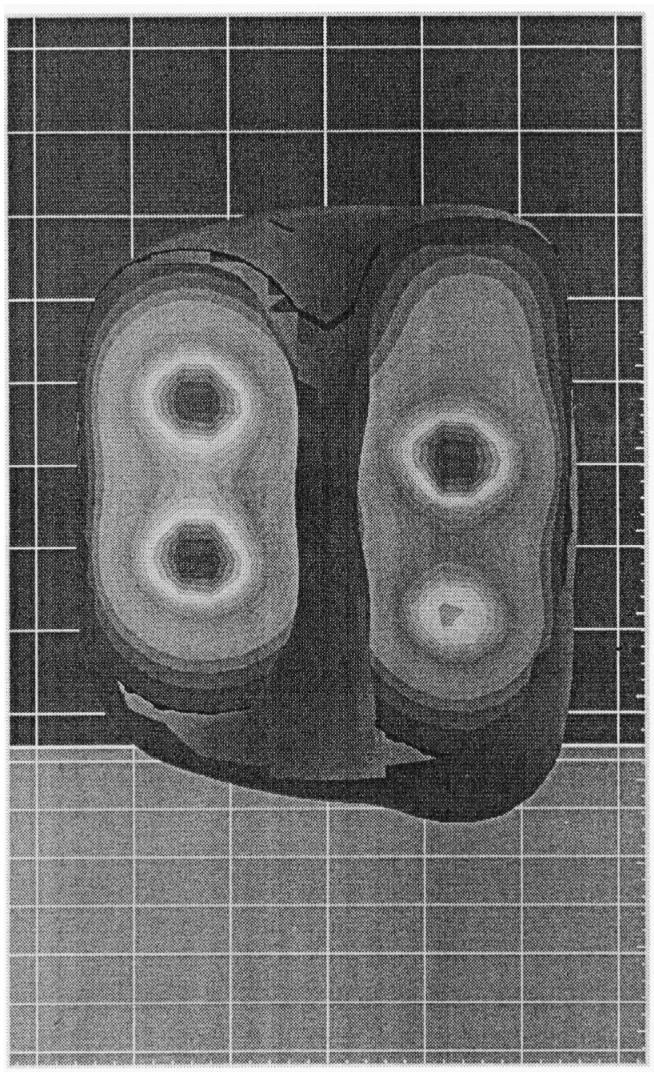


Fig. 1 (A) Helical antenna as generated on a cartesian mesh



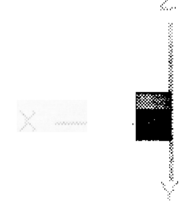


Fig. 1 (B) 3-D contour surface of the solenoidal E-field magnitude. The field is generated by a current in the helical antenna. A cutout of the surface shows other contours of E-field. is bl magnitude. Maximum magnitude is red (in the antenna) and minimum magnitude ^

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