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An Efficient Parallel Algorithm for Electromagnetic Simulations

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Summary

A new approach has been developed for the fast and efficient simulation of electromagnetic phenomena. The new technique enables the accurate solution of Maxwell's equations for complex geometry, with potential to impact a wide range of applications such as high-energy particle accelerators, digital circuits and optical telecommunications.

As part of the Applied Math Research program effort, researchers at LLNL have developed a fast new approach for the accurate simulation of electromagnetic phenomena [1]. This effort is part of a larger project, whose goal is the design, analysis and development of advanced new algorithms for the accurate and efficient solution of partial differential equations in complex geometry and the application of these algorithms to projects of critical interest to the DOE. The modeling of electromagnetic waves is important in a plethora of activities including the design and simulation of high-energy particle accelerators, antennas, microwave circuits, digital circuits, and photonic band gap devices, to name a few.

The propagation of electromagnetic waves is governed by Maxwell's famous system of equations that unified the fields of electricity and magnetism. These partial differential equations describe the evolution of the electric and magnetic fields as they travel at the speed of light through materials.

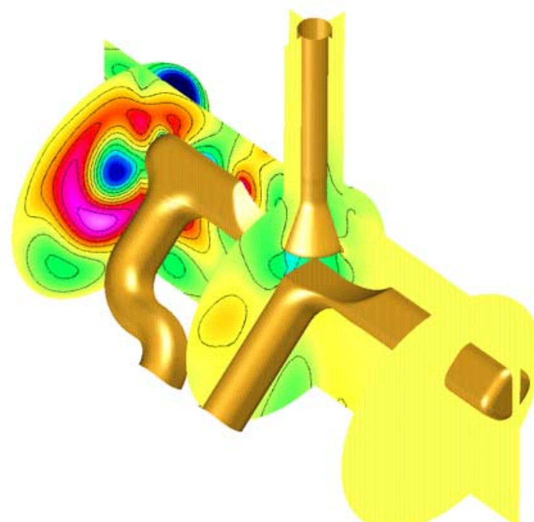

Figure 1: Electromagnetic pulse propagating through a component of a high-energy particle accelerator**.**

The new scheme for solving Maxwell's equations combines the efficiency of methods for Cartesian grids with the flexibility and accuracy for complex geometry of methods based on unstructured grids. The technique uses overlapping grids, with narrow curvilinear grids fitted to boundaries and interfaces, coupled to

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Cartesian grids that occupy most of the domain. The basic Maxwell equations do not dissipate electromagnetic energy as the waves propagate over long distances. It is therefore advantageous to use discrete approximations that have low dissipation, high-order accuracy and low numerical dispersion. We have developed new high-order accurate symmetric approximations for general curvilinear grids that exactly preserve the electromagnetic energy. Unlike many finite element approximations that require the inversion of an implicit mass matrix, these symmetric schemes are fully explicit and efficient to evaluate.

The velocity of the electromagnetic waves can change when the waves move from one material to another (such as when light traveling in air enters a piece of glass). As a result, waves are reflected and transmitted from the interface in a complicated fashion. A key component of the new scheme is the construction of centered, high-order accurate approximations at material interfaces and the development of the mathematical theory to support the properties of these discrete approximations. These new interface conditions directly discretize the set of interface jump conditions that can be analytically derived from the governing equations. As a result, the interface can be treated to high-order accuracy even though the solution and it derivatives can be discontinuous at the interface.

The new algorithm has been developed to perform well on distributed memory parallel computers. The use of structured overlapping grids means that most of the parallel communication is of a regular pattern. Moreover, the algorithm is very memory efficient with a low operation count. Thus, high-order accuracy can be achieved with orders of magnitude less computer memory than corresponding

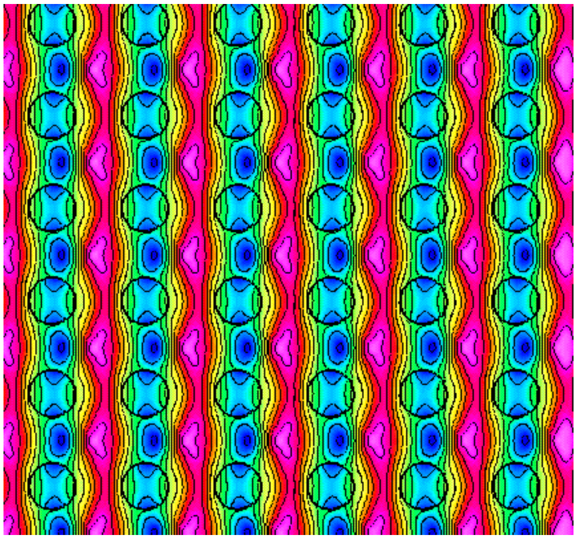

Figure 2: Electromagnetic wave passing through a phontonic band gap device consisting of an array of embedded cylinders with different material properties. The interfaces between the materials are treated with new accurate approximations.

approaches for unstructured grids.

Figure 1 shows a computation of an electromagnetic pulse in a key component of the proposed International Linear collider. This work is in collaboration with Dr. Kwok Ko at the Stanford Linear Accelerator Center. Figure 2 shows the electromagnetic waves propagating through a photonic band gap device that consists of a material with a matrix of embedded cylinders. Such structures forbid the propagation of waves in certain frequency ranges and can be used as optical switches and optical transistors.

[1] W.D. Henshaw, "A High-Order Accurate Parallel Solver for Maxwell's Equations on Overlapping Grids", to appear, SIAM Journal on Scientific Computing, 2006.

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