APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

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2. Camera ready hardcopy of any figures.
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NEWSLETTER ARTICLES AND VOLUNTEERS WELCOME

The ACES Newsletter is always looking for articles, letters, and short communications of interest to ACES members. All individuals are encouraged to write, suggest, or solicit articles either on a one-time or continuing basis. Please contact a Newsletter Editor.

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OFFICER'S REPORTS

PRESIDENT'S REPORT

The Board of Directors held its second meeting this year at the Faculty Club of the University of Western Ontario in Canada, in conjunction with the 1991 International URSI/AP-S Symposium, on Wednesday, the 25th of June. A number of important items of business were transacted. This was the occasion, according to our By-Laws, for the Board to elect officers for the coming two-year term. I can report with pride and great pleasure that the following were elected:

President - Hal Sabbagh
Vice-President - Ray Luebbers
Treasurer - Jim Breakall
Secretary - Dick Adler

The second noteworthy item involved a motion to approve the setting up of an **ACES UK Chapter**. The foundation for this was established by enthusiastic work carried out by Tony Brown and Pat Foster of the UK NEC Users Group. They have formed an initial outline committee including Brian Austin, David Lizius and Jeff Cox. The modality of detailed interaction with ACES headquarters, for the benefit of UK members and ACES, remains to be established by consultation with Dick Adler. Needless to say, I look forward to the start of operations of the Chapter this year. Among the committee reports, a wide-ranging and thorough discussion was devoted to the report submitted by David Stein that noted our successes and areas requiring further effort, those directly in the purview of the Publications Committee, but also those of the society in general. This type of "stock-taking" is important on a continuing basis. One direct result of this review is the initiative for special feature articles in the Newsletter which is noted below.

Within the next few weeks you will be asked to vote for two new members of the Board. Please take the time to review the slate of candidates and do exercise your mandate. The activities and general health of our society are dependent on the efforts and talents of our board members. Your vote signals the society that you care.

Pat Foster and her team have been busy with details of our forthcoming **Annual Review of Progress in Applied Computational Electromagnetics.** In a time of recession and defence cutbacks it will be important for all of us to make every effort to attend and to urge our colleagues to do so. The symposium should continue to be perceived as **the event** where one can obtain the latest information on codes and practical applications and where meaningful short courses provide valuable training.

Elsewhere in the Newsletter you will see the announcement for **ACES Workshop** in Melbourne, Australia on August 14, 1992. Tony Fleming of Telecom Australia Research Laboratories has taken the initiative to exploit the occurrence of the URSI International Symposium on Electromagnetic Theory and the Asia-Pacific Microwave Symposium before and after the workshop date. The Board of Directors has enthusiastically endorsed this important regional activity and it deserves the support of all our members.

This issue includes the first of a series of articles intended to feature the status of computer codes, applications and special purpose computers. It has been my privilege to join Ed Miller and Paul Elliot in approaching potential editors for such user columns in different modelling areas. Do consider participating in this venture by contacting Paul Elliot should you be prepared to submit a survey of a particular code or an application that could be incorporated into one of these feature articles. He will put you in touch with the person who has agreed to be responsible for your modelling area or code. I am looking forward to this feature becoming a valuable source of up-to-date information for our user groups.

During this past summer, I had the opportunity to participate in the AGARD Lecture Series on Electromagnetic Compatibility. The lecture team was headed by Prof. Mike Darnell and included Prof. Andy Marvin, Prof. Clayton Paul, Prof. J. Catryse, Dr. George Hagnand, Dr. Terry FitzSimmons. The tour from Norway to Germany and Portugal produced an exceptionally convivial fellowship among the members of the lecture team that assured the success of the presentations. It reminded me of the successful collaborations of some of our symposium teams and the need to trigger such collaboration within our committees as part of **Vitality 91**. It also gave me an opportunity to publicize the ACES mission and extend an invitation to potential members to avail themselves of our resources. However, I was also reminded of the need for a greater exposure for EMC codes and applications in our regular activities.

Finally, if you signed up for a committee and have not heard from your chairman, why don't you drop him a line. I'll guarantee that he will be happy to hear from you. You see in our organization we can't wait for the other fellow to make the next move!

Stanley J. Kubina
ACES President

COMMITTEE REPORTS

ACES EDITORIAL BOARD

As a result of arrangements which we are finalizing with a US-based professional subscription agency, we anticipate that the **ACES Journal** and the **ACES Newsletter** will soon be on the shelves of more institutional libraries. As a result, our authors (and advertisers) will gain increased exposure and will therefore find our publications more attractive. Furthermore, we anticipate that the increased revenue will position us to increase the publication frequency of the **ACES Journal**, at least to three times per year, so that we can maintain "rapid turnaround" for our regular issue authors as we simultaneously continue our ambitious special issue program, though this publication frequency increase will not be immediate. The agency serves more than 60,000 libraries worldwide, and their services will be at negligible cost to ACES.

In addition to their promotional and catalog listing services, the agency will manage the **ACES Journal/ACES Newsletter** subscription packages (institutional memberships) of those libraries which choose to utilize their services. Our arrangements are on a non-exclusive basis, so that institutional members may continue dealing directly with ACES, and ACES may make similar arrangements with other subscription agencies. Our discussions with a smaller, United Kingdom - based subscription agency, which specializes in service within Europe, are ongoing.

Our recent **ACES Journal** Special Issue (on Applications of High Frequency Methods and Computer Techniques in Electromagnetics), organized and edited by ***Fulvio Bessi*** (Italy), is already an acclaimed publication and has generated new interest in ACES within the professional community. We envision similar success for our two forthcoming special issues: the Special Issue on Bioelectromagnetic Computations, to be organized and edited by ***Ken Joyner*** and ***Tony Fleming*** (Australia), and the Special Issue on Computer Applications in Electromagnetic Applications, which will be organized and edited by CAEME Director ***Magdy Iskander*** (USA).

In other news, ***Wes Williams*** (USA) and ***Duncan Baker*** (South Africa) will be inviting **ACES Journal** papers from many expert authors, including several authors who represent the "low-frequency community". The Joint **ACES/TEAM** Workshop Program (our involvement in which resulted from the **ACES Journal** special issue program) culminated most recently in the Sorrento, Italy workshop, at which many TEAM people became interested in ACES. Unfortunately, the ACES participation was not as high as we would have liked, but we did our best — and understand that these workshops are not a publications responsibility, notwithstanding their potential to generate publishable material! Nonetheless, we anticipate that this workshop program will continue, possibly to include a mini-workshop, featuring benchmark problem solutions in support of code validation efforts, in conjunction with the 1992 ACES Symposium. As a separate activity, ***Tony Fleming*** is organizing a one-day ACES Workshop, which is scheduled for August 1992 in Sydney, Australia. This Workshop, possibly to be co-sponsored by TEAM, will be an ACES activity readily accessible to our Australian and other Pacific members. In addition, we may choose to test an innovative workshop concept there.

New **ACES Newsletter** contributors are being identified — as a result of recent efforts by ***Ed Miller*** and ***Stan Kubina*** — so that we can publish informal articles dealing with codes, computational techniques, and modelling applications. Although in some respects, the **ACES Newsletter** has exceeded the expectations of our founders, our success in our primary mission of informal information exchange has been limited. (We recognize that many authors do not have the same incentive to publish in a newsletter as they have to publish in a scholarly journal; however, we remain inspired by the success of various computer magazines). Also important to the success of the **ACES Newsletter** are an active Software Exchange Committee, Software Performance Standards Committee, and Code User Group Committee.

A comprehensive review of the ACES Journal standards of publication is in progress. Our objectives are threefold: to improve the general understanding of our scope and paper selection criteria, to remain scholarly enough to serve authors but practical enough to serve readers, and to prepare for future needs of computational electromagneticists. All ACES members are invited to share their ideas with us.

David E. Stein
Editor-in-Chief

PERSPECTIVES ON ACES AND COMPUTATIONAL ELECTROMAGNETICS

ACES SOFTWARE ACTIVITIES: INCENTIVES?

Andrew Peterson

It has been more than six years since the inception of ACES and by this time one might expect that the main activities of the society would encapulate a widespread degree of membership participation. By and large, this appears true for the annual symposium; but it is less true for the publications (especially the Newsletter) and can not be said to accurately describe the areas of software sales, exchanges, and related commentary (Newsletter columns on code fixes, modeling notes, and the like). Despite the perception that most ACES members would benefit from the software activities, the society has had difficulty (with the exception of the NEC/NEEDS distribution) getting these activities "off the ground". Why have some activities been much more successful than others?

A likely explanation may be due to the lack of natural incentives associated with software-related activities. Incentives to attend the annual symposium are widespread - attendees have an opportunity to disengage from their daily routine, travel to Monterey, attend a variety of useful presentations, spend time with colleagues and old friends, perhap query "experts", and often are able to accomplish this at their employer's expense. (It is easy to see why there are so many conferences these days)! On the flip side, what are the incentives associated with writing a column for the Newsletter, compiling a dictionary of available software, promoting software exchange, or donating software packages for distribution through ACES? Developing a general-purpose EM code, debugging, validating, documenting, distributing and updating are activities that consume significant resources, and would almost have to involve a profit motive as the primary incentive. Except for software provided by government organizations as a primary job function, does anyone really expect to get good software without paying for it? In addition, Newsletter columns reporting modeling failures, code fixes, and the like would appear to be natural products of the code developer, rather than the user, since software vendors should find their long-term market share somewhat dependent on support activities. In fact, some vendors publish their own newsletters. Do these observations suggest that ACES software activities are doomed to a miniscule level? Or, is there some way that ACES can make use of natural incentives to promote these activites in a different manner?

There are a number of commercial vendors actively engaged in marketing electromagnetics software. Although these vendors exhibit an interest in ACES (i.e., demonstrations and an occasional technical paper at the annual symposium), they have maintained a relatively low profile in and around the society. Yet, software vendors should have the primary incentive to contribute modeling notes, code fixes, and other commentary to the Newsletter in order to promote their products over the long term. I believe that ACES should encourage vendors to get involved in the organization, contribute feature articles to the Newsletter, and explore ways in which their products could be promoted within the society. A relationship of this sort would have to be a two-way street, as it would be unacceptable to provide free advertising without an off-setting return. Perhaps the Newsletter could evolve along the lines of trade magazines, which are quite successful at promoting commercial products while simultaneously providing information on those products to their readers. In addition to potential sources of revenue for the society, cooperation between ACES and vendors might facilitate the sale and distribution of software products at a discount to ACES members. These activities would enhance the value of ACES membership -- shouldn't they be pursued?

Another software-related service not currently available through ACES is an electronic bulletin board. During a recent discussion, I was persuaded that ACES (or somebody) should operate a bulletin board to facilitate the dissemination of EM software, emulating NETLIB at Oak Ridge National Laboratoriees. Such a facility would be of obvious benefit to members (provided software was available to disseminate), but a few questions arise on the role of ACES. First of all, would ACES be able to fund such an activity out of membership dues, or could it be self-supporting? How would the access be restricted to current "dues-paying" members? Where would the software come from? What about restrictions on software distribution?

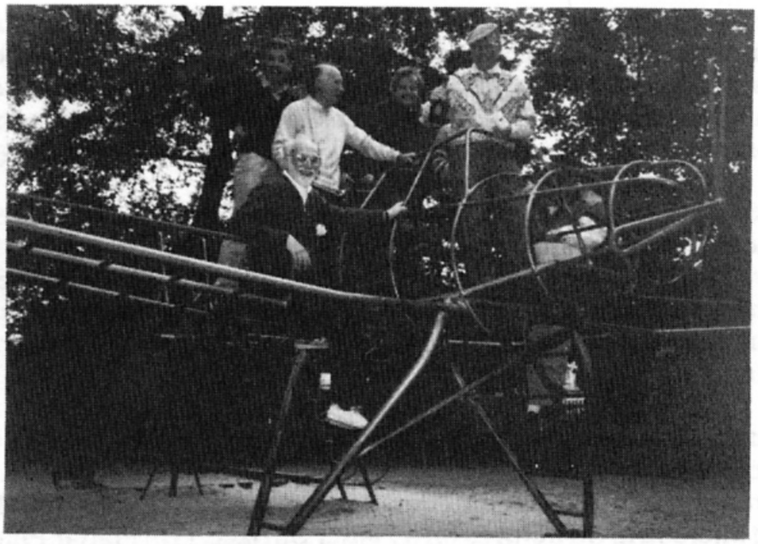
ACES was created in response to a perceived need for interaction between the code developer and code user communities. How do you, the members of ACES, feel about these issues? I would appreciate any feedback on the topics discussed above, the proper role of ACES in the EM community, or any other specific activities that ACES should be promoting.

BIO

Andrew F. Peterson is an Assistant Professor in the School of Electrical Engineering at Georgia Tech. He is currently a member of the ACES Board of Directors, an associate editor of the ACES Journal, and co-chair of the Software Performance Standards Comittee. He can be reached at the School of Electrical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250, 404-853-9831 or ap16@prism.gatech.edu (e-mail).

SPECIAL SESSION" OF AGARD LECTURE DISCOVERS WIRE GRID MODEL OF AIRCRAFT IN SANDLOT

Come on up, it's been tested and it's safe,
he said to his AGARD EPP EMI/EMC LS 177 friends,
(l.to r. Mike Darnell, Terry Fitzsimons, George Hagn,
Andy Marvin, Stan Kubina, and Clayton Paul)



DESCRIPTION OF NEW BOOK ON MOMENT METHODS

J.J.H. Wang, Generalized Moment Methods in Electromagnetics Formation and Computer Solution of Integral Equations, Wiley, 1991

This book is a comprehensive treatise on the generalized method of moments. It covers not only the numerical aspects, but also the analytical background, including electromagnetic theory; thus it is also a book of advanced electromagnetic theory. As a general advanced electromagnetics book, its presentation and coverage are up-to-date and comprehensive, reflecting recent significant advances in electromagnetic theory that have not appeared in other books, almost all of which are now more than two decades old.

As a treatise on numerical methods, the coverage, presentation, and organization are based on the recognition that Harrington's moment methods, iterative methods, mode matching, reaction integralequation methods, etc. can be unified and presented within the framework of a generalized method of moments in a succinct and efficient manner. The book could be useful for both code users and code developers/modifiers.

This book is distinct in three aspects: (1) it broadens Harrington's moment methods to include several other numerical methods under the unifying principle of the generalized method of moments; (2) its presentation of the electromagnetic theory has incorporated the advances, improvements, and revisions of the last three decades; (3) it covers a variety of electromagnetic problems and contains exercises and four general-purpose computer programs.

The book has 553 pages. Chapter 1 introduces the generalized moment method, its relationship to the finite-element and finite-difference methods, and how it encompasses Harrington's moment methods, iterative methods, mode matching, reaction integral equation methods, etc. Chapters 2 and 3 present the generalized method of moments in a more formal and detailed manner. Chapter 4 discusses "some relevant concepts, theorems, and techniques" in electromagnetic theory and Green's functions.

Chapters 5 through 11 address seven major topics in electromagnetics in detail as follows: (5) Thin Wire Antennas and Scatterers, (6) Surface Integral Equation Approach, (7) Volume Integral Equation Approach, (8) Eigenfuction Solutions for Generalized Cylindrical Waveguides, (9) Apertures and Microstrip Structures on a Planar Surface, (10) Planar Phased Arrays and Other Periodic Structures, (11) Time Domain Moment Methods.

The last chapter, 12, addresses "Computer Related Considerations". This is followed by six indices as follows: (A) Formulas in Vector Analysis, (B) Formulas in Dyadic Analysis, (C) A Direct MM Volume Integral Equation Code, (D) An Iterative MM Volume Integral Equation Code, (E) A Surface Integral Equation Code, (F) A Thin Wire Code. In Indices C through F, code listings, user's guides, and example runs are all included.

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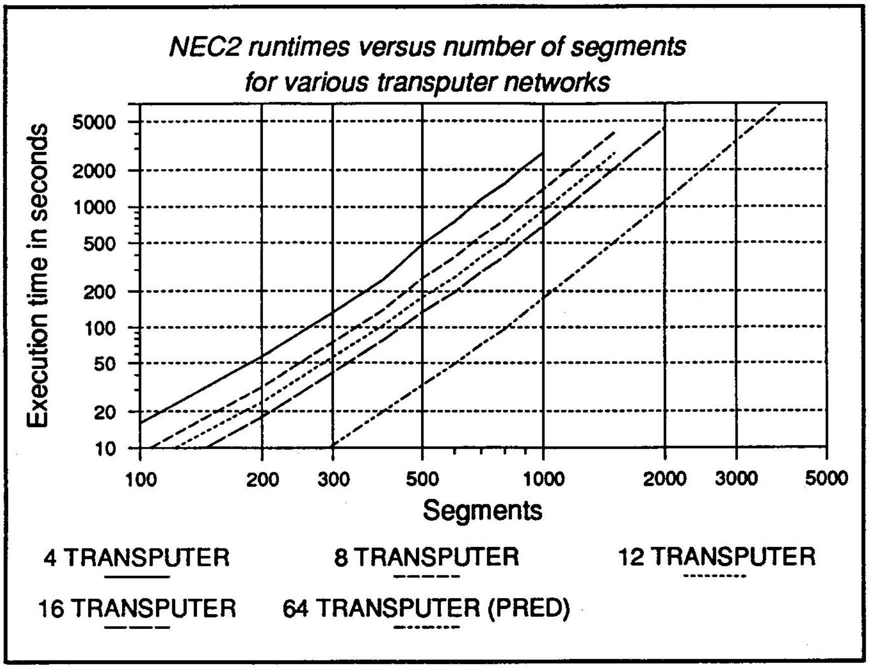
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Applications of Data Transport Computer in Computational Electromagnetics

Check F. Lee and Robert L. Utzschneider

Wavetracer, Inc.
289 Great Road, Acton, MA 01720

***Abstract** - This article summarizes two applications of the Data Transport Computer (DTC) to problems in electromagnetic scattering and radiation. The DTC is a single instruction multiple data 3-D massively parallel computer. Its maximum configuration contains 16,384 processors and 512 MBytes of memory. These processors are arranged in a 3-D lattice which can be unfolded, under program control, to form a 2-D array. Each of these processors is directly connected to its six nearest neighbors. Two primary algorithms are discussed. The finite-difference time-domain algorithm is implemented to take advantage of nearest neighbor connection and virtual processing. A 3-D method of moments algorithm is implemented. This implementation takes advantage of the 2-D unfolding and the DTC-workstation hybrid configuration. These two algorithms have been applied to scattering and radiation problems. Exceptional computational speed and price/performance are obtained, making the DTC an excellent choice for these applications.*

I. Introduction

Numerical techniques in electromagnetics are based on either partial differential equations or integral equations. For scattering and radiation analysis, these equations are usually linear, but the dynamic nature of these problems complicates the analysis by requiring huge number of discretization cells/unknowns. The finite element (FEM) or the finite difference methods are based on partial differential equations. The number of unknowns is proportional to the electrical size of the computational volume. In many applications, each of the three spatial dimensions of this volume is many wavelengths in length. Assuming ten discretization cells per wavelength, the number of unknowns is very large. A similar situation appears in integral equation based methods, such as the method of moments (MoM), except that the MoM matrix is dense while the FEM matrix is very sparse. In short, the computational complexities are very great; the assistance of a supercomputer for most practical applications is required.

Conventional supercomputers contain one or a few very powerful processors, and have been the dominant technology in many applications. Due to physical limitations such as propagation delay, however, this architecture may not satisfy growing demands for computational speed. Parallel computing, on the other hand, is gradually becoming recognized as the future of supercomputing technology. There are two major parallel computing architectures. One is the *multiple instruction multiple data* (MIMD) computer, and the other is the *single instruction multiple data* (SIMD) computer. MIMD computers usually contain from several to a few hundred processors; each of these processors may execute different instructions on different data. SIMD computers are usually massively parallel computers containing thousands of processors. Each processor executes an identical instruction on different data simultaneously. MIMD computers are more flexible in some applications, due to their multiple instruction programming. SIMD computers offer simpler programming in both the development and application environments.

In this article, we discuss the application of the DTC [1] to problems in computational electromagnetics. The architecture and the implementation of the FD-TD and the MoM algorithms are discussed. These two algorithms have been implemented using the multiC programming language [2] and optimized on the DTC. These algorithms have been applied to various scattering and radiation problems. The scattering analysis package, *EM-WAVETRACER* [3], developed jointly with the Massachusetts Institute of Technology, is available commercially.

II. Technology Overview

The DTC's hardware and software parallel computing technologies are designed to tackle multidimensional problems. The DTC is a 3-D SIMD massively parallel computer. This computer and its environment are supported by a multidimensional data-parallel programming language -- multiC. multiC is an extension of ANSI C which provides instructions for parallel operations on data.

The DTC consists of control and array modules. The array modules are controlled by the control module which is controlled by the host workstation through the SCSI interface. This interface is used primarily for instructions and commands. DTC Models contain from 4,096 processors with 128 MBytes of memory (DTC-4) to 16,384 processors with 512 MBytes of memory (DTC-16). Each of these processor elements is a single-bit computer with six data paths in *x,y* and *z* directions (Figure 1). These processors are arranged in a 3-D lattice, so that each processor has direct access to its six nearest neighbors.

This 3-D architecture solves the inefficiencies associated with mapping 3-D data into linear memory (conventional computers) or planar memory (2-D computers). At the same time, it maximizes memory bandwidth by providing every processor element with its own path to a neighboring processor or to its memory; hence, there is no need for data path multiplexing. The DTC provides very high I/O rates. As shown in Figure 2, the 3-D array allows data movement through the edge and face of the cube. For example, the DTC-16 can achieve peak I/O throughputs of 1,024 MBytes/second. Because of these features, the DTC delivers very high performance on complex multidimensional applications.

A powerful feature of the DTC architecture is the ability to "unfold" the 3-D lattice into a 2-D array. This is particularly valuable for those applications better suited in 2-D, such as image processing. This unfolding is controlled by user software. For the DTC-16 in its natural array configuration of 16x32x32, the unfolding results in a 128 by 128 array of processors, with no loss of bandwidth and computing performance.

The multiC programming language is a superset of ANSI C. multiC permits instructions to operate on multidimensional data, thereby eliminating many of the loops found in traditional programming while retaining all the familiar features of the C language. When a multiC program is being executed, the portions of the program which do not contain parallel data are executed in the workstation and the remaining portions are executed in the DTC. This hybrid configuration allows users to fully exploit the computing powers of both the DTC and the workstation.

DTC processors can be configured dynamically to form a much larger 2-D or 3-D virtual processor array. The virtual array can be shaped to suit the problem, thus maximizing application of processors. Virtual processing occurs transparently to the user, thereby eliminating unnecessary programming complications. It should be pointed out that although the size of the virtual array can be very large, the maximum distance between any two processors is limited by the physical size of the array.

III. The FD-TD Algorithm

The FD-TD algorithm is a parallel version of the conventional FD-TD algorithm [4]. Their applicability, accuracy and limitations are similar. This parallel FD-TD algorithm is implemented using the multiC language and optimized in the DTC environment. A technique to share parallel data is employed to minimize memory allocation. Significant development efforts have been expended on user interface and geometry modeling.

A 3-D computational domain is partitioned into many cells. Each of these cells is represented by a processor (virtual processor if necessary) in a 3-D array with address given by (i,j,k). The discretized electric and magnetic fields are placed in a staggered manner (Figure 3). Electric field components of $\mathbf{E_x}(i+1/2,j,k)$, $\mathbf{E_y}(i,j+1/2,k)$, $\mathbf{E_z}(i,j,k+1/2)$ and magnetic field components of $\mathbf{H_x}(i,j+1/2,k+1/2)$, $\mathbf{H_y}(i+1/2,j,k+1/2)$, $\mathbf{H_z}(i+1/2,j+1/2,k)$ are assigned and stored in the memory associated with processor (i,j,k). These fields are calculated using an explicit time marching scheme. Based on this arrangement, the electric fields are updated using the Ampere's law with magnetic fields at (i,j,k), $(i-1,j,k)$, $(i,j-1,k)$, and $(i,j,k-1)$. Similarly, the magnetic fields at (i,j,k) are updated using the Faraday's law with electric fields at (i,j,k), $(i+1,j,k)$, $(i,j+1,k)$ *and* $(i,j,k+1)$. For each processor, these two operations require data from its six neighbors; consequently, they are executed efficiently in the DTC architecture.

The absorbing boundary condition [5] is implemented on the boundary of the computational domain. Two layers of cells are involved in the implementation. Since the data required to update the boundary field come from different directions depending on the face of the boundary, for parallel updating of the boundary fields, appropriate fields are shifted according to their relative position with respect to the boundary face. The numerical operations to update the boundary fields are then executed in parallel. It should be noted that this process is relatively expensive in comparison with the interior field updating, since only a fraction of the processors are active.

There are more variables associated with the boundary processors than with the interior processors. Roughly speaking, there are three electric field and three magnetic field components associated with each interior processor. For the boundary processors, there are additionally four tangential field components. Furthermore, two more components are needed in 3-D. Since a variable in the SIMD computer represents parallel data, this arrangement would potentially waste memory. There are a number of implementation techniques to resolve this problem. In *EM-WAVETRACER* the parallel data is shared. For regions within the scattered object, the excessive memory is used to store material properties. For the region outside the scattered object and inside the boundary, the excessive memory is used to store the complex tangential fields for post processing of the bistatic scattered fields. Eight floating point variables are needed for each frequency (4 complex tangential electric and magnetic fields). As a result, the excessive memory of every four layers are used to store complex fields of three frequencies (Figure 4). At every time step, the integrations for calculating the complex fields are evaluated in parallel.

This parallel version of the FD-TD algorithm has been applied to a number of problems including scattering, radiation, and microstrip line characterization (A description of these applications is available from Wavetracer, Inc.). The *EM-WAVETRACER* package which analyzes scattering and radar cross section problems is available commercially. The package accepts geometry inputs from a list of triangles extracted from a *CATIA* CAD tool. This triangle list describes the geometries of the materials (each material sub-region has a list of triangles). The minimum distance criteria is used to convert the list into a rectangular block description of the objects. This approach is fully automated and can easily be generalized to other CAD tools. For microstrip line and antenna problems, a multi-gridding zone FD-TD algorithm is implemented and applied to problems involving flared slot antenna and characterization of through-holes of printed wire boards. The computational speed varies depending on the application. For example, in the through-hole problem, 0.85 second per time step for a million discretization nodes is obtained in the DTC-16, which is priced at about $400,000. In general, high performance is achieved. Furthermore, the DTC can easily host multimillion discretization cell problems.

IV. The MoM Algorithm

The MoM algorithm developed for the DTC is a parallel version of the MoM algorithm suggested in [6]. This MoM code analyzes the scattering of arbitrarily 3-D conducting objects. The surface geometries of these objects are described by triangular patches extracted from the CAD tool. The input format of the triangle patches is identical to that in the FD-TD code. The bi-triangular basis and testing functions are used. The parallel calculations of the matrix elements are implemented in block manner. Matrix solutions are obtained by using the parallel Gaussian elimination method.

An obvious parallel implementation of the MoM algorithm is based on the *edge-edge* pair; however, this requires about eight times as many operations as the *patch-patch* pair approach [6]. As a result, the *patch-patch* pair approach is used in the DTC MoM code. The DTC is arranged as a 2-D array; the coordinates of patch vertices are spread both in the *x* and *y* directions, so that each processor element has access to necessary information. Interactions between these pairs are calculated, and the results are sent back to the host workstation for final assembly to produce the matrix. The interactions are calculated in either quadruple integral mode or double integral mode. In the double/quadruple integral mode, double/quadruple integrals are calculated. The quadruple integrals are results of surface integral equation and testing. When single-point testing is used, the quadruple integrals become double integrals. These integrations are calculated numerically using seven point Gauss' integration formula. With this DTC-workstation hybrid approach, the number of floating operations is minimized, and the computations are in parallel.

Block implementation is another feature of the MoM code. Since singularity appears only when the observation and test patches are the same, the DTC-16/DTC-8 is configured as a 128 by 128 array (64 by 64 for DTC-4). With this configuration the DTC-16 and DTC-4 are not operated in virtual processing mode. The number of operations involved in treating the singularity is significantly more than for numerical integration; different calculations are invoked depending on the block (Figure 5). Along the diagonal, the singularity treatment is used; for off-diagonal blocks, numerical integration is used.

This MoM code has been tested for a number of geometries and is still in *beta* test for more complex geometries and user friendliness. Accurate radar cross sections are calculated for these geometries. In some cases, the quadruple integral mode provides much better results than the double integral mode for given geometrical modeling. Preliminary results indicate that the DTC is operating at a high percentage of its peak MFLOP performance rating. However, complete measurements of the computational speeds in matrix generation and solution on the DTC-workstation hybrid system is yet to be finished.

V. Summary

This article summarizes the implementations of the FD-TD and MoM algorithms on the DTC. The DTC is a 3-D SIMD massively parallel computer. This computer is supported by the multiC language which extends the C language to include data-parallel programming. The implementation of the FD-TD algorithm utilizes the 3-D, virtual processing and local connectivity features of the DTC. Parallel data is shared to minimize memory requirement. The block implementation technique is used for the MoM algorithm. For this approach, the 2-D unfolding and the workstation are utilized. These programs are applied to many scattering and radiation problems. Very cost-effective performance is obtained. Both the FD-TD and MoM analysis packages are commercially available from Wavetracer for engineering applications.

References

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[6] Rao, S. M., D. R. Wilton, and A. W. Glisson, "Electromagnetic scattering by surface of arbitrary shape," *IEEE* Trans. Ant. Prop., AP-30, 409-418, May 1982.

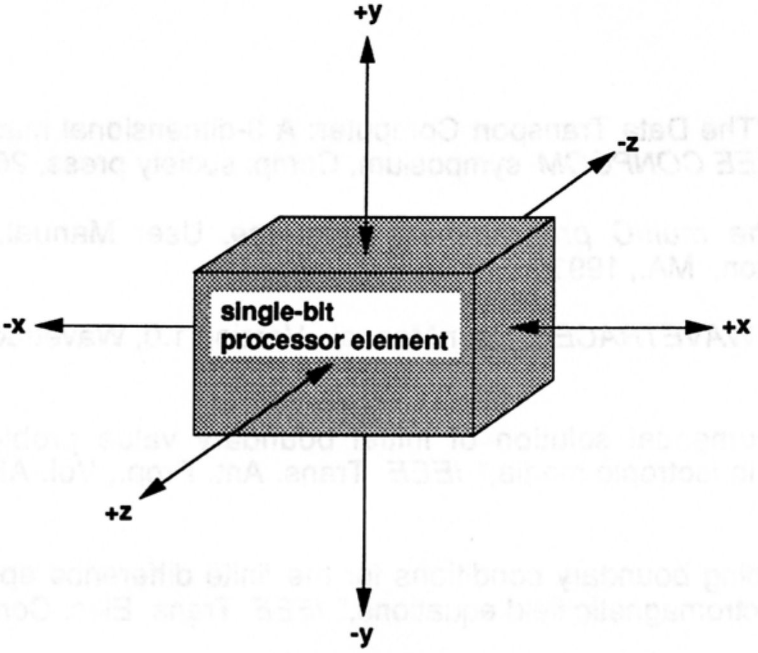

Figure 1

Processing element and interconnections.

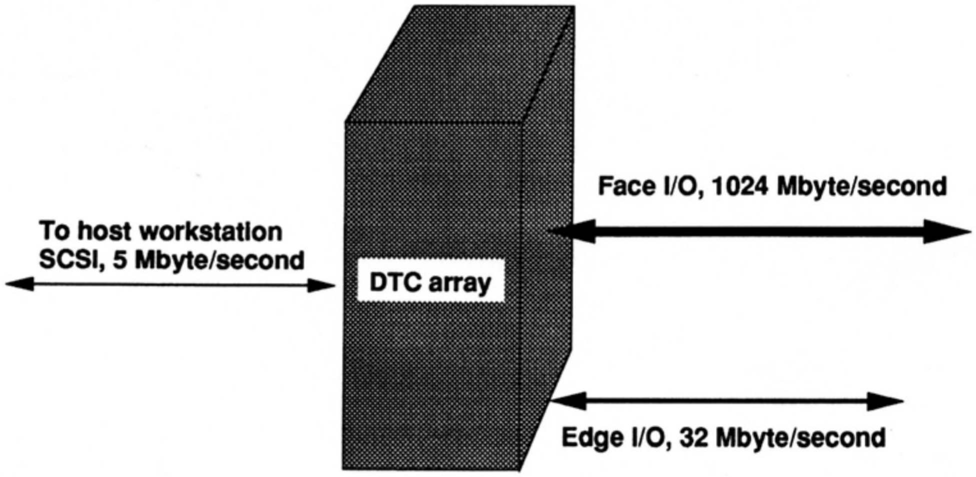

Figure 2

I/O ports of Data Transport Computer.

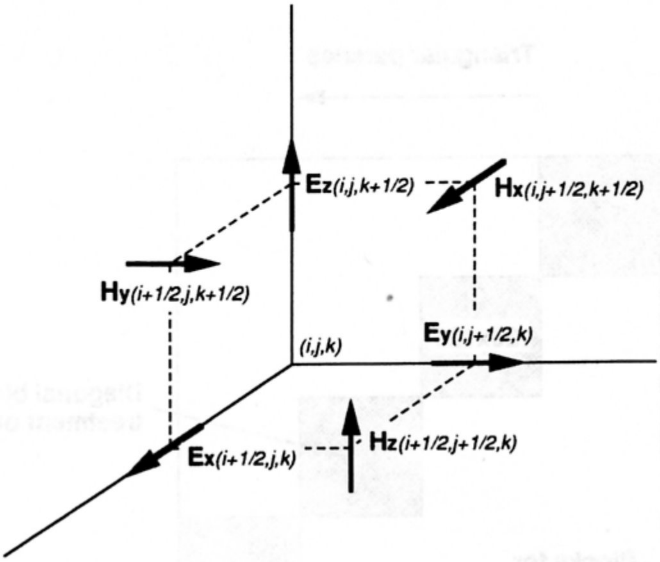

Figure 3

Staggered grid cell.

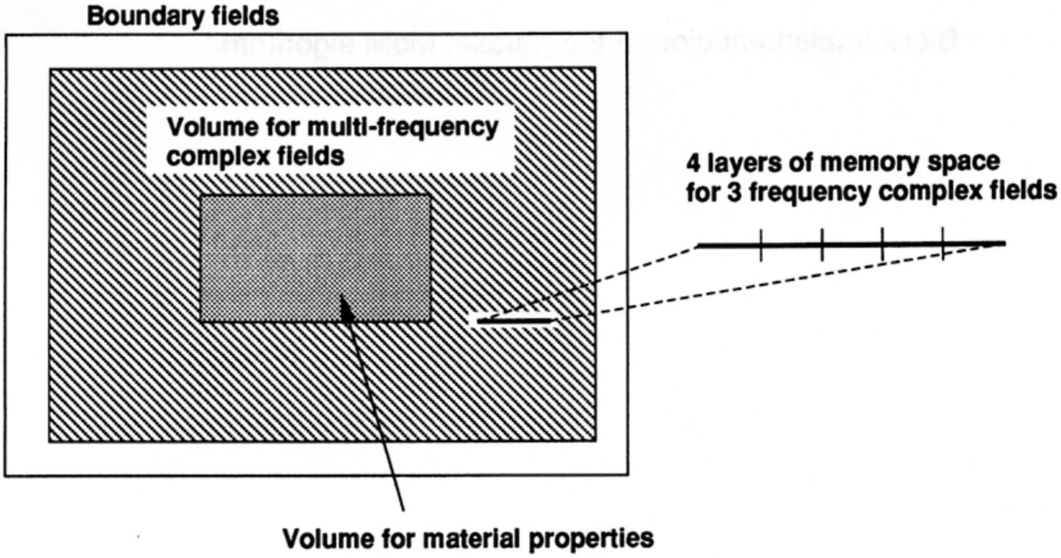

Figure 4

Sharing of parallel data in FD-TD algorithm.

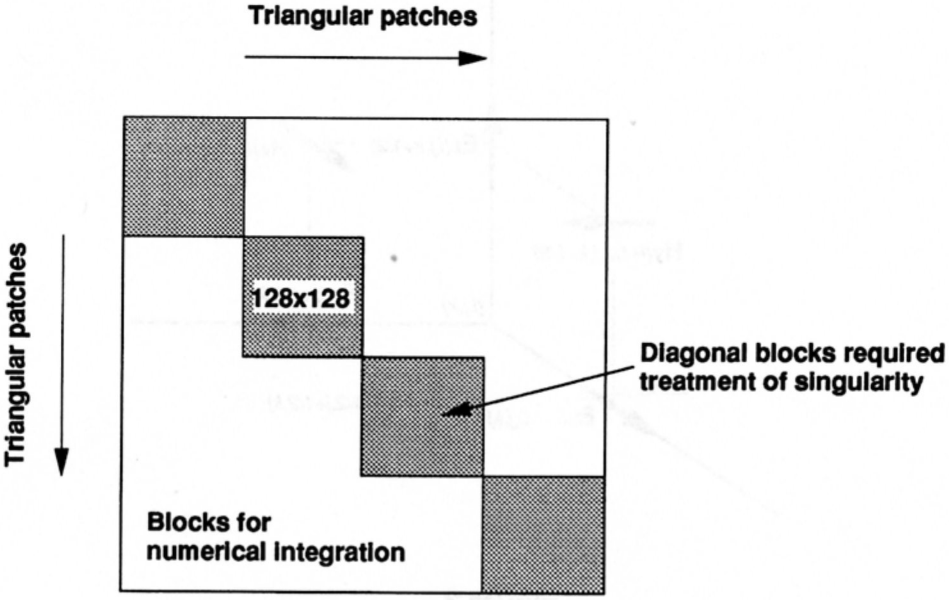

Figure 5

Block implementation of the parallel MoM algorithm.

MEGAERA 4.0:
A code for modelling transient heat flow induced by quasi-static electric fields in lossy media

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Introduction

The first version of MEGAERA was written in FORTRAN IV by A.D. Hiebert [1,2]. It was designed to solve heat evolution problems in lossy media in two dimensions (rectangular or cylindrical coordinates) characterized by quasistatic electric field excitation and material properties which are nonuniform and vary nonlinearly with temperature. In its first application, MEGAERA was used to investigate the viability of heating underground oil sand deposits with electrical conduction current as a means for stimulating oil production [3].

Originally introduced a decade ago, the code has had ample time to mature. In its current release, MEGAERA 4.0 has benefited from numerous modifications which improve code portability and computational accuracy. Having guided MEGAERA through a period of growth and development, we would like to reintroduce the program to the em modelling community by outlining the scope of its capabilities and illustrating its ease of use.

Background

At the core of MEGAERA's computational engine is a procedure for solving Fourier's heat transfer equation:

$$\rho C^b \frac{\partial T}{\partial t} = Q + \nabla \bullet (k \nabla T) - \rho C^f \vec{u} \bullet \nabla T;$$

ρC^b	volumetric heat capacity of the bulk, J m^{-3} $°C^{-1}$
T	temperature, °C
t	time, s
Q	volumetric heating rate, W m^{-3}
k	thermal conductivity of the bulk, W m^{-1} $°C^{-1}$
ρC^f	volumetric heat capacity of the fluid, J m^{-3} $°C^{-1}$
$\vec{u}$	fluid velocity, m s^{-1}.

The equation accommodates conductive heat transfer through a bulk material as well as the convection of heat by an interstitial single-phase fluid.

In MEGAERA, the internal heat term Q arises from the time-averaged dissipation of electrical energy, viz., $Q = \sigma\vec{E} \bullet \vec{E}^*$, where σ is the electrical conductivity of the lossy bulk material and $\vec{E}$ and $\vec{E}^*$ represent the rms phasor electric field and its complex conjugate. Assuming that the electric field which is induced by the magnetic field is negligible and that the wavelength in the material is much larger than the problem domain, the electric field may be considered to be conservative, that is, $\vec{E} = -\nabla\Phi$, Φ being the electric potential. Assuming further that the loss tangent $\sigma/\omega\varepsilon$ is much larger than one, the current density is given by $\vec{J} = \sigma\vec{E}$. Subsequently enforcing current continuity in a source-free region, $\nabla \bullet \vec{J} = 0$, yields an equation for the electric potential:

$$\nabla \bullet (\sigma\nabla\Phi) = 0.$$

MEGAERA solves this equation for Φ, which is used to calculate $\vec{E}$ and from this, Q.

The fluid velocity $\vec{u}$ is obtained by application of Darcy's law $\vec{u} = -(\kappa/\mu)\nabla P$ which describes the motion of an incompressible fluid through a porous medium. In this equation, κ is the absolute permeability of the medium, μ is the fluid viscosity, and P is the gauge pressure of the fluid. Again, enforcing continuity — this time of mass-flow — in a source-free region produces an expression identical in form to the electric potential equation:

$$\nabla \bullet \left(\frac{\kappa}{\mu}\nabla P\right) = 0.$$

Thus, fluid velocity is obtained indirectly from the solution of a boundary value problem for pressure.

The spatial components of the three governing partial differential equations are discretized over a two-dimensional finite difference grid in either rectangular or axisymmetric cylindrical coordinates within a bounded problem domain. MEGAERA treats electrical conductivity and fluid viscosity as possibly being inhomogeneous. Moreover, these material properties are considered temperature dependent. As such, MEGAERA projects the temperature distribution $T^i(x_1,x_2)$ forward in time to $T^{i+1}(x_1,x_2)$ via Fourier's equation based on the Q and $\vec{u}$ calculated at $T^i(x_1,x_2)$. (x_1,x_2 are generalized coordinates, representing either rectangular or r,z cylindrical coordinates.) Time step size is dynamically adapted by monitoring the maximum change in temperature, electrical conductivity, or fluid viscosity within the problem boundary. Normally, the time step size will be much greater than the period of the applied ac field, justifying the use of time-average quantities in the calculation of Q.

Algorithms

In rectangular coordinates, the equation for electrical potential takes the form

$$\frac{\partial}{\partial x}\left(\sigma\frac{\partial\Phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\sigma\frac{\partial\Phi}{\partial y}\right)=0.$$

The gradient operation within each term is approximated by a forward and backward difference expression which takes into account the continuity of electric current and potential at the interface between adjacent grid blocks. Assuming the electric field is uniform with each grid block, the backward difference formula in the x-direction, for example, is

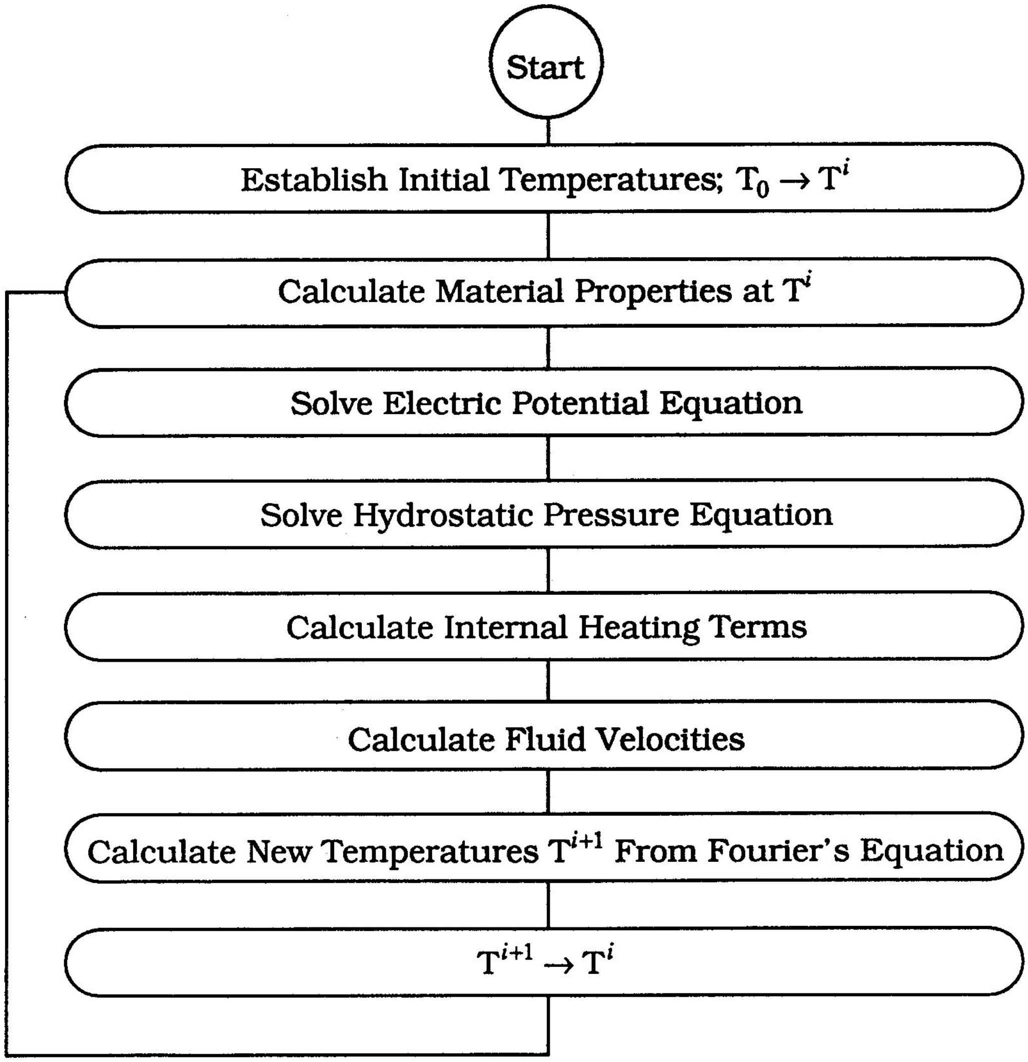
$$\frac{\partial\Phi_{i,j}}{\partial x}\approx\frac{\Phi_{i,j}-\Phi_{i-1,j}}{\frac{\Delta x_i}{2}+\left(\frac{\sigma_{i,j}}{\sigma_{i-1,j}}\right)\frac{\Delta x_{i-1}}{2}},$$

where Δx_i and Δx_{i-1} are the width of the ith and $(i-1)th$ grid block, respectively. Similar expressions describe the forward difference and those differences for the y-direction. The divergence operation, that is, the second derivative in the original equation, is subsequently formed by differencing these forward- and backward-difference equations for the gradient.

The ensemble of difference equations yields a sparse system of linear equations whose number equals the total number of grid blocks and whose bandwidth is determined by the number of horizontal or vertical grid divisions. A separate system is generated for each of the three governing partial differential equations. In each case, the method of ADI is used to obtain a solution. Iterative techniques such as ADI are efficient in this application because the solutions from the previous time step can be used as the starting points for the solution of the next time step. In addition, storage requirements are moderate.

The sequence of calculations is illustrated in the flow chart which follows. Note that a solution is generated for each of the three phenomena electric potential, hydraulic fluid flow, and heat transfer. MEGAERA archives results for each in an output file.

Boundary conditions and variations in the composition of the problem domain are handled by overlaying rectangular subdomains, or regions, on the finite difference grid. A region can be specified to comprise either (1) interior points, (2) source/sink points, or (3) insulating or no-flow points. Several regions of various type and size can be overlain to model the geometry of a wide variety of physical problems. Moreover, a region's electric, hydraulic, and thermal type are assigned independently of each other, allowing many combinations.



Example Input

MEGAERA accepts problem specifications through a data file which uses the NAMELIST extension to standard FORTRAN 77 I/O. With this technique, data files have a self-documenting quality. Namelist members are collected into appropriate groups which define grid geometry, region description, output format, and heating control.

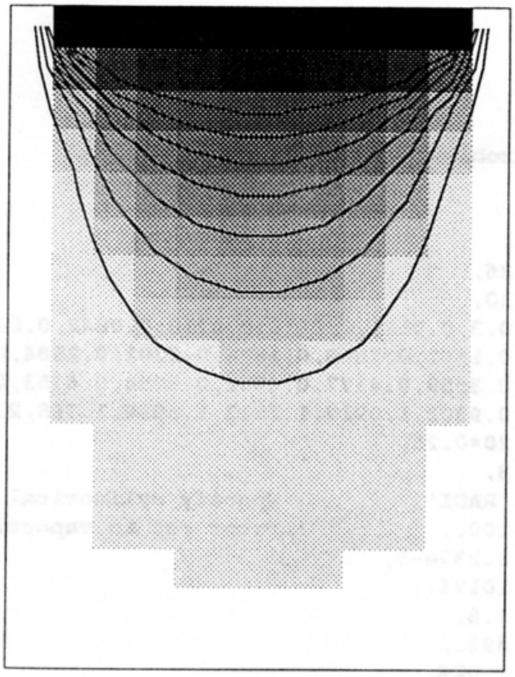
A simple application of MEGAERA is the solution of the two-dimensional electrostatic field problem described on p. 198ff of *Fields and Waves in Communication Electronics* by Ramo, Whinnery, and Van Duzer — a "potential box" filled with air and capped with a metal lid. Although no heat transfer or fluid flow takes place, input parameters for these calculations are required. The input data file for this problem is as follows.

```
&INMOD
    NRUN = 1,                          ! Number of time steps needed.
&END

&LABELS
    LABEL1 = 'Potential Box',          ! Identify the simulation.
&END

&INPUT1
    NX          = 12,                  ! Number of grid blocks in x-direction.
    NY          = 16,                  ! Number of grid blocks in y-direction.
    DELTAX      = 12*1.0,              ! Grid-block widths in x-direction.
    DELTAY      = 16*1.0,              ! Grid-block widths in y-direction.
    NREG        = 5,                   ! Number of material regions.
    va          = 3.239e-5,            ! Coefficients of the viscosity curve...
    vb          = 10176.,
    vc          = 1.8,
    vd          = 492.,
    fluid_THMRC = 2.0e6,               ! Fluid thermal heat capacity.
&END

&REGION
    MINI     = 1,                      ! Grid-block range for region 1...
    MAXI     = 12,
    MINJ     = 1,
    MAXJ     = 16,
    ETYPE    = 'DOMA',                 ! Region 1 is an electrical conductor.
       C24   = 1.e-2,                  ! Electrical conductivity of region 1.
    TTYPE    = 'COND',                 ! Region 1 is a thermal conductor.
       THMRC = 1.5e6,                  ! Heat capacity of region 1.
       THMK  = 1.0,                    ! Thermal conductivity of region 1.
    ptype    = 'DOMA',                 ! Region 1 permits fluid flow.
&END
&REGION
    MINI            = 1,               ! The characteristics of region 2
    MAXI            = 1,               !   and the other three regions are
    MINJ            = 1,               !   are stacked to produce a composite
    MAXJ            = 16,              !   problem domain.
    ETYPE           = 'ELEC',          ! Region 2 is an electrode.
       VOLTS        = 0.0,             ! Electrode voltage.
    TTYPE           = 'INSU',          ! Region 2 is a thermal insulator.
    ptype           = 'PROD',          ! Region 2 is a fluid source/sink.
       abs_pressure = -0.5,            ! Code to establish fixed, zero pressure.
&END
&REGION
    MINI            = 2,
    MAXI            = 11,
    MINJ            = 1,
    MAXJ            = 1,
    ETYPE           = 'ELEC',
       VOLTS        = 0.0,
    TTYPE           = 'INSU',
    ptype           = 'PROD',
       abs_pressure = -0.5,
&END
```

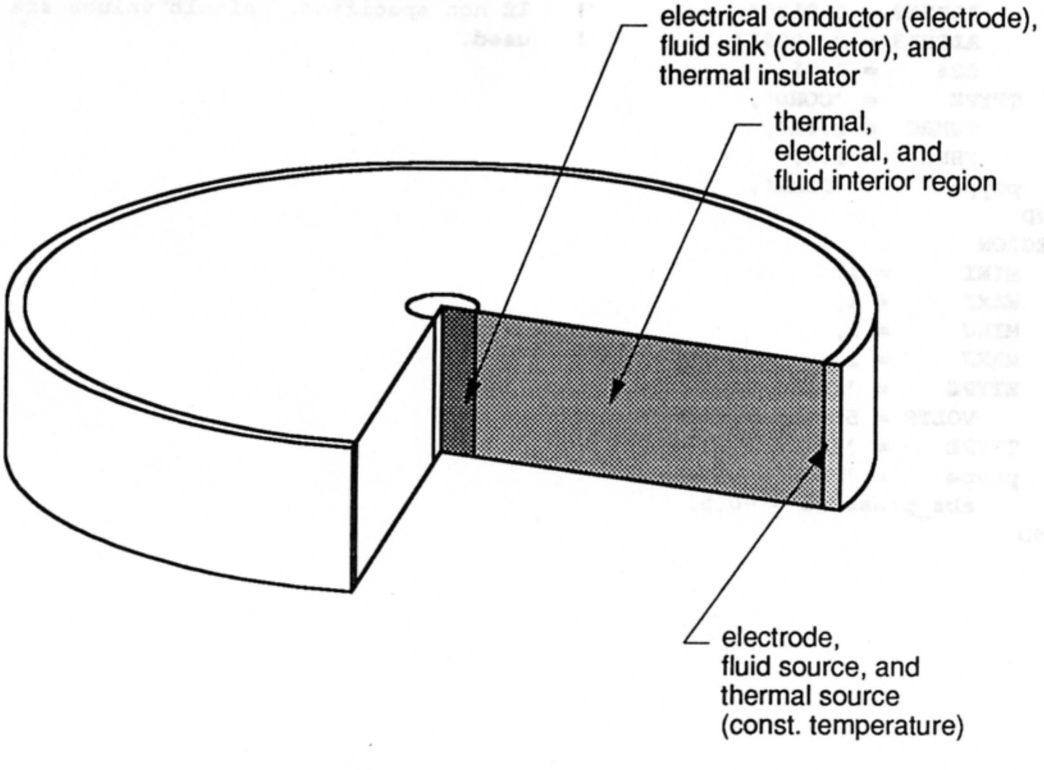
```
&REGION
    MINI           = 12,
    MAXI           = 12,
    MINJ           = 1,
    MAXJ           = 16,
    ETYPE          = ‘ELEC’,
       VOLTS       = 0.0,
    TTYPE          = ‘INSU’,
    ptype          = ‘PROD’,
       abs_pressure = -0.5,
&END
&REGION
    MINI           = 2,
    MAXI           = 11,
    MINJ           = 16,
    MAXJ           = 16,
    ETYPE          = ‘ELEC’,
       VOLTS       = 1.0,
    TTYPE          = ‘INSU’,
    ptype          = ‘PROD’,
       abs_pressure = -1.0,        ! Code for fixed nonzero positive pressure.
&END

&INPUT2
    NPX = 12,                      ! Set the coordinates at which output
    NPY = 16,                      !   quantities are to be recorded.
&END

&INPUT3
    TINIT      = 22.,              ! Initial temperature.
    DTIME      = 1.0,              ! Initial time step size.
    HTIME      = 3.0,              ! Heating time.
    CVOL       = 1.0,              ! Maximum potential difference.
    NCI        = 11,               ! For monitoring electric current.
    epspress   = 1.e-4,            ! Convergence criterion.
    fluid_flow = .false.,          ! Suppress convection heat transfer.
&END
```

Output from MEGAERA is recorded into several text files which can be imported into a variety of graphical presentation software. One such package is Spyglass™, a commercial version of NCSA Image, for the Macintosh® II family of computers. A typical Spyglass graphic for the potential box problem appears on the next page. The figure shows electric potential contours superimposed on a grey-scale image of the potential values in each finite difference cell.

The solution of a more complex problem demonstrates the full range of MEGAERA's capabilities and highlights the interesting results which can be obtained. Consider a technique in the oil recovery industry for enhancing production known as single well heating. In this process, electric current is made to flow between electrodes which have been placed in a heavy oil formation. In principle, the heat generated by the current lowers oil viscosity, thereby improving production.



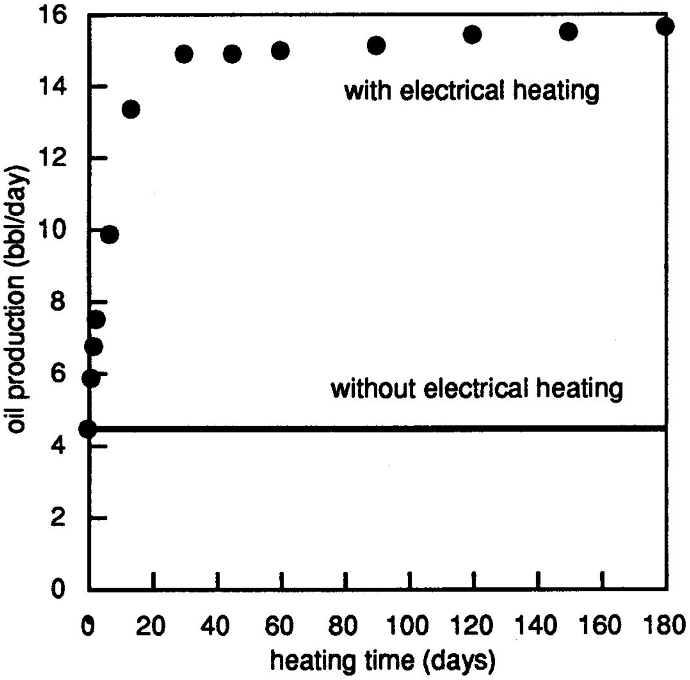
A model of this technique, idealized here for simplicity, is illustrated in the following figure. The applied electric potential difference establishes radially-directed current flow between the concentric electrodes. In a similar fashion, the presence of a fluid collector at the center establishes a hydraulic pressure gradient which tends to make oil flow towards the collector from the outer boundary of the model. The MEGAERA data file for this problem follows on the next page.



```
&INMOD
    NRUN = 999,
&END

&LABELS
    LABEL1 = ‘Test Problem - 1D’,
&END

&INPUT1
    NX             = 26,
    NY             = 20,
    DELTAX         = 0.3,0.0521,0.0611,0.0718,0.0842,0.0989,0.1160,
                     0.1362,0.1598,0.1876,0.2201,0.2584,0.3032,
                     0.3559,0.4177,0.4902,0.5754,0.6753,0.7926,
                     0.9302,1.0917,1.2813,1.5038,1.765,2.0715,0.3,
    DELTAY         = 20*0.25,
    NREG           = 3,
    GEOMET         = ‘RADI’,        ! Specify cylindrical geometry.
    boiling_point  = 100.,          ! Water set to vapourize at this temp.
    va             = 3.239e-5,
    vb             = 10176.,
    vc             = 1.8,
    vd             = 492.,
    fluid_THMRC    = 2.0E6,
&END

&REGION
    MINI      = 1,
    MAXI      = 26,
    MINJ      = 1,
    MAXJ      = 20,
    ETYPE     = ‘DOMA’,
       ALPHA1 = 0.0263,             ! Coefficients of the conductivity curve.
       ALPHA2 = 0.01306,            !   If not specified, default values are
       ALPHA3 = 0.009924,           !   used.
       C24    = 0.01,
    TTYPE     = ‘COND’,
       THMRC  = 2.0E6,
       THMK   = 1.8,
    ptype     = ‘DOMA’,
&END
&REGION
    MINI     = 1,
    MAXI     = 1,
    MINJ     = 1,
    MAXJ     = 20,
    ETYPE    = ‘ELEC’,
       VOLTS = 500.,
    TTYPE    = ‘INSU’,
    ptype    = ‘PROD’,
       abs_pressure = -0.5,
&END
```

```
&REGION
    MINI      = 26,
    MAXI      = 26,
    MINJ      = 1,
    MAXJ      = 20,
    ETYPE     = ‘ELEC’,
      VOLTS   = 0.,
    TTYPE     = ‘CTEM’,
      TEMPER  = 15.,
    ptype     = ‘PROD’,
      abs_pressure = -5.75e6,
&END

&INPUT2
    NSPO   = 1000,                  ! Printing parameters...
    NPTIME = 11,
    PTIME  =   86400.,              ! Save results at these times...
              172800.,
              259200.,
              604800.,
             1209600.,
             2592000.,
             3888000.,
             5184000.,
             7776000.,
            10368000.,
            12960000.,
    LINPRI = .TRUE.,                ! Extract results at these coordinates...
    NPX    = 24,
    NPY    = 1,
    XPRINT = 0.32605,0.38267,0.44912,0.52712,0.61866,0.72609,0.85219,
             1.00018,1.17387,1.37772,1.61697,1.89777,2.22734,
             2.61414,3.06810,3.60091,4.22624,4.96016,5.82154,6.83250,
             8.01903,9.41160,11.04601,12.96425,
    YPRINT = 2.875,
&END

&INPUT3
    TINIT      = 15.,
    DTIME      = 1.0,
    HTIME      = 15552000.,
    NTYPE      = 1,                 ! Constant voltage heating.
    CVOL       = 500.,
    NTSIZE     = 4,                 ! Time step size linked to viscosity.
    DSIGMA     = .05,               ! Time stepping criterion.
    NIJ        = 1,                 ! Codes for monitoring electric current...
    NCI        = 9,
    MMAX       = 999,               ! Maximum number of iterations of ADI.
    EPSELE     = .0005,             ! Convergence criterion for elect. solver.
    fluid_flow = .true.,
&END
```

As shown in the following figure, MEGAERA predicts an oil production rate which rises with time to a value that is almost four times as large as the initial production rate. Without electrical heating, the production rate would be constant with time.



Simple problems like the potential box take only seconds to execute on commonly available desktop microcomputers. Long term heating studies, on the other hand — those that include fluid flow — may require more computing power, depending on the modelling parameters. A typical 90- to 180-day oil reservoir heating simulation terminates after 300 to 400 time steps and takes about 15 minutes to execute on a 1.5-MFLOP machine. (MEGAERA 4.0 is used on a Macintosh II with an installed Tektronix® RP88 NuBus™ coprocessor board.)

Conclusion

MEGAERA is a versatile program which should be of interest to workers in the field of resource recovery, heating of biological tissue, evaluation of powerline hazards, design of heat sinks, and others. Except for one timing routine, MEGAERA is exclusively FORTRAN 77 source code and should compile with any compiler that supports NAMELIST. Additional information about the program and its use is available from the authors.

References

[1] A.D. Hiebert, "Computer simulation of *in situ*, low frequency, electrical heating of oil sand formations," M.Sc. Thesis 1981, University of Alberta, Edmonton, Alberta, Canada, T6G 2G7.

[2] A.D. Hiebert, C.E. Capjack, F.S. Chute, and F.E. Vermeulen, "A simulation code for investigating 2D heating of material bodies by low frequency electric fields," *Applied Mathematical Modelling*, vol. 7, pp. 366–371, Oct. 1983.

[3] F.S. Chute, F.E. Vermeulen, and L.G. Stevens, "A study of the technical and economical feasibility of an electric preheat process for *in situ* recovery from Athabasca oil sands," *AOSTRA Journal of Research*, vol. 3, pp. 139-154, 1987.

Advantages of using variable transformations in a finite difference algorithm for the solution of potential problems in cylindrical geometry

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Introduction

A general statement of the potential problem is

$$\nabla \bullet (\alpha \nabla \Phi) = 0.$$

In electrostatics, this describes the continuity of conduction current if Φ is interpreted as electric potential and α, as electrical conductivity. Likewise, reading temperature and thermal conductivity for the generic parameters, this equation represents steady state heat conduction. Note that inhomogeneous material properties are admitted by the expression.

In rectangular coordinates, the two-dimensional potential problem expands to

$$\frac{\partial}{\partial x}\left(\alpha \frac{\partial \Phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\alpha \frac{\partial \Phi}{\partial y}\right) = 0, \tag{1}$$

while in cylindrical coordinates, for a geometry which is symmetric about the z-axis, it expands to

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\alpha \frac{\partial \Phi}{\partial r}\right) + \frac{\partial}{\partial z}\left(\alpha \frac{\partial \Phi}{\partial z}\right) = 0.$$

After manipulating the derivatives in r and rearranging and collecting like terms, the cylindrical-coordinate expression can be written as

$$\left[\frac{\partial}{\partial r}\left(\alpha \frac{\partial \Phi}{\partial r}\right) + \frac{\alpha}{r}\frac{\partial \Phi}{\partial r}\right] + \frac{\partial}{\partial z}\left(\alpha \frac{\partial \Phi}{\partial z}\right) = 0. \tag{2}$$

This is similar to the rectangular-coordinate expression but for the term in $1/r$.

Equations (1) and (2) are solved by approximating the first and second derivatives with difference formulas which are defined over an orthogonal grid structure. Depending on the nature of the problem, the so-called discretization error resulting from this process is more or less sensitive to the number of grid divisions in each direction. Moreover, in those case where the solution varies rapidly near the central axis of a cylindrical problem, there is a possibility that the discretization error will be magnified because of the $1/r$-term multiplying the derivative.

In this communication, we would like to outline a method that reduces the discretization error associated with the solution of cylindrical-coordinate potential problems. Rather than adopt a finer grid—which would require more storage, prolong execution time, and possibly increase round-off errors — a simple variable transformation is proposed. This approach has the added advantage of reusing the discretization code for the rectangular-coordinate form of the equation.

Variable Transformation

We will demonstrate the method by solving a simple one-dimensional problem in electrostatics, namely, the potential distribution between two infinitely long, concentric perfect conductors separated by a dissipative material. The governing equation for this problem may be written as

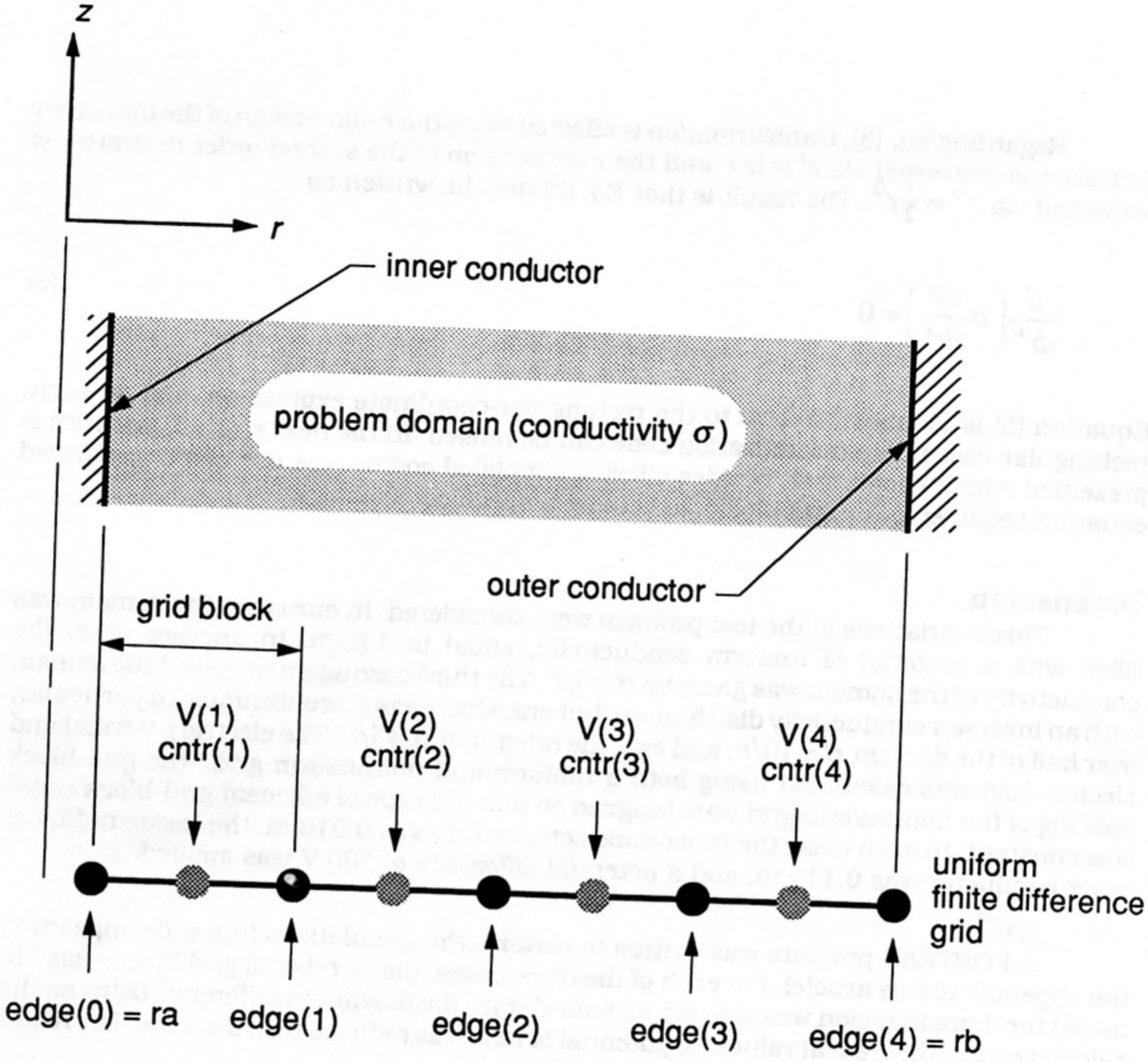
$$\frac{1}{r}\frac{d}{dr}\left(r\sigma\frac{dV}{dr}\right)=0 \tag{3}$$

or

$$\frac{d}{dr}\left(\sigma\frac{dV}{dr}\right)+\underbrace{\frac{\sigma}{r}\frac{dV}{dr}}_{\text{"radial term"}}=0, \tag{4}$$

where V is the electrostatic potential and σ is the electrical conductivity of the material occupying the space between conductors. SI units are assumed. Equation (3) could be integrated once to reduce the order of differentiation; however, this is not done in order to be consistent with the two-dimensional form of the equation. As well, a so-called radial term is identified in Eq. (4) because it distinguishes the cylindrical-coordinate form of the expansion from the rectangular-coordinate form, Eq. (1).

The geometry for this problem and a representative finite difference grid structure are illustrated in the following figure. Initially, forward and backward difference expressions for the nonradial $\frac{dV}{dr}$-term in Eq. (4) are defined at the grid-block centers, where it is



assumed that adjacent grid blocks may comprise different conductivities. These expressions are further differenced to generate approximations to the second order derivative. The radial $\frac{dV}{dr}$-term is handled with a weighted-average difference formula.

For the grid in question, this process yields a tridiagonal system of four linear equations in the four unknowns $V(1),\ldots,V(4)$. The elements of the coefficient matrix are functions of the grid dimensions and the electrical conductivities, while the right-hand-side vector is zero except for one member whose value depends on the potential of the center electrode, the dimensions, and the conductivities.

Solving the system of linear equations produces an estimate of the potential distribution throughout the problem domain. The electric field distribution may be calculated from this approximate, discrete potential function by numerical differentiation (weighted-average of the forward and backward difference, taking into account nonuniform electrical conductivity).

As outlined above, the presence of the radial term in Eq. (4) necessitates additional difference expressions which are multiplied by σ/r. With appropriate variable transformations, these additional expressions become unnecessary.

Regarding Eq. (3), transformation is affected thus: the r-dimension of the first order derivative is converted via $r' = \ln r$ and the r-dimension of the second order derivative is converted via $r'' = \frac{1}{2}r^2$. The result is that Eq. (3) may be written as

$$\frac{d}{dr''}\left(\sigma\frac{dV}{dr'}\right) = 0. \tag{5}$$

Equation (5) is identical in form to the rectangular-coordinate expression, and as such, rectangular-coordinate discretization code can be reused. In the next section, evidence is presented which shows that, besides offering simplified coding, the use of a transformed equation requires fewer grid blocks to achieve a specified accuracy.

Discussion

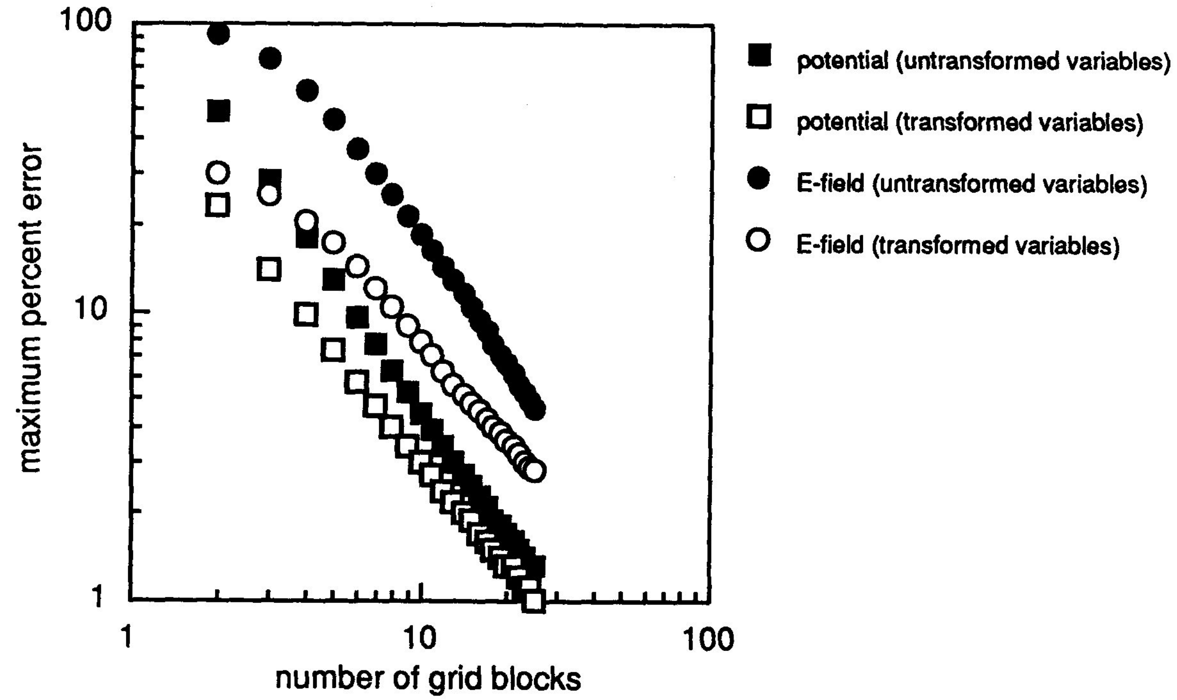
Three variations of the test problem were considered. In one case, the domain was filled with a material of uniform conductivity, equal to 1 S/m. In another case, the conductivity of the domain was given by $\sigma = 1/r$. The third case again modelled the domain with an inverse-r conductivity distribution, but one which was discontinuous. In particular, over half of the domain $\sigma = 10/r$, and over the other half $\sigma = 1/r$. The electric potential and electric field was calculated using both a uniform and nonuniform grid. The grid-block spacing of the nonuniform grid was designed so that the ratio of adjacent grid-block edges was constant. In each case, the inner-conductor radius was 0.010 m, the inside radius of outer conductor was 0.110 m, and a potential difference of 100 V was applied.

A FORTRAN program was written to perform the calculations (the code appears in the appendix to this article). For each of the three cases, the number of grid blocks used to model the domain region was steadily increased until the maximum difference between the calculated and theoretical values for potential or field was reduced to at least 5%. The result of this analysis is shown in the following table.

Number of grid blocks required to reduce maximum error to at least 5%.

		uniform grid		nonuniform grid	
domain conductivity	transformed	potential	electric field	potential	electric field
uniform	no	6	18	8	11
	yes	<2	13	<2	7
inverse	no	10	24	15	13
	yes	7	15	12	7
discontinuous, inverse	no	8	26	14	22
	yes	6	17	12	17

When presented graphically, the trends become apparent. A plot of maximum error versus number of grid blocks for the case of a uniform grid applied to a $1/r$-conductivity domain shows that, for the same number of grid blocks used, the maximum error will be less when the variables are transformed. As well, with transformed variables, the maximum error increases less rapidly as fewer grid blocks are used. These trends are characteristic of all the cases tested.



Conclusions

Applying variable transformations has been shown to reduce the discretization error in the finite difference solution of one-dimensional potential problems that display azimuthal symmetry in cylindrical coordinates. Additionally, discretization code developed for a rectangular geometry can be reused as the transformed equation takes on a rectangular form. The benefit of code reusability is immediately extendible to problems in two dimensions. Studies are planned to quantifying the impact of variable transformations on discretization error in 2D.

Appendix

```
program Cylinder

  integer grid_type                      ! Declare grid-type variable.
  integer UNIFORM_GRID, PROP_GRID

  parameter (UNIFORM_GRID = 1)
  parameter (PROP_GRID    = 2)

  integer sig_type                       ! Declare conductivity-type variable.
  integer UNIFORM_SIG, INVERSE_SIG, DISCONTINUOUS_SIG
```

```
  parameter (UNIFORM_SIG       = 1)
  parameter (INVERSE_SIG       = 2)
  parameter (DISCONTINUOUS_SIG = 3)

  parameter (SIG_1 = 10.0)              ! Coefficient of first conductivity zone.
  parameter (SIG_2 =  1.0)              ! Coefficient of second conductivity zone.

  parameter (MAXDIM = 500)              ! Maximum array dimensions.

  dimension a      (MAXDIM,4)           ! Tri-diagonal matrix of coefficients.
  dimension e_field(MAXDIM)             ! Calculated E-field.
  dimension edge   (0:MAXDIM)           ! Array of grid block edges.
  dimension cntr   (MAXDIM)             ! Grid-block mid-point array.
  dimension sig    (MAXDIM)             ! Array of material conductivities.

  logical transformed                   ! Transformation state.

  common /params/ ra,rb,rm,va,sls2      ! Global variables.

! Initialize the problem.
  read(*,*) ra                          ! Radius of inner conductor.
  read(*,*) rb                          ! Radius of outer conductor.
  read(*,*) rm                          ! Intermediate radius.
  read(*,*) va                          ! Potential on inner conductor.
                                        !   Potential on outer conductor is zero.

  read(*,*) grid_type                   ! Type of finite difference grid.
  read(*,*) sig_type                    ! Type of conductivity distribution.
  read(*,*) nseg                        ! Number of segments.
  read(*,*) transformed                 ! Variable transformation flag.

  nedge = nseg + 1

! Verify parameters.
  if ((rb - ra) < 0.) then
    write(*,*) ‘## rb must be greater then ra.’
    stop
  end if
  if (nseg > MAXDIM) then
    write(*,*) ‘## Too many segments.’
    stop
  end if

! Coordinates of grid-block edges.
  edge(0) = ra
  select case (grid_type)
    case (UNIFORM_GRID)
      h = (rb - ra)/nseg
      do (i = 1,nseg-1)
        edge(i) = edge(i-1) + h
      end do
    case (PROP_GRID)
      h = exp(log(rb/ra)/nseg)
      do (i = 1,nseg-1)
        edge(i) = edge(i-1) * h
      end do
  end select
  edge(nseg) = rb

! Coordinates of grid-block centers.
  do (i = 1,nseg)
    cntr(i) = (edge(i-1) + edge(i))/2.
  end do
```

```
! Assign conductivities.
  select case (sig_type)
    case (UNIFORM_SIG)
      do (i = 1,nseg)
        sig(i) = 1.0
      end do
    case (INVERSE_SIG)
      do (i = 1,nseg)
        sig(i) = 1.0/cntr(i)
      end do
    case (DISCONTINUOUS_SIG)

      ! Locate the intermediate point on a grid-block edge.
      im = 0
      do (i = 1,nseg)
        if (rm < cntr(i) .and. rm >= edge(i-1)) then
                    im = i - 1
                    exit
        else if (rm < edge(i) .and. rm >= cntr(i)) then
                    im = i
                    exit
        else
                    im = i
        end if
      end do
      rm = edge(im)

      ! Assign conductivities
      do (i = 1,nseg)
        if (i <= im) then
                    sig(i) = SIG_1/cntr(i)
        else if (i > im) then
                    sig(i) = SIG_2/cntr(i)
        end if
      end do

      ! Calculate the conductivity ratio at the intermediate point.
      if (im == 0 .or. im == nseg) then
        s1s2 = 1.0
      else
        s1s2 = SIG_1/SIG_2
      end if
  end select


! Fill the tridiagonal matrix row by row.
! Check to see whether or not to perform
! variable transformations.
  do (i = 1,nseg)

    ! First row is special...

    if (i == 1) then

      sp = sig(i)/sig(i+1)

      if (.not. transformed) then
        dx1  = cntr(i)               - edge(i-1)
        dx2  = (edge(i) - cntr(i)) + sp*(cntr(i+1) - edge(i))
        dxdx = (cntr(i+1) + cntr(i))/2. - (cntr(i) + edge(i-1))/2.
        a(i,1) = 0.0
```

```
      a(i,2) = (1./dx1 + 1./dx2)/dxdx
      a(i,3) = (       - 1./dx2)/dxdx
      a(i,4) = (va/dx1         )/dxdx

      ! Radial term...
      w1 = dx1
      w2 = dx2
      w  = w1 + w2
      a(i,1) = a(i,1)
      a(i,2) = a(i,2) - ((w2/w)   /dx1 - (w1/w)/dx2)/cntr(i)
      a(i,3) = a(i,3) - (                (w1/w)/dx2)/cntr(i)
      a(i,4) = a(i,4) - ((w2/w)*va/dx1             )/cntr(i)
    else if (transformed) then
      dx1  = log(cntr(i))                  - log(edge(i-1))
      dx2  = (log(edge(i)) - log(cntr(i))) + sp*(log(cntr(i+1)) - log(edge(i)))
      dxdx = 0.5*(((cntr(i+1) + cntr(i))/2.)**2 - ((cntr(i) + edge(i-1))/2.)**2)
      a(i,1) = 0.0
      a(i,2) = (1./dx1 + 1./dx2)/dxdx
      a(i,3) = (       - 1./dx2)/dxdx
      a(i,4) = (va/dx1         )/dxdx
    end if

  ! ...middle rows, if any...

  else if (i > 1 .and. i < nseg) then

    sm = sig(i)/sig(i-1)
    sp = sig(i)/sig(i+1)

    if (.not. transformed) then
      dx1  = (cntr(i) - edge(i-1)) + sm*(edge(i-1) - cntr(i-1))
      dx2  = (edge(i) - cntr(i))   + sp*(cntr(i+1) - edge(i))
      dxdx = (cntr(i+1) + cntr(i))/2. - (cntr(i) + cntr(i-1))/2.
      a(i,1) = (-1./dx1         )/dxdx
      a(i,2) = ( 1./dx1 + 1./dx2)/dxdx
      a(i,3) = (        - 1./dx2)/dxdx
      a(i,4) = 0.0

      ! Radial term...
      w1 = dx1
      w2 = dx2
      w  = w1 + w2
      a(i,1) = a(i,1) + ((w2/w)/dx1             )/cntr(i)
      a(i,2) = a(i,2) - ((w2/w)/dx1 - (w1/w)/dx2)/cntr(i)
      a(i,3) = a(i,3) - (             (w1/w)/dx2)/cntr(i)
      a(i,4) = a(i,4)
    else if (transformed) then
      dx1  = (log(cntr(i)) - log(edge(i-1))) + sm*(log(edge(i-1)) - log(cntr(i-1)))
      dx2  = (log(edge(i)) - log(cntr(i)))   + sp*(log(cntr(i+1)) - log(edge(i)))
      dxdx = 0.5*(((cntr(i+1) + cntr(i)  )/2.)**2 - ((cntr(i) + cntr(i-1))/2.)**2)
      a(i,1) = (-1./dx1         )/dxdx
      a(i,2) = ( 1./dx1 + 1./dx2)/dxdx
      a(i,3) = (        - 1./dx2)/dxdx
      a(i,4) = 0.0
    end if

  ! ...last row is special.

  else if (i == nseg) then

    sm = sig(i)/sig(i-1)

    if (.not. transformed) then
```

```
    dx1  = (cntr(i) - edge(i-1)) + sm*(edge(i-1) - cntr(i-1))
    dx2  = edge(i)               - cntr(i)
    dxdx = (edge(i) + cntr(i))/2. - (cntr(i) + cntr(i-1))/2.
    a(i,1) = (-1./dx1         )/dxdx
    a(i,2) = ( 1./dx1 + 1./dx2)/dxdx
    a(i,3) = 0.0
    a(i,4) = 0.0

    ! Radial term...
    w1 = dx1
    w2 = dx2
    w  = w1 + w2
    a(i,1) = a(i,1) + ((w2/w)/dx1             )/cntr(i)
    a(i,2) = a(i,2) - ((w2/w)/dx1 - (w1/w)/dx2)/cntr(i)
    a(i,3) = a(i,3)
    a(i,4) = a(i,4)
   else if (transformed) then
    dx1  = (log(cntr(i)) - log(edge(i-1))) + sm*(log(edge(i-1)) - log(cntr(i-1)))
    dx2  = log(edge(i))                    - log(cntr(i))
    dxdx = 0.5*(((edge(i) + cntr(i))/2.)**2 - ((cntr(i) + cntr(i-1))/2.)**2)
    a(i,1) = (-1./dx1         )/dxdx
    a(i,2) = ( 1./dx1 + 1./dx2)/dxdx
    a(i,3) = 0.0
    a(i,4) = 0.0
   end if
  end if
 end do

! Solve the system of equations.
 call tridg(a,nseg,MAXDIM)

! Calculate E-field.
 do (i = 1,nseg)

  ! First row is special...

  if (i == 1) then

   sp = sig(i)/sig(i+1)

   dx1  = cntr(i)             - edge(i-1)
   dx2  = (edge(i) - cntr(i)) + sp*(cntr(i+1) - edge(i))
   w1 = dx1
   w2 = dx2
   w  = w1 + w2

   e_field(i) = -((w2/w)*(a(i,4) - va)/dx1 + (w1/w)*(a(i+1,4) - a(i,4))/dx2)

  ! ...middle rows, if any...

  else if (i > 1 .and. i < nseg) then

   sm = sig(i)/sig(i-1)
   sp = sig(i)/sig(i+1)

   dx1  = (cntr(i) - edge(i-1)) + sm*(edge(i-1) - cntr(i-1))
   dx2  = (edge(i) - cntr(i))   + sp*(cntr(i+1) - edge(i))
   w1 = dx1
   w2 = dx2
   w  = w1 + w2

   e_field(i) = -((w2/w)*(a(i,4) - a(i-1,4))/dx1 + (w1/w)*(a(i+1,4) - a(i,4))/dx2)
```

```
    ! ...last row is special.

    else if (i == nseg) then

      sm = sig(i)/sig(i-1)

      dx1  = (cntr(i) - edge(i-1)) + sm*(edge(i-1) - cntr(i-1))
      dx2  = edge(i)               - cntr(i)
      w1 = dx1
      w2 = dx2
      w  = w1 + w2

      e_field(i) = -((w2/w)*(a(i,4) - a(i-1,4))/dx1 + (w1/w)*(0.0 - a(i,4))/dx2)

    end if
  end do

! Display the solution.
  select case (grid_type)
    case (UNIFORM_GRID)
      write(*,*)  '### Uniform Grid                            ###'
    case (PROP_GRID)
      write(*,*)  '### Proportional Grid                       ###'
  end select
  write(*,*)
  select case (sig_type)
    case (UNIFORM_SIG)
      write(*,*)  '### Uniform Conductivity                    ###'
    case (INVERSE_SIG)
      write(*,*)  '### Inverse Conductivity                    ###'
    case (DISCONTINUOUS_SIG)
      write(*,*)  '### Discontinuous, Inverse Conductivity ###'
  end select
  write(*,*)
  if (transformed) then
    write(*,*)      '### Transformed Variables                 ###'
  else
    write(*,*)      '### Untransformed Variables               ###'
  end if
  write(*,*)
  write(*,'(a,i3)')    'Number of segments = ',nseg
  write(*,'(a,f6.4)') 'ra                 = ',ra
  write(*,'(a,f6.4)') 'rb                 = ',rb
  if (sig_type == DISCONTINUOUS_SIG) then
    write(*,'(a,1p,e12.6)') 'rm               = ',rm
  end if
  write(*,'(a,f5.1)') 'Vo                 = ',va
  write(*,*)
  write(*,'(a8,2x,a8,2x,a8,2x,a8,2x,a8,2x,a8,2x,a8,2x,a8)') &
    'Grid Blk','Coord','V Calc','V Theo','V %error','E Calc','E Theo','E %error'
  write(*,*)          '-----------------------------------------'

  errmax_V = 0.0
  errsum_V = 0.0
  imax_V   = 0

  errmax_E = 0.0
  errsum_E = 0.0
  imax_E   = 0
```

```
  do (i = 1,nseg)

    call theoretical(cntr(i),sig_type,volts,field)

    percent_V = abs(100.*(volts - a(i,4))/volts)
    errsum_V  = errsum_V + percent_V
    if (errmax_V < percent_V) then
      errmax_V = percent_V
      imax_V   = i
    end if

    percent_E = abs(100.*(field - e_field(i))/field)
    errsum_E  = errsum_E + percent_E
    if (errmax_E < percent_E) then
      errmax_E = percent_E
      imax_E   = i
    end if

    write(*,'(i8,2x,f8.6,2x,f8.4,2x,f8.4,2x,1p,e8.2,0p,2x,f8.2,2x,f8.2,2x,1p,e8.2)')
i,cntr(i),&
      a(i,4),     volts, percent_V,&
      e_field(i), field, percent_E
  end do

  errave_V = errsum_V/nseg
  errave_E = errsum_E/nseg

  write(*,*) ‘---------------------------------------’
  write(*,*) ‘Potential:’
  write(*,*) ‘Max error     = ’,errmax_V,’ at node ’,imax_V
  write(*,*) ‘Average error = ’,errave_V
  write(*,*)
  write(*,*) ‘E-field:’
  write(*,*) ‘Max error     = ’,errmax_E,’ at node ’,imax_E
  write(*,*) ‘Average error = ’,errave_E
  write(*,*)
‘################################################################################’

  stop
end



! Theoretical potential distribution.
!   volts signifies electric potential
!   field signifies electric field

subroutine theoretical(r,sig_type,volts,field)

  integer sig_type
  integer UNIFORM_SIG, INVERSE_SIG, DISCONTINUOUS_SIG
  parameter (UNIFORM_SIG       = 1)
  parameter (INVERSE_SIG       = 2)
  parameter (DISCONTINUOUS_SIG = 3)

  common /params/ ra,rb,rm,va,sls2
```

```
select case (sig_type)
  case (UNIFORM_SIG)
    volts = -va/log(rb/ra)*log(r/rb)
    field =  va/log(rb/ra)*(1./r)
    return
  case (INVERSE_SIG)
    volts = -va/(rb - ra)*(r - rb)
    field =  va/(rb - ra)
    return
  case (DISCONTINUOUS_SIG)
    c1 = rm - ra
    c2 = sls2*(rb - rm)
    if (r <= rm) then
      volts = -va/(c1 + c2)*((r - rm) - c2)
      field =  va/(c1 + c2)
    else if (r > rm) then
      volts = -va/(c1 + c2)*sls2*(r - rb)
      field =  va/(c1 + c2)*sls2
    end if
    return
 end select
end


!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! This is an unmodified version of the tridiagonal matrix
! solver TRIDG shown on p. 157 of Gerald and Wheatley.
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! a    - tridiagonal matrix of coefficients, including r.h.s.
! n    - number of equations
! ndim - first dimension of A in the calling program
!
! The solution is returned in the fourth column of A.
!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

subroutine tridg(a,n,ndim)

  dimension a(ndim,4)

! Forward reduction phase
  Do i = 2,n
    a(i,1) = a(i,1)/a(i-1,2)
    a(i,2) = a(i,2) - a(i,1)*a(i-1,3)
    a(i,4) = a(i,4) - a(i,1)*a(i-1,4)
  End Do

! Back substitution phase
  nm1 = n - 1
  a(n,4) = a(n,4)/a(n,2)

  Do i = nm1,1,-1
    a(i,4) = (a(i,4) - a(i,3)*a(i+1,4))/a(i,2)
  End Do

  return
end
```

INTERNATIONAL WORKSHOP
on
APPLIED COMPUTATIONAL ELECTROMAGNETICS

DIRECTIONS FOR THE NINETIES
at
Telecom Australia Research Laboratories
Clayton Victoria Australia

14 AUGUST 1992

Historically the application of computational methods in electromagnetics has been centered upon scatterer and antenna modelling using moment methods, as well as high-and- low frequency computational techniques. These methods have enabled metallic structures of widely varying geometry, and interactions with media and materials such as ground planes to be analyzed. The major beneficiaries have been the defence and communications industries, and progress in these areas would not have been possible without the computational skills presently available. The application of finite element, finite difference and finite difference time-domain methods has become of particular interest within the professional EM community, since these tools allow the modelling of more complex problems such as the design of generators and motors, the response of biological tissues to electromagnetic radiation, and the analysis of modern structures with composite materials.

This Workshop is intended to be a timely survey of computational efforts in code development and application, matched to present and emerging needs to the end of the decade. It is sponsored jointly by Telecom Australia Research Laboratories, ACES, the IEEE Victoria Section, and the Defence Science and Technology Organization. The Workshop format will include presentations by eminent speakers, audience participation, and specialized software demonstrations.

Among the invited speakers will be Prof. Tapan Sarkar, Dr. Edmund Miller, Mr. Gerry Burke, Prof. Bach Anderson, and others. This will be an excellent opportunity to benefit from their experience and insight, to discuss your applications and to become aware of available codes.

The Workshop has been scheduled between the Asia-Pacific Microwave Conference in Adelaide (11-13 Aug) and the URSI Electromagnetic Theory Symposium in Sydney (17-20 Aug). Arrangements are being made with travel agencies for special fares for parts or all of the circuit for visitors to Australia.

For additional information contact:

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Telephone: +61-3-541-6155
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APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY

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2. Paper size can be either standard A4 (21 cm x 29.5 cm) or standard American (8.5 in x 11.0 in). The text itself should be centered and enclosed within a rectangle of 6.5 in x 9.0 in.

3. Type should be single line spaced with double line spaces between paragraphs which should not be indented. Where necessary within the text, the line spacing should be adjusted (to 1.5) to accomodate superscripts and subscripts which should be used only where essential. Typeface should be either 10 point Times Roman or Prestige Elite, or similar, using fixed or proportional pitch.

4. The title, author name(s), abstract, and (space permitting) beginning of the paper itself shall all be on the first page. The title, author name(s), and author affiliations shall be center-justified.

5. Either British English or American English spellings may be used, providing that spelling is consistent throughout the paper.

6. References shall be given by author name(s) and year in the body of the paper, using square brackets, e.g. [Abramowitz and Stegun, 1970], with an alphabetic listing of all references at the end of the paper.

7. Units employed shall be SI.

8. Internal consistency shall be maintained for other elements of style, such as equation numbering where the numbers shall be placed in parenthesis at the right hand margin.

9. It is RECOMMENDED that figures and tables be placed within the paper, and as close to the relevant text as possible.

10. For review purposes, authors should submit three copies of the preliminary printed manuscript so that any changes arising from reviews can be made prior to the preparation of the final camera-ready copy.

11. Authors will be sent further details regarding both copyright and camera-ready requirements upon acceptance of their manuscripts for publication in the Special Issue.

CALL FOR PAPERS

Applied Computational Electromagnetics Society

announces a special issue of the
ACES Journal on

Computer Applications in Electromagnetics Education

The Applied Computational Electromagnetics Society, in cooperation with the NSF/IEEE Center on Computer Applications in Electromagnetics Education (CAEME), is pleased to announce the publication of a 1992 special issue in the area of computer applications in electromagnetic education. There has been a remarkable increase in interest in this topic and with the establishment of the CAEME Center, many individualized efforts have been integrated and a useful collection of software and computer-generated videos is now available to education. Furthermore, with the fast-paced development in the computer technology and the availability of sophisticated graphics and new technologies such as multimedia presentations, new and expanding opportunities continue to be available to educators to help support this drive in boosting electromagnetic education. This special issue will help focus on this issue that directly impacts academia and industry alike.

Suggested Topics for Papers

- Software for electromagnetic education
- Graphics and computer I/O issues
- New evolving technologies including interactive videos
- Novel applications and effective implementation of computers and software tools in education including in and out-of-classroom teaching
- New courses and computer-based curriculum in electromagnetics
- Computer use in laboratories
- Examples of educational use of commercial and government-owned software
- Funding challenges and opportunities

Deadline for papers is April 30, 1992

Send papers and inquiries to:

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THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY

ANNOUNCES

The 8th Annual Review of Progress in Applied Computational Electromagnetics

March 17-19, 1992
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Share your knowledge and expertise with your colleagues

The Annual ACES Symposium is an ideal opportunity to participate in a large gathering of EM Analysis enthusiasts. All aspects of electromagnetic computational analysis are represented but particular emphasis will be placed on these applications:

THEORY AND ALGORITHMS
Electromagnetic Compatibility
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Transmission Line Method
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 (inc Aperture Antennas/GTD)
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Asymptotic Solutions
Moment Method Theory

APPLICATIONS
EMC/EMI/EMP
Materials
Specific Code Applications
 (e g NEC, GEMACS, TLM, FDTD)
High Frequency Applications
 (inc Aperture Antennas/GTD)
Microwave Circuits
Antennas
CAEME

The Symposium features four areas of interest to the EM analysis enthusiast, short courses, demonstrations, vendors' booths and Symposium papers which are solicited from all areas of electromagnetic computation. The Symposium will also include invited speakers and poster sessions. The NSF/IEEE CAEME (Computer Applications in Electromagnetics Education) Center will organise a special session of technical presentations on Computer Applications covering topics of interest in education/training, evolving computer technologies and the latest in EM computation and analysis. (In conjunction with the special session, there will be booths dedicated to the interchange of ideas and software). Please contact Magdy Iskander for CAEME details. Contact Pat Foster or Perry Wheless for details of the other events.

SHORT COURSES

These will cover numerical techniques, computational methods, surveys of EM analysis and code usage instruction. Fees for a short course are $80.00 per person for a half-day course and $130.00 for a full day, if booked before March 2, 1992. Details and schedules are attached.

DEMONSTRATIONS

These will cover computer demonstrations, software demonstrations, and in particular CAEME software.

VENDOR BOOTHS

These will cover product distribution, small company capabilities, new commercial codes. Contact the Chairman or Co-Chairman for details.

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SHORT COURSES AT THE 8TH ANNUAL REVIEW OF PROGRESS IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

The Applied Computational Electromagnetics Society is pleased to announce eight short courses to be offered in conjunction with its annual conference of March 17-19, 1992. Times of the individual short courses are noted. Registration begins at 7:30 am on Monday, March 16, 1992. ACES has the right to cancel a course at any time *with full refund.* For further information contact R.W. Adler (408) 646-2352; (408) 646-2955 for fax.

COURSE INFORMATION

FULL-DAY COURSE (Monday, March 16, 8:30-11:30 am, 1:00-4:30 pm)

"Time Domain Modeling of Guiding and Radiating Structures with TLM" by Wolfgang J.R. Hoefer, Professor, University of Ottawa.

Numerical TLM modeling of 2D and 3D electromagnetic structures in the time domain is introduced. Emphasis will be on the algorithms and procedures as well as their implementation. The relation between the numerical formulation and the classical analytical presentation of electromagnetics will be stressed. At the same time, typical guiding and radiating structures as well as EMI/EMC situations will be performed in real-time to facilitate the understanding of the various algorithms by observing their effect directly on the screen.

FULL-DAY COURSES (Friday, March 20, 8:30-11:30 am, 1:00-4:30 pm)

"Using GEMACS to Solve Practical Problems" by Buddy Coffey, Advanced Electromagnetics

The General Electromagnetic Model for the Analysis of Complex Systems (GEMACS) has been used to predict currents and fields from a wide variety of structures and radiators. The focus of the course will be to illustrate how GEMACS commands and geometry inputs are constructed for the analysis of antenna radiation, corruption of antenna patterns, scattering, and external-to-internal coupling via apertures. Emphasis will be on practical solutions, including solution method selection (MOM, GTD, FD), hybrids of methods, overcoming computational limitations (matrix size, number of rays traced), and "believability" of results.

"Electromagnetic Microwave Design" by Dr. James C. Rautio, Sonnet Software, Inc.

Electromagnetic simulation of microwave circuits has become an important part of the microwave design cycle. This short course first provides a brief overview of existing electromagnetic techniques with emphasis on those techniques which are commercially available. The remainder of the course deals in detail with a popular product, **em**^{tm} and its application to the design of predominantly planar microwave circuits. An added feature of the course is use of full color computer display and animation of current distribution, so-called "electromagnetic visualization". This course will allow a microwave designer to quickly and confidently come up to speed in applied electromagnetic design techniques.

MORNING HALF-DAY COURSE (Monday, March 16, 8:30-11:30 am)

"An Introduction to FDTD and Its Applications" by Dr. K. Kunz and Dr. R. Luebbers, Pennsylvania State University

FDTD fundamentals will be presented stressing the separate field formulation for perfect conductors and lossy dielectrics. Applications will be demonstrated using video tapes of several coupling and scattering geometries including canonical scatterers, cavities and waveguides, in which color renditions of the fields in and about the interaction objects are followed in time. The art of FDTD modeling, in particular resource requirements and allocation will be explored in detail. A basic perfect conductor version of the code will be provided on diskette.

AFTERNOON HALF-DAY COURSE (Monday, March 16, 1:00-4:30 pm)

"Signal Representation and Model-based Parameter Estimation Applications in Computational EM" by E.K. Miller, Los Alamos National Laboratory and G. Burke, Lawrence Livermore National Laboratory

First-principle physics models such as are used in computational electromagnetics are capable of accounting for spatial and temporal variations of sources on objects being modeled to scales that are a fraction of a wavelength or period. Such detail is rarely needed or observed in practical applications where frequency spectra and angle-dependent patterns are often of most concern. By introducing reduced-order models that describe physical observations more parsimoniously, it is possible to not only develop more efficient computational models and to make more efficient use of computed results, but to develop more insightful interpretation of electromagnetic physics. This short course will address some of these signal-representation and estimation issues with the primary emphasis on increasing modeling efficiency and improving physical understanding.

SPLIT FULL-DAY COURSE (Monday, March 16, 8:30-11:30 am and Tuesday, March 17, 1:00-4:30 pm)

"Antenna Radiation in Natural Environments - Special Topics" by Dr. Robert N. Bevensee, BOMA Enterprises

This course will advance the following topics: numerical improvement of WAGCOMP for computation of the groundwave over general (irregular and/or inhomogeneous) terrain, ground screen optimization of the groundwave over general terrain, and antenna design principles for optimized communication over general terrain. Extensive typed notes will be provided.

SPLIT FULL-DAY COURSE (Monday, March 16, 1:00-4:30 pm and Tuesday, March 17, 1:00-4:30 pm)

"UTD and its Practical Applications" by Dr. R.J. Marhefka, The Ohio State University Electroscience Laboratory

The Uniform Geometrical Theory of Diffraction (UTD) is a high-frequency ray-based method that is well suited for the analysis of electromagnetic scattering from complex structures. A brief discussion of UTD is provided in the context of its use in practical applications such as antenna siting, antenna-to-antenna coupling, and radiation hazard studies. The NEC-Basic Scattering Code (NEC-BSC) is used as the primary example. An introduction of its capabilities is presented. Various examples to illustrate the art of translating engineering situations into useable models and then validating the results is discussed.

MORNING HALF-DAY COURSE (Friday, March 20, 8:30-11:30 am)

"The 3D MMP Code for Computational Electromagnetics on PCs" by Ch. Hafner, Swiss Federal Institute of Technology

The theoretical background of the 3D MMP code, i.e., the Generalized Multipole Technique (GMT), is outlined and its advantages and drawbacks are discussed. In order to overcome the drawbacks, additional features of the MMP code are introduced and it is demonstrated how the combination of different techniques known from finite elements, methods of moments, geometric optics, and other methods can be used for solving a large number of different problems. It is shown how the graphic input editor and plot program can be applied for modelling and for analyzing the results. All participants will obtain a demo version of the 3D MMP code for PCs that allow solution of small and medium scattering problems on a 386 or 486 machine.

SHORT COURSE
REGISTRATION INFORMATION

To register for any of the courses, fill out the form below and include a check to THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY, or ACES for the indicated amount and mail to R.W. Adler, Attn: ACES, Naval Postgraduate School, Code EC/AB, Monterey, CA. 93943. NON-U.S.A. PARTICIPANTS should remit via: BANK DRAFTS (WHICH MUST BE DRAWN ON U.S.BANK & HAVE ROUTING NUMBERS); INTERNATIONAL MONEY ORDERS; or TRAVELER'S CHECKS (IN U.S. $$).

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____ **Time Domain Modeling of Guiding and Radiating Structures with TLM,** full-day, 16 March
Fee: $130 before 3/2/92, $140 after 3/2/92, $150 after 3/15/92

____ **Using GEMACS to Solve Practical Problems,** full-day, 20 March
Fee: $130 before 3/2/92, $140 after 3/2/92, $150 after 3/15/92

____ **Electromagnetic Microwave Design,** full-day, 20 March
Fee: $130 before 3/2/92, $140 after 3/2/92, $150 after 3/15/92

____ **An Introduction to FDTD and Its Applications,** half-day, morning 16 March
Fee: $80 before 3/2/92, $90 after 3/2/92, $100 after 3/15/92

____ **Signal Representation and Model-based Parameter Estimation Applications in Computational EM**
half-day, afternoon 16 March
Fee: $80 before 3/2/92, $90 after 3/2/92, $100 after 3/15/92

____ **Antenna Radiation in Natural Environments - Special Topics,** split-days, morning 16 & afternoon 17 March
Fee: $130 before 3/2/92, $140 after 3/2/92, $150 after 3/15/92

____ **UTD and its Practical Applications,** split-days, afternoon 16 & 17 March
Fee: $130 before 3/2/92, $140 after 3/2/92, $150 after 3/15/92

____ **The 3D MMP Code for Computational Electromagnetics on PCs,** half-day, morning 20 March
Fee: $80 before 3/2/92, $90 after 3/2/92, $100 after 3/15/92

SHORT COURSE FEES DO NOT INCLUDE ATTENDANCE AT THE SYMPOSIUM.
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A SPECIAL ISSUE OF THE ACES JOURNAL

Summer 1991

"APPLICATIONS OF HIGH FREQUENCY METHODS AND COMPUTER TECHNIQUES IN ELECTROMAGNETICS"

Guest Editor: FULVIO BESSI

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"Introduction to the Special Issue on Applications of High Frequency Methods and Computer Techniques in Electromagnetics"

"GTD, PO, PTD, and GAUSSIAN Beam Diffraction Analysis Techniques Applied to Reflector Antennas"

"Modern High Frequency Techniques for RCS Computation: A Comparative Analysis"

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"Antennas on Dielectric Coated Convex Surfaces: Theory and Experimentation"

"Analysis and Simulation of Collision Avoidance TCAS Antennas Mounted on Aircraft"

"Numerical Techniques to Determine the UTD Bistatic Creeping Wave Paths and Parameters for an Ellipsoid"

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THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY, INC.

ACES sponsors a 3-day Annual Review of Progress in Applied Computational Electromagnetics around the third week in March in Monterey, CA. Publications of the society include the Annual Conference Proceedings, 2 Journals and 3 Newsletters per year. In addition, special publications are produced as the need rises. A special Journal issue on Computer Code Validation and the ACES Canonical Problem Set are examples. The Newsletter informs members of Society activities and provides a forum for modeling and code information exchanges.

The Software Committee provides a means to exchange information about electromagnetic computational codes and maintains a small software library.

The Technical Activities Committee identifies needs in applied computational electromagnetics. This committee also identifies and implements ways to address those needs.

Membership in ACES is attained through payment of a membership/subscription fee (see below).

For further information regarding ACES or on becoming a member in the Applied Computational Electromagnetics Society, contact ACES Secretary, Dr. Richard W. Adler, Code EC/AB, Naval Postgraduate School, Monterey, CA. 93943, telephone (408) 646-2352, Fax: (408) 646-2955. You can subscribe to the Journal and become a member of ACES by completing and returning the form below.

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