APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

Vol. 7 No. 1 March 1992

TABLE OF CONTENTS

EDITOR'S COMMENTS

This issue presents several intriguing and informative commentaries on computational EM. For those of you who enjoy mental challenges and puzzles, Prof. Chalmers Butler presents an EM paradox. For NEC users who own IBM desktops, the article comparing FORTRAN compilers may save you lots of CPU minutes. The article on modeling waveguides using a finite element approach is likely to be of considerably interest, especially since it describes the use of the well documented UNAFEM finite element code. If you are on Internet, sign up on Randy Jost's list. Antenna Engineers may be able to use the device described by Prof. Duncan Baker.

We also will present many interesting follow-up articles in the near future: Randy Jost will present a tutorial article on the use of Internet to transfer files. Prof. Chalmers Butler will reveal the solution to the paradox he presents in this issue. We expect to have an article on NEC run times on 486 machines for large numbers of segments. Also Ray Perez, our Associate Editor, has done a great job contacting administrators of funding agencies in the U.S. and around the world, so we will be featuring some of their viewpoints in upcoming issues.

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ACES NEWSLETTER COPY INFORMATION

Issue	Copy Deadline
March	January 25
July	May 25
November	September 25

Send copy to Paul Elliot at the above address in the following formats:

1. A hardcopy.
2. Camera ready hardcopy of any figures.
3. If possible also send text on a floppy disk. We can read MICROSOFT-WORD, and ASCII files on both IBM and Macintosh disks. On IBM disks we can also read Wordperfect and Wordstar files. If it is not possible to send a Macintosh disk then the hardcopy should be in Courier font <u>only</u> for scanning purposes. If any software other than Microsoft Word has been used on Macintosh Disks, contact the Secretary <u>BEFORE</u> submitting a diskette.

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.

AUTHORSHIP AND BERNE COPYRIGHT CONVENTION

The opinions, statements and facts contained in this Newsletter are solely the opinions of the authors and/or sources identified with each article. Articles with no author can be attributed to the editors or to the committee head in the case of committee reports. The United States recently became part of the Berne Copyright Convention. Under the Berne Convention, the copyright for an article in this newsletter is legally held by the author(s) of the article since no explicit copyright notice appears in the newsletter.

OFFICER'S REPORTS

PRESIDENT'S REPORT

You will have noticed that it has been my practice to discuss two types of subjects in this column. The first usually deals with society business and the second with the mission and activities of the Society.

Elsewhere in this Newsletter you will find a brief summary of the status of the Society that was prepared by Dick Adler. This will be elaborated in the yearly report which will be presented at our March meeting in Monterey. In spite of the world-wide recession, our society is reaching out for new members, new associations, and for a solidification of the services that we provide to our members and our technical community.

Once more it is gratifying for me to see the slate of candidates for election to our Board of Directors. I am proud to be associated with a society that can field such candidates. Personally and on your behalf, I wish to thank each one of them for offering their services.

Before the end of the year I received the good news from Tony Brown that the ACES UK Chapter had been formed. The officers are:

Dr. A.K. Brown, Chairman
Dr. P. Foster, Treasurer
Dr. D. Lizius, Secretary

Other members of the founding committee are:

Dr. J. Moore
Dr. J. Cox
Dr. B. Austin

It is expected that we can put in place mechanisms for financial transfers that would benefit the U.K. members and serve as a model for chapters in other regions. I am particularly interested in reviving our European chapter. Also it is my hope that we can move towards having one official contact person in each country.

You will see from the preliminary program of our **8th Annual Review of Progress in Computational Electromagnetics** that Pat Foster and her team have organized almost five full days of short courses, demonstrations and technical papers. We are looking forward to an effective and convivial atmosphere for the presentation of important poster papers on Tuesday afternoon. This is an experiment that deserves to be successful. I have started to agitate with all my friends to make their reservations early and to convince their supervisors about the importance of attending this important meeting so that we can minimize the impact of economic restraints. Do join me in this effort.

Also please remember the **ACES Workshop** in Melbourne, Australia on August 14, 1992. TonyFleming of Telecom Australia Research Laboratories has taken the initiative to organize this exceptional opportunity for those attending the URSI International Symposium on Electromagnetic Theory and the Asia-Pacific Microwave Conference. It is a wonderful opportunity for a working holiday in this part of the world.

Having recently attended the Technical Program Committee meeting in Chicago for the forthcoming 1992 AP-S and URSI Symposium, Ed Miller and I were struck by the very high proportion and diversity of papers devoted to numerical methods. This continues to be an endorsement of the importance of our mission and an incentive for us to harness this enthusiasm in new ways.

See you in Monterey!

Stanley J. Kubina
ACES President

THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY, INC.

NOTICE OF THE ANNUAL BUSINESS MEETING

Notice is hereby given that the annual business meeting of the Applied Computational Electromagnetics Society, Inc. will be held at 122 Ingersoll Hall, Naval Postgraduate School, Monterey, CA. on Tuesday 17 March 1992 at 7:30 AM PST for purposes of:

1. Receiving the Financial Statement and auditors report for the year ending 31 December 1991.
2. Announcement of the Ballot Election of the Board of Directors.
3. Summary of the activities of incorporation and report of the non-profit status of the corporation.
4. Other business to be announced at the time of this meeting.

By Order of the Board of Directors
Richard W. Adler, Secretary

ANNUAL REPORT 1991

As required in the Bylaws of the Applied Computational Electromagnetics Society, Inc. a California Nonprofit Public Benefit Corporation, this report is provided to the members. (Additional information and an auditors report will be presented at the Annual Meeting and that same information will be included in the July Newsletter for the benefit of members who could not attend the Annual Meeting.

MEMBERSHIP REPORT

As of 31 December 1991, the paid-up membership totaled 525, with approximately 26% of those from non-U.S. countries. There were 8 student, 83 industrial (organizational) and 434 individual members. The total membership has increased since 1 January 1991 by 10%, but non-U.S. membership has declined by 14%.

Richard W. Adler, Secretary

ANNOUNCEMENT ON DUES INCREASE

In accordance with a 5-year financial plan adopted by the Board of Directors in May 1990, for the purpose of maintaining ACES as a financially solvent non-profit corporation, the annual membership dues will increase by $10, effective 1 April 1992, and will increase by an additional $10 each year.

MEMBERSHIP RATES EFFECTIVE 1 APRIL 1992

Individual membership:	$ 55	US
	$ 65	NON-US
	$ 60	CANADIAN MEMBERS
Organizational membership	$105	US
	$115	NON-US
Student membership:	$ 25	

FINANCIAL REPORT

ASSETS **BANK ACCOUNTS**	**1 Jan 1991**	**31 Dec 1991**
MAIN CHECKING	7,151.25	5,609.84
EDITOR CHECKING	2,109.09	2,495.78
SECRETARY CHECKING	2,521.64	1,765.83
SAVINGS	2,180.68	2,268.96
CD #1	9,927.80	10,617.07
CD #2	9,927.80	10,617.07
TOTAL ASSETS	$ 33,818.26	$ 33,374.55
LIABILITIES		0
NET WORTH 31 December 1991	$34,325.86	$ 33,374.55

INCOME

Conference	46,014.00
Publications	2,845.50
Membership	23,902.50
Software	3,773.00
Interest & misc.	4,341.15
TOTAL	80,876.15

EXPENSES

Conference	17,291.26
Publications & Flyers	33,822.36
Software	1,541.27
Services (Legal, Taxes	2,562.42
Postage	13,847.29
Supplies & misc.	15,809.62
TOTAL	$ 84,874.22

NET INCREASE: $-3,998.07
for 1991

The losses for 1991 are due to increased postal rates and cost of flyers.

James K. Breakall, Treasurer

COMMITTEE REPORTS

ACES EDITORIAL BOARD

The promise of electronic publishing technology is gaining greater recognition among scientists, engineers, editors, publishers and libraries. Several of our own members have suggested that ACES establish our own electronic bulletin board. Most recently, Andrew F> Peterson discussed this possibility in his "Perspectives" article (*ACES Newsletter*, Vol. 6, No. 3, November 1991). Contingent upon satisfactory resolution of several issues (including access, funding, and other issues identified by Prof. Peterson), the electronic bulletin board can be a valuable service to our members; however, it is not a project which would normally be initiated by the ACES Editorial Board. Our own interest derives from the new possibilities presented by "electronic journals", as envisioned by my colleagues in professional editors' associations, and from conceivable near-term payoffs in membership affordability and in standardization of font and format.

Membership affordability remains a major issue as overseas postal rates continue rising. Parallel printing operations on two or more continents are not presently economical, nor do we fare significantly better by bulk-mailing our publications to distribution points on several continents. I shall propose a "see-mail option" for non-US members who do not require timely delivery at the higher airmail rates, but I am not convinced that this is an optimal solution. Electronic versions of our publications are a possible long-term solution to the affordability problem for members who have access to the appropriate electronic networks -- though this mode of publishing is not without its own problems, especially during the startup phase.

Yet, electronic publishing also circumvents another issue, that of standardizing our font and layout, both "on-line" and in "hard-copy" produced therefrom. Several of our members have presented convincing arguments that standardization will enhance the professional appearance of the *ACES Journal*; yet, we are reluctant to create disincentives for authors to publish with us (for example, by requiring the use of designated word processing software), and we do not have the resources to typeset every *ACES Journal* paper from hard copy. As an intermediate measure, we shall encourage but not require authors to submit disc versions of their papers (with a choice among several word processors which we can accomodate), together with the camera-ready copy. This measure will help position us for electronic publishing, should we later decide to proceed in this direction. More immediately and importantly, we will gain capability to implement partial standardization of font and layout and to make "last-minute" corrections of typographical and other errors which otherwise would delay publication of papers. (Optical recoqnition technology is a promising supplemental tool, although we have not yet investigated ways to implement it).

In addition to providing possible payoffs in subscription rate reduction and in standardization of appearance, electronic publishing may indeed be the future trend -- although presently, it is too visionary even for me. Unconditional advocacy would be premature, but we will want to remain open-minded about adding electronic publishing to our "bag of tricks". A test of feasibility would be the proposed electronic bulletin board, which is somewhat more readily achievable, though not necessarily within the purview of the ACES Editorial Board. Suggestions will be appreciated by the ACES leadership. Likewise appreciated by all of us will be contributions of time and effort.

David E. Stein
Editor-in-Chief

ATTENTION E-MAIL USERS!

One of the stated purposes of ACES is to promote the exchange of information between members of the electromagnetics community. In this age of desktop-based computer activity, access to E-mail services is becoming increasingly common.

To facilitate communication between members of ACES, and to lay the ground work for information exchange, including software, bug fixes, etc., it is proposed that an E-mail "phone directory" of members be created. If the community is interested in supporting this concept, send me an E-mail message and I will collate it and pass it along to those who desire it. Send your E-mail message to:

jost@wdc.sri.com

At a minimum, the following information is requested:

Name
Mailing Address
E-mail Address
Phone/FAX Numbers

If there is sufficient interest in the community, I would be willing to turn this into an on-line database for EM code users, to include such items as member interests, codes available, site capabilities, etc.

For those that do not currently have E-mail capability, but desire a copy of the collected list, send requests to:

Randy J. Jost
SRI International
1611 N. Kent St.
Arlington, VA 22209-2192
Phone: (703) 247-8415
FAX: (703) 247-8569

Send me your thoughts on these matters, whether by E-mail, FAX, phone or mail. What is being proposed is but the first step in achieving some of the possibilities inherent in modern communication and information technology. The existence, as well as the usefulness of this proposed "database" will be dependent upon the EM community's interest. The July Newsletter will provide a short tutorial article on the use of the Internet to transfer files and software.

PERSPECTIVES ON ACES AND COMPUTATIONAL ELECTROMAGNETICS

Some Technical Societies Where ACES Can Have an Impact

Reinaldo Perez

In the July issue of the ACES Newsletter I commented on the need of making ACES better known among other technical societies. Though I mentioned only the recently undertaken promotional efforts of ACES with other two societies (IEEE-AP and IEEE-EMC), the call went out to all ACES members, who are members of other societies, to promote ACES technical activities within such societies.

In this article I will go one step further by outlining some additional technical societies for which the aforementioned task can be pursued. The list is by no means complete, but it serves as a foundation for some of you to "add-on" to it. I also state, for each society, just one technical reason (among possibly several others), for which their members may benefit from ACES.

IEEE Societies:

a) Biomedical Engineering -- Modeling induced currents in body tissue.

b) Electron Devices -- Characterization of fields from integrated circuits.

c) Microwave Theory amd Techniques -- CAD of microwave devices and components.

d) Magnetics -- Computational aspects of magnetic fields.

e) Remote Sensing -- scattering of targets.

IEE Societies:

Those societies whose objectives matches thoseof the IEEE Societies described above

Other Societies:

a) American Institute of Aeronautics and Astronautics -- modeling antennas and antenna performance in aircraft and rockets.

b) Royal Aeronautical Society -- same as above.

BIO

Reinaldo Perez is Associate Editor of the ACES Newsletter.

A PARADOX IN COMPUTING ELECTRIC FIELD FROM CURRENTS

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It is well known that one can compute the electric field due to electric current and charge from the magnetic vector potential and the electric scalar potential or from the vector potential alone. When doing so one must be careful to interpret the results properly. This is particularly important in computational techniques involving the so-called electric field integral equation (*EFIE*) and its numerical solution. If effective numerical methods are to be developed for solving the *EFIE*, one must have a precise understanding of the full meaning of the electric field integral equation, either in its form based upon electric field expressed in terms of mixed potentials, i.e., in terms of both vector potential and scalar potential, or in its form based upon electric field expresed in terms of the vector potential alone. To illustrate this point, the electric field due a current distribution is computed both ways below to obtain results that are different.

The interested reader is invited to inspect the dual derivations below for expressions for electric field and explain why the results are different. If one is not interested in the simple mathematical steps leading to the results, he or she may simply choose to read the first few sentences below in which the current is described and then skip to the two different results for electric field given in Eqs. (14) and (15). Many readers will immediately understand why (14) and (15) are different. If you do not and if you are interested in developing your own numerical methods for solving the EFIE, or in critically reviewing those created by others, then it behooves you to investigate this paradox further. Why (14) and (15) are different will be addressed in the next issue (July, 1992) of the **ACES NEWSLETTER**. A full discussion of the paradox will be presented.

We consider a simple case of a $z-$directed surface current of density $\mathbf{J} = J(z)\hat{\mathbf{z}}$ which resides on a (imaginary) cylinder of radius a and length $2h$. For convenience, let the cylinder axis coincide with the z axis of a cylindrical coordinate system and let the center of the cylinder be at the coordinate origin, which means that the upper and lower ends of the cylinder are at $z = h$ and $z = -h$, respectively. This current distribution is of harmonic time variation $e^{j\omega t}$, is circumferentially invariant, i.e., independent of ϕ, and is embedded in a homogeneous space of infinite extent characterized by (μ, ϵ). We wish to determine the $z-$directed electric field on the z axis by two methods. One method is based on the use of the fundamental "mixed potential" expression

$$\mathbf{E} = -j\omega\mathbf{A} - \nabla\Phi \tag{1}$$

while the other is based on the following expression involving only the vector potential:

$$\mathbf{E} = -j\frac{\omega}{k^2}\left(k^2\mathbf{A} + \nabla(\nabla\cdot\mathbf{A})\right). \tag{2}$$

In (1) and (2), $\mathbf{E}$ is the electric field, $\mathbf{A}$ is the magnetic vector potential, Φ is the electric scalar potential, ω is the angular frequency, and k $(= \omega\sqrt{\mu\epsilon})$ is the wave number. One recalls that (2) follows from (1) through a simple procedure in which the *Lorentz* condition is invoked. In our little example, we focus attention on the z component of electric field E_z ($= \hat{\mathbf{z}} \cdot \mathbf{E}$) created by the $z-$directed current $\mathbf{J} = J(z)\hat{\mathbf{z}}$. On the basis of (2), E_z can be expressed as

$$E_z = -j\omega A_z - \frac{\partial}{\partial z}\Phi \tag{3}$$

while (2) leads to

$$E_z = -j\frac{\omega}{k^2}\left(k^2 A_z + \frac{\partial^2}{\partial z^2}A_z\right). \tag{4}$$

On the z axis, the z component of the vector potential A_z due the current described above can be determined readily from the general potential integral to be

$$\begin{aligned} A_z(z) =& \mu \int_{-h}^{h} J(z') \int_{-\pi}^{\pi} \frac{e^{-jk\sqrt{a^2+(z-z')^2}}}{4\pi\sqrt{a^2+(z-z')^2}} a d\phi' dz' \\ =& \mu \int_{-h}^{h} I(z') K_0(z-z') dz' \end{aligned} \tag{5}$$

in which the total axial current I is defined for convenience to be

$$I(z) = 2\pi a J(z) \tag{6a}$$

and in which the free space Green's function evaluated on the z axis simplifies to

$$K_0(z-z') = \frac{e^{-jk\sqrt{a^2+(z-z')^2}}}{4\pi\sqrt{a^2+(z-z')^2}}. \tag{6b}$$

The electric scalar potential Φ on the axis is

$$\Phi(z) = \frac{1}{\epsilon}\int_{-h}^{h}\int_{-\pi}^{\pi} q(z')\frac{e^{-jk\sqrt{a^2+(z-z')^2}}}{4\pi\sqrt{a^2+(z-z')^2}} a d\phi' dz' \tag{7}$$

where q is the surface charge density that is related to the surface current density by the continuity equation,

$$\frac{d}{dz}J(z) + j\omega q(z) = 0 \tag{8}$$

which allows one to express the potential conveniently as

$$\Phi(z) = j\frac{\eta}{k}\int_{-h}^{h}\frac{d}{dz'}I(z')K_0(z-z')dz'. \tag{9}$$

Substitution of A_z and Φ of (5) and (9) into (3) yields

One should observe that (14) and (15) are the same apart from the first term of the latter. *But due to the presence of this term, the expression (14) for electric field E_z on the z axis is different from the expression (15) !* Close inspection reveals that, if $I(h) = I(-h) = 0$, the two expressions are the same. Otherwise, they are not. For example, if $I(z) = \cos kz$, the identical integral terms of (14) and (15) are zero but the expressions are different unless the cylinder of current is one-half wavelength ($\lambda = 2\pi/k$) in length $2h$ causing $I(\pm h)$ to be zero: $\cos(\pm kh) = \cos(\pm 2\pi h/\lambda) = \cos(\pm\pi/2) = 0$. The two expressions for E_z are the same if the current is zero at both ends $z = h$ and $z = -h$, but, otherwise, they are in general different.

Clearly, both expressions cannot be correct. Which is correct? Why are the expressions the same if $I(\pm h) = 0$? Can the wrong expression be corrected easily?

The paradox, which involves a fundamental principle, will be resolved in the July, 1992, issue of the **ACES NEWSLETTER**. As will be explained, it is important that those who wish to develop **effective** numerical methods to solve the *EFIE* understand this principle and its consequences.

BIO

Chalmers M. Butler is Professor of Electrical and Computer Engineering at Clemson University. He has been a faculty member at Lousiana State University, the University of Mississippi, and the University of Houston. He is a fellow of IEEE, serves as the Chairman of the U.S. National Committee for URSI, and has served two terms on the IEEE Antenna and Propagation Society AdCom. In addition he has served as a member of the editorial boards or as associate editor of the **IEEE Transactions on Antennas and Propagation**, **Electromagnetics**, the **ACES Journal**, and the **IEEE Transactions on Education**. Professor Butler's major research interest is in mathematical and numerical methods in electromagnetics with principal interest in integral equation techniques. He has published more than 60 journal papers on these subjects.

Noticed 2 Sept '93
several pp. missing -- errata in later issues?
or some

yes - sep. 18 - next issue
ACES Newsletter July '92
v. 7 - No. 2

NEC RUN TIME COMPARISON FOR IBM-DOS FORTRAN COMPILERS

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This article compares the Lahey and the Microway Fortran compilers for a NEC2 problem. It appears that the the Microway compiled NEC code runs faster, although the Lahey compiles faster. The computer platform used was an IBM compatible 486-33 MHz with Weitek math coprocessor and enough RAM so that paging to disk was not needed for the sample NEC2 problem. The NEC2 source code was ported to the IBM from Gerry Burke's Macintosh version as briefly described in the July 1990 ACES Newsletter article by Tom Wallace, which also provides some comments on run times. Both compilers used protected mode DOS extenders. The compilers and cases run are the following, with any differences in compiler switch settings shown in parenthesis. The widely used Microsoft Fortran compiler was not compared because to the best of my knowledge it cannot compile NEC due to the size of the NEC subroutines. Fortran versions of MiniNec can be compiled by Microsoft Fortran.

Compiler 1: Microway NDP Fortran-386 v.3.1.0 with the Pharr-Lap DOS extender v.3.0.
    1a. Weitek on, optimizations on (-n4 -n7 -n8 -OM -on)
    1b. Weitek off, optimizations on (-OM -on)
    1c. Weitek on, optimizations off (-n4 -n7 -n8)
    1d. Weitek off, optimizations off (-off)

Compiler 2: Lahey Fortran F77EM/32 v.3.01 with the Lahey Ergo OS/386 DOS extender v.2.1.05.
    2a. Weitek on, optimizations on (/K /Z1 /nB)
    2b. Weitek off, optimizations on (/nK /Z1 /nB)

The run times in minutes are shown in Tables 1 and 2. This is the total time from when the command to run NEC2 is entered until NEC2 has completely finished and has returned control to the DOS command line. It therefore includes approximately 0.1 minutes to load the dos extender and the NEC2 executable and to open a virtual memory swap file, so the time is longer than the CPU time usually reported at the end of the NEC2 output.

Table 1. NEC2S Single Precision Run Time
(in minutes including load time).

NDP Compiler	Time	Lahey Compiler	Time
1a	1.00	2a	2.29
1b	1.45	2b	2.17
1c	1.03		

1d	1.48

Table 2. NEC2D Double Precision Run Time
(in minutes including load time).

NDP Compiler	Time	Lahey Compiler	Time
1a	1.63	2a	N.A.
1b	1.78	2b	2.30
1c	1.58		
1d	1.73		

The NEC input file used for the comparison was the following:

```
CE
GW  1  101    0.  0.  0.     0.  0.  .5    .0001
GE
EX  0  1  51  00    1.   0.
FR 0  10  0  0  250.  10.
XQ
EN
```

It appears that the Microway NDP compiler offers faster run times than Lahey. Another possible drawback to Lahey is that it will not run double precision complex arithmetic with the Weitek. Also, the largest array in the current version of Lahey cannot be larger than 16 MB which, with no symmetry, would limit NEC to about 1400 segments single precision or 1000 segments double precision. Version 5 of Lahey expected in April, 1992 will permit much larger arrays, but will still be unable to use a Weitek with double precision NEC.

The Lahey single precision ran a little slower with the Weitek than without it. Lahey technical help says this is because I used a 486 machine, and that version 5 of the compiler will run faster on a 486 with a Weitek (for single precision NEC). Lahey compiles faster than Microway, and Lahey, in my opinion, offers much better error messages, so I always use Lahey for code development and debugging, but not running big codes.

The Weitek clearly offers a speed boost for the Microway compiled code, especially in single precision. Microway had trouble initially with my Weitek until bugs were resolved which were probably caused by less than 100% compatibility between the compiler, the Weitek, the Phoenix BIOS, and/or the Micronics 486 EISA motherboard design (in general, work at the cutting edge of computing technology tends to be very "buggy"). A more recent version of the Microway compiler (v.3.2.0) would not run NEC with the Weitek unless all error messages are turned off. According to Microway, this problem should be alleviated in version 4.0 expected to be available in March 1992. A preliminary comparison of run times without the Weitek for NDP Fortran versons 3.1 versus 3.2 shows no significant speed difference. Microway also sells compiler versions optimized for the 486 which I have not had the opportunity to try. I used the 386 versions of the compilers running on a 486 machine.

The RISC workstations such as SUN and OPUS would also offer relatively low cost platforms for NEC. In terms of cost-effectiveness (speed vs. cost) they should currently be roughly equivalent to a 486 with a Weitek.

Comments on this article are invited from readers. Upcoming issues of the Newsletter will feature any follow up comments, and also NEC run times obtained for much larger input files (thousands of segments).

Computation of the RCS of an Array of PEC Rectangular Waveguides Using Waveguide Modes Computed By the FEM

Terry Bohning and Henry Helmken
Department of Electrical Engineering
Florida Atlantic University
Boca Raton, Florida

January 31, 1992

INTRODUCTION

When enforcing field continuity between two regions which permit modal expansions of the fields in each region, a popular approach for determining the unknown modal expansion coefficients has been to derive an Integral Equation and solve it via the Method of Moments. This paper applies this approach to the computation of the RCS of an array of PEC rectangular waveguides. The waveguide modes are computed using an instructional Finite Element program called UNAFEM. Solutions using the FEM computed modes and analytically computed waveguide modes are compared.

FIELD OF INFINITE PERIODIC ARRAY

For an infinite periodic array of identical cells subject to an incident plane wave, the field scattered from the array is spatially periodic except for a phase shift which is constant from cell to cell. Therefore, by Floquet's theorem [1], the field may be described in terms of a Floquet space harmonic expansion. Derivations of Floquet space harmonics are provided

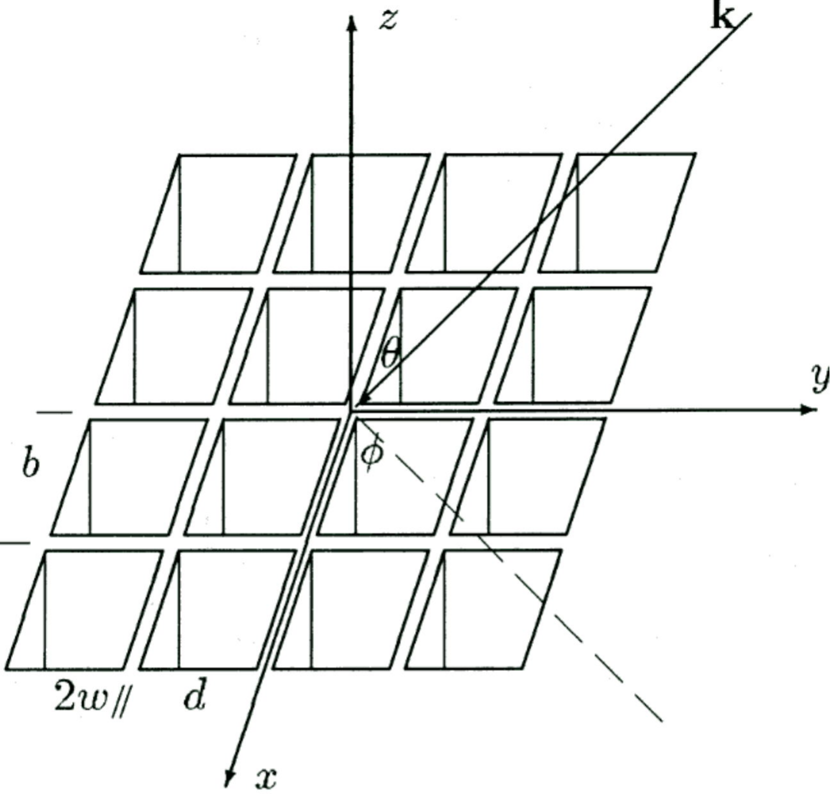

Figure 1: Array of Rectangular Waveguides

in [2] , [3], [4], and [5]. Floquet space harmonics are also referred to as Floquet modes.

A useful method for computing scattering from an infinite periodic array is to expand the field in the free-space region using a truncated series of Floquet modes and in the array region using a truncated series expansion of suitable eigenfunctions. An integral equation is derived by enforcing continuity of the tangential electromagnetic fields. The integral equation is then solved for the unknown tangential electric field using the Method of Moments [2] [3] [6] [7] [8] [5].

PROBLEM DESCRIPTION

The problem of interest is plane wave scattering from a periodic array of waveguides. The problem description parallels that found in [2], except that their problem is the radiation from an excited waveguide array. Another presentation of the same problem may also be found in [5]. A portion of an infinite periodic array of rectangular waveguides is shown in Figure 1. For an infinite array, the total field is periodic from cell to cell except for intercell phase shifts in the $\mathbf{a_x}$ and $\mathbf{a_y}$ directions given by ψ_x and ψ_y where

$$\psi_x = kb \sin\theta \cos\phi \quad \text{and} \quad \psi_y = kd \sin\theta \sin\phi \tag{1}$$

In these equations, b and d are the intercell spacings in the $\mathbf{a_x}$ and $\mathbf{a_y}$ directions respectively. A waveguide wall width w is also shown. Since each waveguide has this wall width, the total spacing between apertures is $2w$. The angles θ and ϕ are spherical coordinates which define the direction of an incident plane wave. These quantities are illustrated in Fig. 1. The phase constant is given by $k = 2\pi/\lambda = \omega\sqrt{\mu\epsilon}$.

In the free-space region ($z \geq 0$), the reflected tangential electric field can be described by an infinite summation of Floquet modes propagating in the $+\mathbf{a_z}$ direction. Floquet modes are used to represent the tangential electromagnetic field at the aperture ($z = 0^+$) [2] [5]. An $e^{j\omega t}$ time dependence of all field components is suppressed in this paper. The z-dependence of all field components is of the form $e^{\pm j\Gamma_{st}z}$, where Γ_{st} is the $\mathbf{a_z}$ directed propagation constant for the (s,t)th Floquet mode. Since this exponential factor becomes unity at the aperture, it does not appear in the expressions below.

Floquet Modes

The tangential component of the orthonormalized (s,t)th Transverse Electric (TE) Floquet mode is given by

$$\mathbf{\Psi}_{1st}(x,y) = \sqrt{\frac{1}{bd}}\left\{\frac{\mathbf{a_x} k_{y_t} - \mathbf{a_y} k_{x_s}}{k_{c_{st}}}\right\} e^{j(k_{x_s}x + k_{y_t}y)} \tag{2}$$

where the subscript 1 denotes a TE mode. The tangential electric and magnetic field intensities due to the (s,t)th TE Floquet mode are related by $\mathbf{a_z} \times \mathbf{H}_{t_{st}} = -(Y_{1_{st}})\mathbf{E}_{t_{st}}$ where $Y_{1_{st}} = \Gamma_{st}/\omega\mu$. is defined as the TE modal admittance. The free-space electric field will be expressed as a linear combination of Floquet Modes.

The tangential component of the orthonormalized (s,t)th Transverse Magnetic (TM) Floquet mode is given by

$$\mathbf{\Psi}_{2st}(x,y) = \sqrt{\frac{1}{bd}}\left\{\frac{\mathbf{a_x} k_{x_s} + \mathbf{a_y} k_{y_t}}{k_{c_{st}}}\right\} e^{j(k_{x_s}x + k_{y_t}y)} \tag{3}$$

where the subscript 2 denotes a TM mode. The tangential electric and magnetic field intensities due to the (s,t)th TM Floquet mode are related by $\mathbf{a_z} \times \mathbf{H}_{t_{st}} = -(Y_{2_{st}})\mathbf{E}_{t_{st}}$ where $Y_{2_{st}} = \omega\epsilon/\Gamma_{st}$ is defined as the TM modal admittance.

For Floquet modes incident on the array, which are propagating in the $-\mathbf{a_z}$ direction, the sign of $\mathbf{a_z} \times \mathbf{H}_{t_{st}}$ is reversed, since the sign of Γ_{st}, and hence the sign of the modal admittance, is reversed.

In the above equations, k_{x_s}, k_{y_t}, and Γ_{st} are the $\mathbf{a_x}$, $\mathbf{a_y}$, and $\mathbf{a_z}$ directed propagation constants, respectively, and are given by

$$k_{x_s} = (2\pi s - \psi_x)/b \qquad k_{y_t} = (2\pi t - \psi_y)/d \qquad \Gamma_{st}^2 = k^2 - k_{x_s}^2 - k_{y_t}^2 \tag{4}$$

The quantity $k_{c_{st}}$ is defined by

$$k_{c_{st}}^2 = k^2 - \Gamma_{st}^2 = k_{x_s}^2 + k_{y_t}^2 \tag{5}$$

and is the cutoff wavenumber.

Besides being orthonormal and satisfying the homogeneous vector Helmholtz equation, the Floquet modes are spatially periodic in x and y except that there is an additional phase shift given by (1), i.e.,

$$\mathbf{\Psi}(x + rb, y + sd) = \mathbf{\Psi}(x, y)e^{-j(r\psi_x + s\psi_y)} \tag{6}$$

Because of this property, once the field is known over one cell of an infinite periodic array, it can be determined over any other cell by applying the appropriate phase shift.

Vector Rectangular Waveguide Modes

As is well known [1] [9] [10], the field inside a conducting rectangular waveguide consists of a summation of eigenfunctions (modes), which satisfy Maxwell's Equations and the boundary conditions.

The transverse components of orthonormalized modes, $\mathbf{\Phi}$, in a perfectly conducting rectangular waveguide, are presented in [1]. The following modal equations assume a finite wall width w.

Since the field within the waveguides is propagating in the $-\mathbf{a_z}$ direction, the z dependence of the field is of the form $e^{j\gamma_{pq}z}$ for each mode, although at the aperture ($z = 0$), this factor becomes unity.

The tangential component of the orthonormalized (p, q) Transverse Electric (TE) waveguide mode is given by

$$\mathbf{\Phi}_{1pq} = \sqrt{\frac{1}{k_{c_{pq}}^2}}\sqrt{\frac{\epsilon_{0p}\epsilon_{0q}}{bd}} \Big(\mathbf{a_x} k_{y_q} \cos(k_{x_p}(x - w)) \sin(k_{y_q}(y - w)) - \mathbf{a_y} k_{x_p} \sin(k_{x_p}(x - w)) \cos(k_{y_q}(y - w))\Big) \tag{7}$$

where ϵ_{0n} is the Neumann factor defined by

$$\epsilon_{0n} = \begin{cases} 1 & \text{for } n = 0 \\ 2 & \text{for } n > 0 \end{cases} \tag{8}$$

and

$$k_{x_p} = p\pi/b \qquad k_{y_q} = q\pi/d \qquad \gamma_{pq}^2 = k^2 - k_{c_{pq}}^2 \tag{9}$$

The quantity $k_{c_{pq}}$ is defined by

$$k_{c_{pq}}^2 = k^2 - \gamma_{pq}^2 = k_{x_p}^2 + k_{y_q}^2 \tag{10}$$

and is the cutoff wavenumber.

These quantities are analogous to those given in (4) and (5) for Floquet modes.

For $-\mathbf{a_z}$ directed propagation, $\mathbf{E}_{t_{pq}}$ and $\mathbf{H}_{t_{pq}}$ are related by $\mathbf{a_z} \times \mathbf{H}_{t_{pq}} = y_{1_{pq}} \mathbf{E}_{t_{pq}}$ where $y_{1_{pq}} = \gamma_{pq}/\omega\mu$ is defined as the waveguide TE modal admittance. The tangential component of the orthonormalized (p, q) Transverse Magnetic (TM) waveguide mode is given by

$$\mathbf{\Phi}_{2pq} = \sqrt{\frac{1}{k_{c_{pq}}^2}}\sqrt{\frac{\epsilon_{0p}\epsilon_{0q}}{b}} \Big(\mathbf{a_x} k_{x_p} \cos(k_{x_p}(x-w)) \sin(k_{y_q}(y-w)) + \mathbf{a_y} k_{y_q} \sin(k_{x_p}(x-w)) \cos(k_{y_q}(y-w))\Big) \tag{11}$$

For $-\mathbf{a_z}$ directed propagation, $\mathbf{E}_{t_{pq}}$ and $\mathbf{H}_{t_{pq}}$ are related by $\mathbf{a_z} \times \mathbf{H}_{t_{pq}} = y_{2_{pq}} \mathbf{E}_{t_{pq}}$ where $y_{2_{pq}} = \omega\epsilon/\gamma_{pq}$ is defined as the waveguide TM modal admittance.

The TE_{00} mode does not exist nor does any TM mode which has p or q equal to 0.

APERTURE MATCHING USING INTEGRAL EQUATION

An equation of continuity for the tangential electric field at the aperture of the reference cell may be found by expressing the fields on the waveguide and free-space sides of the interface as

$$\mathbf{E}_t^{inc} + \mathbf{E}_t^{ref} = \mathbf{E}_t^{xmt} \tag{12}$$

where $\mathbf{E}_t^{inc}$ and $\mathbf{E}_t^{ref}$ are the incident and reflected tangential electric fields, respectively. The tangential electric field on the waveguide side of the interface which is transmitted into the semi-infinite waveguide is $\mathbf{E}_t^{xmt}$.

On the waveguide side of the interface, $(z = 0^-)$, the tangential electric field over the reference cell can be expressed as a weighted sum of waveguide modes by

$$\mathbf{E}_t(x,y,z=0^-)=\sum_{r=1}^{2}\sum_{p=0}^{\infty}\sum_{q=0}^{\infty}b_{rpq}\boldsymbol{\Phi}_{rpq}(x,y)=\sum_{n=0}^{\infty}b_n\boldsymbol{\Phi}_i(x,y) \tag{13}$$

where the triple summation has been replaced by a single summation over the "super-index", n, to ease bookkeeping during computation.

On the free-space side of the interface, ($z = 0^+$), the tangential reflected electric field over a reference cell can be expressed as a weighted sum of Floquet modes by

$$\mathbf{E}_t^{ref}(x,y,z=0^+)=\sum_{r=1}^{2}\sum_{s=-\infty}^{\infty}\sum_{t=-\infty}^{\infty}b_{rst}\boldsymbol{\Psi}_{rst}(x,y)=\sum_{m=0}^{\infty}a_m\boldsymbol{\Psi}_i(x,y) \tag{14}$$

where the triple summation has been replaced by the index m.

The incident plane wave with unit electric field intensity can be expressed in terms of (0,0) Floquet modes [6] [8] via

$$\mathbf{E}_t^{inc}=\sum_{r=1}^{2}A_{r00}\boldsymbol{\Psi}_{r00}=\sum_{m=1}^{2}A_m\boldsymbol{\Psi}_m \tag{15}$$

that is, a weighted sum of the TE_{00} and TM_{00} Floquet modes.

Using (13), (14), and (15), equation (12) can be written as

$$\sum_{m=1}^{2}A_m\boldsymbol{\Psi}_m+\sum_{m=1}^{M}a_m\boldsymbol{\Psi}_m=\sum_{n=1}^{N}b_n\boldsymbol{\Phi}_n \tag{16}$$

where equality holds only when M and N are infinite. In computation, M and N are truncated to a numerically tractable value.

Since we are interested in the aperture field ($z = 0$), both propagating and evanescent modes of both types are included.

The analogous result for the magnetic field is

$$\sum_{m=1}^{2}A_mY_m\boldsymbol{\Psi}_m-\sum_{m=1}^{M}a_mY_m\boldsymbol{\Psi}_m=\sum_{n=1}^{N}b_ny_n\boldsymbol{\Phi}_n \tag{17}$$

which enforces continuity of $\mathbf{a}_z \times \mathbf{H}_t$ at the aperture. Note that we have used the fact that $\mathbf{a}_z \times \mathbf{H}_t$ is of opposite sign for waves traveling in opposite directions.

An integral equation in terms of the unknown tangential electric field may be derived by enforcing continuity between the tangential electric and magnetic fields [2] [5].

To solve the integral equation, the tangential electric field is approximated by a finite sum of waveguide modes so that

$$\mathbf{E}_t(x',y') \approx \sum_{a=1}^{N} b_a \boldsymbol{\Phi}_a(x',y') \tag{18}$$

If we make this substitution in the integral equation and then take moments with respect to $\boldsymbol{\Phi}_q(x,y)$, where $1 \leq q \leq N$ (Galerkins' Method), we ultimately obtain

$$\begin{aligned}
&2\sum_{m=1}^{2} A_m Y_m \iint_A \boldsymbol{\Phi}_q(x,y)\cdot\boldsymbol{\Psi}_m(x,y)\,dx\,dy \\
&= \sum_{a=1}^{N} b_a \left\{ \sum_{n=1}^{N} y_n \iint_A \boldsymbol{\Phi}_n(x,y)\cdot\boldsymbol{\Phi}_q(x,y)\,dx\,dy \iint_A \boldsymbol{\Phi}_n(x',y')\cdot\boldsymbol{\Phi}_a(x',y')\,dx'\,dy' \right. \\
&\qquad \left. + \sum_{m=1}^{M} Y_m \iint_A \boldsymbol{\Phi}_q(x,y)\cdot\boldsymbol{\Psi}_m(x,y)\,dx\,dy \iint_A \boldsymbol{\Phi}_a(x',y')\cdot\boldsymbol{\Psi}^*_m(x',y')\,dx'\,dy' \right\} \\
&= \sum_{a=1}^{N} b_a \left\{ y_q \delta_{qa} + \sum_{m=1}^{M} Y_m C_{qm} C^*_{am} \right\} = \sum_{a=1}^{N} b_a A_{qa}
\end{aligned} \tag{19}$$

For analytical waveguide modes, the required integrations can be performed in closed form. The region of integration for those integrals involving waveguide modes reduces to the aperture area, where the waveguide modes are nonzero.

Equation (19) can be enforced at N values of q to yield an N x N system of equations and thus supply the values of b_n and hence an approximation to $\mathbf{E}_t$ as given by (18). Once $\mathbf{E}_t$ at the aperture is found in terms of waveguide modes, the a_m coefficients of (16) may be found by applying modal orthonormality.

RCS DETERMINATION

Once the tangential aperture field of a single cell of the infinite array has been determined, the RCS of the finite array can be obtained. This is done by using a radiation integral to determine the field due to a single waveguide cell at a point far from the array. Then this field is multiplied by the array factor for a planar array which has uniform amplitude excitation and progressive intercell phase shift. Implicit in this approach is the assumption that the finite array may be treated as extracted from the infinite array, i.e., boundary effects due to truncation of the array are ignored. Once the far field at the distant point has been found, the RCS may be determined from the incident and scattered fields at that point. If the RCS is computed separately using the waveguide and Floquet mode expansions for the reflected field and the results plotted, an indication of the aperture match can be obtained.

For a waveguide or Floquet mode, we have the following relation between the tangential electric and magnetic fields due to a particular mode

$$\mathbf{a_z} \times \mathbf{H}_t = (\pm\Upsilon)\mathbf{E}_t \tag{20}$$

where the sign is negative for waves propagating in the $+\mathbf{a_z}$ direction, and positive for waves propagating in the $-\mathbf{a_z}$ direction. The modal admittance for the particular waveguide or Floquet mode is represented by Υ.

Using (20) and introducing primed coordinates for the source point on the aperture, unprimed coordinates for the observation point, transforming from rectangular to spherical coordinates and allowing θ_o and ϕ_o to represent the angles of the observation point, the radiation integral given by

[11, pg 257] for the field at a far-field point P can be written as

$$\begin{aligned}
\mathbf{E}_P = {} & \frac{j\,k}{4\pi}\frac{e^{-jkr_1}}{r_1} \\
& \Bigg\{\mathbf{a}_\mathbf{x}\Big\{\sin^2\theta_o\sin\phi_o(\pm\Upsilon)\eta_0(\cos\phi_o\mathrm{I}_\mathrm{y}-\sin\phi_o\mathrm{I}_\mathrm{x})-\cos\theta_o\mathrm{I}_\mathrm{x}((\pm\Upsilon)\eta_0\cos\theta_o-1)\Big\} \\
& +\mathbf{a}_\mathbf{y}\Big\{\cos\theta_o\mathrm{I}_\mathrm{y}(-(\pm\Upsilon)\eta_0\cos\theta_o+1)-\sin^2\theta_o\cos\phi_o(\pm\Upsilon)\eta_0(\cos\phi_o\mathrm{I}_\mathrm{y}-\sin\phi_o\mathrm{I}_\mathrm{x})\Big\} \\
& +\mathbf{a}_\mathbf{z}\Big\{\sin\theta_o\cos\phi_o\mathrm{I}_\mathrm{x}((\pm\Upsilon)\eta_0\cos\theta_o-1)-\sin\theta_o\sin\phi_o\mathrm{I}_\mathrm{y}(-(\pm\Upsilon)\eta_0\cos\theta_o+1)\Big\}\Bigg\}
\end{aligned} \tag{21}$$

where we define

$$\mathrm{I}_\mathrm{x} = \int_{y'_1}^{y'_2}\int_{x'_1}^{x'_2} E_x(x',y')e^{jk\sin\theta_o\cos\phi_o x'}e^{jk\sin\theta_o\sin\phi_o y'}\,dx'\,dy' \tag{22}$$

Taking advantage of the fact that E_x is separable in x' and y' for both waveguide and Floquet modes, (22) can be rewritten as

$$\mathrm{I}_\mathrm{x} = \int_{x'_1}^{x'_2} E_x(x')e^{jk\sin\theta_o\cos\phi_o x'}\,dx'\int_{y'_1}^{y'_2} E_x(y')e^{jk\sin\theta_o\sin\phi_o y'}\,dy' \tag{23}$$

Similarly,

$$\mathrm{I}_\mathrm{y} = \int_{x'_1}^{x'_2} E_y(x')e^{jk\sin\theta_o\cos\phi_o x'}\,dx'\int_{y'_1}^{y'_2} E_y(y')e^{jk\sin\theta_o\sin\phi_o y'}\,dy' \tag{24}$$

To find the total scattered field, the various E_P's due to each mode are summed.

Waveguide Mode Expansion

For the n^{th} waveguide mode with (p, q) modal indices

$$\begin{aligned} \mathrm{I_x} &= K_n \Phi_{x_k} \int_{x'_1}^{x'_2} \cos(k_{x_p} x') e^{jk \sin\theta_o \cos\phi_o x'}\, dx' \int_{y'_1}^{y'_2} \sin(k_{y_q} y') e^{jk \sin\theta_o \sin\phi_o y'}\, dy' \\ \mathrm{I_y} &= K_n \Phi_{y_k} \int_{x'_1}^{x'_2} \sin(k_{x_p} x') e^{jk \sin\theta_o \cos\phi_o x'}\, dx' \int_{y'_1}^{y'_2} \cos(k_{y_q} y') e^{jk \sin\theta_o \sin\phi_o y'}\, dy' \end{aligned} \tag{25}$$

where the region of integration is over the aperture area since that is where the waveguide modes are defined.

The constant K_n is given by $K_n = \sqrt{1/k^2_{c_{pq}}}\sqrt{(\epsilon_{0p}\epsilon_{0q}/bd)}$.

For TE waveguide modes, $\Phi_{x_k} = k_{y_q}$ and $\Phi_{y_k} = -k_{x_p}$. For TM waveguide modes, $\Phi_{x_k} = k_{x_p}$ and $\Phi_{y_k} = k_{y_q}$. The reflected tangential field is written as

$$\mathbf{E}_t = \sum_{n=1}^{N} b_n \mathbf{\Phi}_n - \sum_{i=1}^{2} A_i \mathbf{\Psi}_i \quad \text{and} \quad \mathbf{a_z} \times \mathbf{H}_t = \sum_{n=1}^{N} y_n b_n \mathbf{\Phi}_n - \sum_{i=1}^{2} Y_i A_i \mathbf{\Psi}_i (26)$$

where the b_n's are determined from the moment method solution of (19).

Floquet Mode Expansion

For the m'th Floquet mode,

$$\begin{aligned} \mathrm{I_x} &= K_m \Psi_{x_k} \int_{x'_1}^{x'_2} e^{j(k_{xm} + k \sin\theta_o \cos\phi_o)x'}\, dx' \int_{y'_1}^{y'_2} e^{j(k_{ym} + k \sin\theta_o \sin\phi_o)y'}\, dy' \\ \mathrm{I_y} &= K_m \Psi_{y_k} \int_{x'_1}^{x'_2} e^{j(k_{xm} + k \sin\theta_o \cos\phi_o)x'}\, dx' \int_{y'_1}^{y'_2} e^{j(k_{ym} + k \sin\theta_o \sin\phi_o)y'}\, dy' \end{aligned} \tag{27}$$

where the region of integration is over the aperture area where the field has been determined.

The constant K_m is defined by $K_m = a_m\sqrt{1/bd}(1/k_{c_m})$ The quantity a_m is the expansion coefficient defined by (28).

For TE Floquet modes, $\Psi_{x_k} = k_{y_m}$ and $\Psi_{y_k} = -k_{x_m}$. For TM Floquet modes, $\Psi_{x_k} = k_{x_m}$ and $\Psi_{y_k} = k_{y_m}$.

On the free space side of the aperture ($z = 0^+$), the reflected tangential field is approximated by a summation of Floquet modes as

$$\mathbf{E}_t^{ref} = \sum_{m=1}^{M} a_m \mathbf{\Psi}_m \quad \text{and} \quad \mathbf{a_z} \times \mathbf{H}_t^{ref} = - \sum_{m=1}^{M} a_m Y_m \mathbf{\Psi}_m \tag{28}$$

Array Field

Once the reflected far field due to a single array cell at a particular point has been determined, the field due to the finite array can be found by multiplying it by the array factor. For an $M \times N$ planar array with uniform amplitude excitation and progressive intercell phase shift the array factor is given by [12, pg 263] as

$$\mathrm{AF}(\theta_o, \phi_o) = \left\{ \frac{\sin(M(\beta_x/2))}{\sin(\beta_x/2)} \right\} \left\{ \frac{\sin(N(\beta_y/2))}{\sin(\beta_y/2)} \right\} \tag{29}$$

where θ_o and ϕ_o are the angles of the observation point and β_x and β_y are defined by

$$\beta_x = kb \sin\theta_o \cos\phi_o + \psi_x \quad \text{and} \quad \beta_y = kd \sin\theta_o \sin\phi_o + \psi_y \tag{30}$$

respectively. The quantities ψ_x and ψ_y are the intercell phase shifts in the $\mathbf{a_x}$ and $\mathbf{a_y}$ directions defined by (1). If the point of observation lies on the incident wave's propagation vector **k** (Fig. 1) then this is the monostatic case and the angles of observation are the same as the angles of incidence.

Once the reflected field as a function of r has been found from (21), then the three-dimensional RCS can be determined from the following equation [13, pg 578]

$$\sigma_{3_D} = \lim_{r \to \infty} \left[4\pi r^2 \frac{|\mathbf{E}^s|^2}{|\mathbf{E}^i|^2} \right] \tag{31}$$

If we are interested in a specific polarization, such as VV or HH, then these components must be picked out of the incident and scattered E-fields before computing the RCS.

Observing (21), we note that all the far field components have a common $1/r_1$ amplitude term. This will become a $1/r_1^2$ amplitude factor when the squared magnitude is computed which will cancel the r^2 term in (31).

The squared magnitude of the incident wave can be found as

$$|\mathbf{E}_i|^2 = \frac{1}{bd}\left\{|A_1|^2 + |A_2|^2 + |A_2|^2\frac{\sin^2\theta}{\cos^2\theta}\right\} \tag{32}$$

THE UNAFEM FINITE ELEMENT PROGRAM

The problem described above has been implemented in Fortran-77 using both waveguide modes which are computed analytically and waveguide modes computed using the Finite Element Method.

The FEM solution is constructed using the UNAFEM program (UNderstanding and Applying the Finite Element Method) which is the program used as the instructional vehicle in the book *Finite Element Analysis - From Concepts to Applications* [14]. This extremely lucid 844 page text provides full documentation and explanation of the FEM using the UNAFEM program. As the text's preface notes, the primary objective is to provide the reader with a solid foundation in the basic concepts and methods of FE analysis. The author, Dave Burnett, has succeeded admirably in this goal.

UNAFEM is very well-written and is small enough (4500 lines) to be compiled and run on an IBM PC compatible. Development and debugging of the code discussed herein was in fact done on an 80386 based PC compatible. A VAX 6320 was used to obtain the final results. The Fortran-77 source code for UNAFEM is available from the author of [14], Dave Burnett, on floppy diskette for $79.00. Mr. Burnett may be reached at Bell Laboratories at (201) 386-3286.

Little modification to the UNAFEM program itself was required, although quite a bit of support code to calculate the RCS had to be written and interfaced. This is described in the next section.

UNAFEM was also modified to accept input from a file called UF.IN instead of the keyboard (standard input). This was done by simply opening UF.IN using file specifier 5, which FORTRAN by default assigns to the standard input device.

Because UNAFEM's problem description input data consists of a lot of column oriented data, it is very painful and error-prone to key the input file in manually for large problems. To circumvent this problem, a C program was written which generates the UNAFEM input file for the rectangular waveguide. The C program obtains the waveguide dimensions by reading values from the problem's data file so that it will be consistent with the RCS calculation code, which reads the same file. The C program accepts the number of elements desired along the x and y axes and the order of Gaussian Quadrature as command line input.

SOLUTION USING UNAFEM

UNAFEM's eigenproblem solver produces solutions to the scalar Helmholtz equation [14, pg. 689]. Therefore, we can interpret its solutions as a scalar wave potential so that the TE solution corresponds to H_z and the TM solution to E_z for each mode. UNAFEM's solution to the eigenproblem consists of eigenvalues, $k_{c_{pq}}$ of equation (10), and eigenvectors in the form of coefficients of the shape functions at each node.

We can compute the tangential components from the axial components by [10, pg. 130]

$$E_x = -\frac{j\omega\mu}{k^2_{c_{pq}}}\frac{\partial H_z}{\partial y} \quad \text{and} \quad E_y = \frac{j\omega\mu}{k^2_{c_{pq}}}\frac{\partial H_z}{\partial x} \tag{33}$$

for TE modes and

$$E_x = \frac{j\gamma}{k^2_{c_{pq}}}\frac{\partial E_z}{\partial x} \quad \text{and} \quad E_y = \frac{j\gamma}{k^2_{c_{pq}}}\frac{\partial E_z}{\partial y} \tag{34}$$

for TM modes. Since UNAFEM has routines which compute the derivatives of the element shape functions (axial field), the tangential field components can be computed fairly easily.

Since γ_{pq} can be found from (10), the waveguide modal admittances, y_n may also be computed.

A flow diagram of subroutine calls which are used in the FEM solution and a brief description is presented in Figure 2.

Calculate and Normalize Modes

First, the waveguide modes are calculated. Fortunately, the waveguide modes, unlike the Floquet modes, only need to be calculated once for all

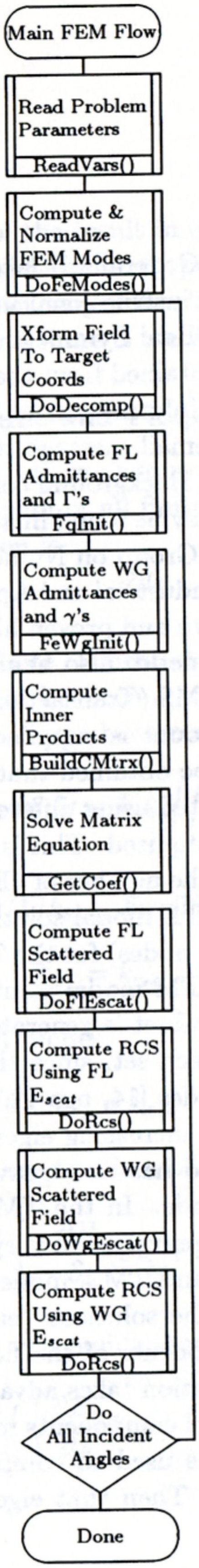

Figure 2: Flow Diagram of FEM Subroutine Calls

angles of incidence.

Instead of UNAFEM's GENJAC() (Generalized Jacobi) subroutine, which is admittedly less efficient owing to its instructional intent, the EISPACK subroutine RSG() is used to solve the Real Symmetric Generalized eigenproblem. The subroutine RSG() was obtained from the electronic mail site netlib@research.att.com. For further information and index of software available through the netlib, send an email message to the netlib address consisting of the one line "send index". Background concerning netlib may be found in [15]. Current information may be found in a quarterly column in the ACM's SIGNUM (Special Interest Group on Numerical Mathematics) Newsletter and the SIAM (Society for Industrial and Applied Mathematics) Newsletter. Aside from many well-known and proven libraries such as LINPACK, QUADPACK, and EISPACK, netlib also has source code for the algorithms published in the ACM's TOMS (Transactions on Mathematical Software). Since an Internet mail account is supplied with Compuserve membership, netlib software may also be obtained that way.

Since TE and TM modes are computed using different boundary conditions, two passes of the eigensolver are required. This is done by setting the global variable Numebc (which defines the number of "Essential" boundary conditions) to 0 in order to obtain the TE modal solution and restoring it to its original value (the number of edge nodes) for the TM modal solution.

A subset of the computed TE and TM modal solutions is used in the actual integral equation solution. The subset is generated using the modes which have the lowest eigenvalues in each set, since these will in general be more accurate than higher order modes [14, pgs 429,693]. The subroutine RSG() sorts the modes in order of increasing eigenvalues. In the TE solution, the first mode is unusable and has an eigenvalue of zero. This apparently corresponds to the TE_{00} mode. In the TM solution, the first several modes are unusable and have eigenvalues of very nearly 1.0. These modes apparently correspond to TM_{0x} and TM_{x0} modes.

The subroutine RSG() normalizes the solutions (eigenvectors). However, since it solves for the axial components of the field, this is what it normalizes. The integral equation derivation takes advantage of tangential orthonormality. Therefore, the tangential components must be normalized. For each mode, Gaussian Quadrature is used to compute the tangential inner product of the mode with itself. Then that eigenvector is divided by the square root of the result in order to normalize the tangential inner product. Since UNAFEM already performs its integrations using Gaussian Quadrature, it was not very difficult to do this, since the Gauss Points are already computed and there is plenty of exemplary code.

Compute Waveguide and Floquet Mode Inner Products

In accordance with [14], we adopt $\tilde{U}$ as the approximate FE solution for a waveguide mode (sum of all finite element solutions) where a particular finite element solution is

$$\tilde{U}^{(e)} = \sum_{i=1}^{8} a_i \phi_i^{(e)} \tag{35}$$

and the ϕ_i are the finite element shape functions.

The inner product between a waveguide mode and mth Floquet mode over a single finite element becomes

$$\iint_A \tilde{U}_x \Psi_x + \tilde{U}_y \Psi_y \, dx\, dy = K_m \iint_A \left\{ \tilde{U}_x \Psi_{x_k} + \tilde{U}_y \Psi_{y_k} \right\} e^{j(k_{xm}x + k_{ym}y)} \, dx\, dy \tag{36}$$

where $K_m = \sqrt{1/bd}(1/k_{c_m})$. For TE Floquet modes

$$\Psi_{x_k} = k_{y_m} \quad \text{and} \quad \Psi_{y_k} = -k_{x_m} \tag{37}$$

and for TM Floquet modes,

$$\Psi_{x_k} = k_{x_m} \quad \text{and} \quad \Psi_{y_k} = k_{y_m} \tag{38}$$

Using (33), for TE waveguide modes equation (36) becomes

$$K_m \iint_A \left\{ -\frac{\partial H_z}{\partial y} \Psi_{x_k} + \frac{\partial H_z}{\partial x} \Psi_{y_k} \right\} e^{j(k_{xm}x + k_{ym}y)} \, dx\, dy \tag{39}$$

Using (34), for TM waveguide modes equation (36) becomes

$$K_m \iint_A \left\{ \frac{\partial E_z}{\partial x} \Psi_{x_k} + \frac{\partial E_z}{\partial y} \Psi_{y_k} \right\} e^{j(k_{xm}x + k_{ym}y)} \, dx\, dy \tag{40}$$

These are the expressions which are numerically integrated in order to find the components of the matrix given by (19).

Find RCS Using Radiation Integral

To find the RCS using the waveguide mode expansion, we need to find $\mathrm{I_x}$ and $\mathrm{I_y}$ for a given mode with $\mathrm{I_x}$ and $\mathrm{I_y}$ defined by equations (22) and (24).

For a TE waveguide mode, equations (22) and (24) become

$$\begin{aligned} \mathrm{I_x} &= -\iint\limits_A \frac{\partial H_z}{\partial y'} e^{jk\sin\theta_o\cos\phi_o x'} e^{jk\sin\theta_o\sin\phi_o y'}\, dx'\, dy' \\ \mathrm{I_y} &= \iint\limits_A \frac{\partial H_z}{\partial x'} e^{jk\sin\theta_o\cos\phi_o x'} e^{jk\sin\theta_o\sin\phi_o y'}\, dx'\, dy' \end{aligned} \tag{41}$$

For a TM waveguide mode, equations (22) and (24) become

$$\begin{aligned} \mathrm{I_x} &= \iint\limits_A \frac{\partial E_z}{\partial x'} e^{jk\sin\theta_o\cos\phi_o x'} e^{jk\sin\theta_o\sin\phi_o y'}\, dx'\, dy' \\ \mathrm{I_y} &= \iint\limits_A \frac{\partial E_z}{\partial y'} e^{jk\sin\theta_o\cos\phi_o x'} e^{jk\sin\theta_o\sin\phi_o y'}\, dx'\, dy' \end{aligned} \tag{42}$$

Once $\mathrm{I_x}$ and $\mathrm{I_y}$ are found numerically, the scattered field can be found using equation (21) and then the RCS for the array can be found as outlined earlier.

NUMERICAL RESULTS

The monostatic RCS of a 12 x 24 cell array was computed for $\theta = 0°$ to $50°$ in 1.0° steps. The integral equation was solved and the RCS computed using both analytical waveguide modes, as given by (7) and (11), and waveguide modes computed using UNAFEM. The waveguide dimensions used were 2.0 in. x 1.0 in. with 1/16 in. wall thickness.

To obtain the solution, the highest modal indices used for the waveguide modes were (5,5), and for the Floquet modes were (3,3). This yields 98 Floquet modes (49 TE, 49 TM) and 60 Waveguide modes (35 TE, 25 TM).

Although these values of modal indices do not satisfy the relative convergence criterion exactly [16] [5, pg. 360], it is noted in [17, pg. 36] that solutions are generally quite stable about the nominal values of modal indices.

The reason more Floquet modes were not used is that a large amount of computation time is required to compute the inner products between all the waveguide and Floquet modes. On the multi-user university computer which was used, this translates into extremely long actual times, sometimes days. Throw in an occasional system crash, and the potential for a lot of lost computation time becomes a concern. In any event, experimentation with the code which uses analytical waveguide mode solutions indicates that the values obtained are very close to those obtained using more Floquet modes.

Since the FEM solution produces the values of $k_{c_{pq}}$, we cannot determine the (p, q) modal indices independently. However, the modes with the lowest eigenvalues, which are the ones used, generally correspond to the modes with the lowest modal indices.

The VV RCS was computed using both the Floquet and waveguide mode field expansions. Results at 3.2GHz are plotted in Figure (3). For the solution obtained using analytical waveguide modes, the RCS obtained using the Floquet and waveguide mode aperture field expansions matched exactly. The graph shows that RCS as well as the RCS computed using the FEM waveguide modes to solve the integral equation. For the FEM solution, RCS computed using both waveguide and Floquet mode aperture fields is shown.

On a VAX 6320, about 6 minutes of CPU time were required to obtain the analytical waveguide mode solution and about 3 hours CPU time were required for the FEM waveguide mode solution. For the FEM solution, 50 finite elements were used (10 x 5) and 3 point Gaussian Quadrature was used (9 points per finite element) to compute the inner product integrals of (36) and the radiation integrals. The FEM solution used UNAFEM's C^0-Quadratic Isoparametric Quadrilateral finite element.

Inner products between waveguide and Floquet modes are computed once per angle of incidence by the routine BuildCMtrx() and stored for later use in constructing the components of the matrix given by (19). To get some idea of the computation involved, consider that for each inner product computed, the integrand must be evaluated at 9 Gauss points on each element. For 50 elements, this is 450 evaluations. For 98 Floquet modes and 60 waveguide modes, this is 5880 inner products, so that the integrand of (36) must be evaluated (450)(5880) = 2,646,000 times.

Fortunately, this can be reduced substantially by noting that for 10 x 5 elements, there are only (10)(3)=30 unique values of y over the cell and (5)(3)=15 values of x over the cell, we can precompute the exponential terms involved in each inner product, reducing the number of complex exponentiations by a factor of 450/(30+15) = 10.

Another useful optimization is the use of Euler's identity

$$e^{jx} = \cos(x) + j\sin(x) \tag{43}$$

to evaluate the imaginary exponentials instead of the CEXP() intrinsic function, because CEXP() evaluates both the real and imaginary portions of the exponent. Since the real portion is zero for a pure imaginary, this is wasted time.

Another optimization is the definition of the following statement function to multiply a real times a complex value

```
*    multiply real times complex
      complex rcmul, c1
      real r1
      rcmul(r1,c1) = cmplx( r1*real(c1), r1*aimag(c1) )
```

Now, instead of casting the value `r1` into a complex value and performing a complex multiply consisting of 4 real multiplications, the compiler performs only the required 2 real multiplications. Additionally, since `rcmul()` is a statement function, the compiler generates inline code. Depending upon the compiler, this may have the additional advantage of avoiding a call to a run-time library function which performs complex multiplication.

Whether or not the preceding two suggestions improve run-time depends upon how optimized a compiler's output already is. But it is fairly easy to write a test program consisting of a loop with a large number of iterations in order to see if any improvement is gained for a particular compiler.

Library routine LSLCG() from the IMSL math package was used to solve the complex general system of linear equations.

CONCLUSION

The Integral Equation method of matching modal fields has been examined. The modal expansion coefficients of the aperture field over a single rectangular waveguide of an infinite periodic array were determined using the integral equation approach. Using these coefficients, the RCS of a finite array was computed using the field on each side of the aperture. The integral equation was solved and the RCS computed using both analytically derived waveguide modes and modes computed using the Finite Element Program Program UNAFEM.

Although the FEM solution requires substantially more CPU time, the fact that it compares favorably with a solution which uses analytical waveguide modes indicates that the RCS of a large array of arbitrarily shaped waveguides could be successfully determined using modes computed via the FEM.

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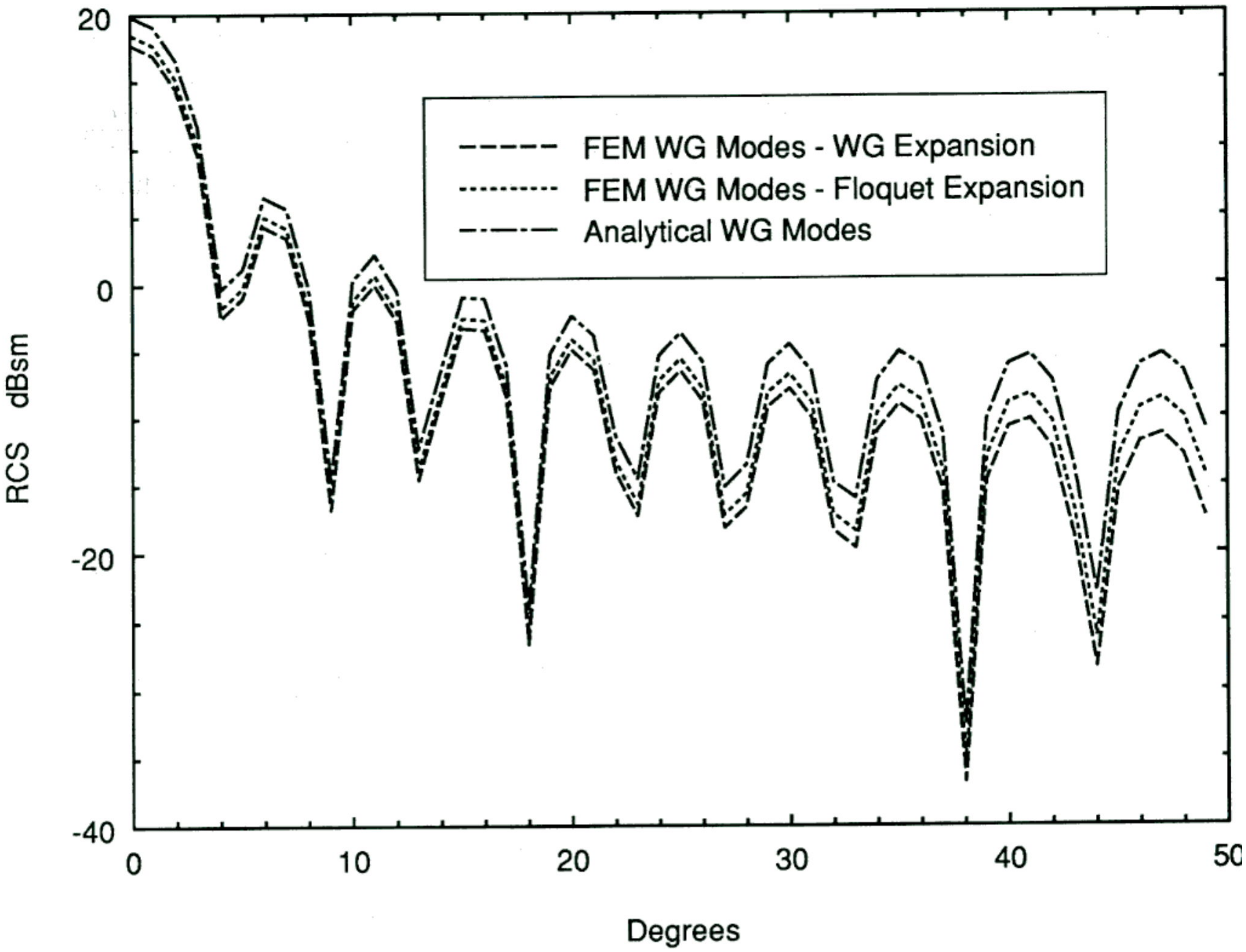
Figure 3 Array RCS - 3.2 GHz / VV Polarization



$$E_z(z) = -j\frac{\eta}{k}\left\{k^2\int_{-h}^{h} I(z')K_0(z-z')dz' + \frac{d}{dz}\int_{-h}^{h}\frac{d}{dz'}I(z')K_0(z-z')dz'\right\} \tag{10}$$

while substitution of A_z of (5) into (4) leads to

$$E_z(z) = -j\frac{\eta}{k}\left(k^2 + \frac{d^2}{dz^2}\right)\int_{-h}^{h} I(z')K_0(z-z')dz' \tag{11}$$

in which η ($= \sqrt{\mu/\epsilon}$) is the wave impedance.

We next wish to manipulate these two expressions for E_z on the z axis into alternate forms which reveal their differences. Under the requirement that the cylinder radius be finite, the integrals in (10) and (11) are sufficiently well behaved that one can interchange the differentiation and integration operations. (This is possible because $\sqrt{a^2 + (z-z')^2}$ is never zero with the observation points on the z axis and the source points on the finite-radius cylinder.) The observation

$$\frac{d}{dz}K_0(z-z') = -\frac{d}{dz'}K_0(z-z') \tag{12}$$

allows one to carry out the following integration by parts:

$$\begin{aligned}\frac{d}{dz}\int_{-h}^{h} I(z')K_0(z-z')dz' &= -\int_{-h}^{h} I(z')\frac{d}{dz'}K_0(z-z')dz' \\ &= -\Big[I(z')K_0(z-z')\Big]_{z'=-h}^{h} + \int_{-h}^{h}\frac{d}{dz'}I(z')K_0(z-z')dz' \end{aligned} \tag{13}$$

Interchanging differentiation with respect to z and integration in the second term of (10) and employing the above integration by parts, with $I(z')$ replaced by $\frac{d}{dz'}I(z')$, one can readily convert (10) to

$$\begin{aligned}E_z(z) = -j\frac{\eta}{k}\Big\{ &- \left[\frac{d}{dz'}I(z')K_0(z-z')\right]_{z'=-h}^{h} \\ &+ \int_{-h}^{h}\left\{\left(\frac{d^2}{dz'^2} + k^2\right)I(z')\right\}K_0(z-z')dz'\Big\}. \end{aligned} \tag{14}$$

In a similar way, interchange of differentiation and integration plus integration by parts twice (in the manner of (13)) allow one to rewrite (11) in the following form:

$$\begin{aligned}E_z(z) = -j\frac{\eta}{k}\Big\{ &- \left[I(z')\frac{d}{dz}K_0(z-z')\right]_{z'=-h}^{h} - \left[\frac{d}{dz'}I(z')K_0(z-z')\right]_{z'=-h}^{h} \\ &+ \int_{-h}^{h}\left\{\left(\frac{d^2}{dz'^2} + k^2\right)I(z')\right\}K_0(z-z')dz'\Big\}. \end{aligned} \tag{15}$$

MECHANICAL DAMPING OF VIBRATION OF STAYWIRES ON ANTENNA MASTS

Duncan C. Baker

Department of Electronics and Computer Engineering
University of Pretoria, Pretoria, 0002, South Africa

Some of the readers of the ACES Newsletter may be interested in a problem recently experienced with antennas installed near an airport at the coast in South Africa.

A number of log-periodic dipole (LPD) HF arrays, similar to that described in [1], were built and installed near an airport at the coast. In the original electrical design it was assumed that all the dipole elements of the array were in the same plane. For a number of reasons, the potential effects of sag in the dipole structures themselves or in the supporting catenaries or central feedline were not investigated. The mechanical design specifications therefore followed the recommendations of [2]. One of these recommendations is that for reasonably constant take-off angles over the design frequency range, no element should deviate by more than 2.5% of its half-length from the desired plane. The result of this is a relatively high loading in the catenaries and consequently the stay wires for the antenna masts.

Because of the proximity of the antennas to an airport and the fact that mast heights were about 45 metres, civil aviation regulations required warning lights on all the masts. During the day it was found that the continual seabreeze set up sustained vibrations on the catenaries and stay wires. The amplitudes of these vibrations were such that the warning lights were subjected to excessive shock and vibration, resulting in unacceptably high failure rates. The proposed solutions included relaxing the loading on the catenaries and stays, or loosely wrapping several turns of polyethylene rope around them to damp out the vibrations. The first approach could violate the sag limits set by [2], while the second would require that the LPD arrays be taken out of commission and lowered in order to wrap rope around the catenaries. Both these solutions thus presented operational problems.

A simple elegant solution was proposed by Jasco International, trading as Webb Industries, the contractor responsible for installing the antennas. This was to use spiral vibration dampers which are routinely used in the power industry to damp out vibrations in overhead power lines. The coils are preformed from a hard plastic material and resemble an outsize corkscrew. These helical coils were loosely fitted at the bottom end of each staywire, with the wire passing through the turns of the helix. The coils very effectively damped out the wind induced vibration on the stays and catenaries.

For reference, the helical coils used are manufactured by Preformed Line Products, Cleveland, Ohio. The specific model was made from extruded plastic material with a diameter of about 12.5 mm. The overall length was about 1.4 m with 11 turns gradually increasing in pitch from 9 to 15 cm while the radius of the turns increased from about 1 to 2.5 cm, measured to the centre of the plastic extrusion itself.

This short case study illustrates the need for close interaction between the antenna designer and the mechanical designer ultimately responsible for specifying the configuration for catenaries, masts, stays and other hardware. Such interaction would enable the antenna designer to evaluate the effect of practical constructional considerations, such as sag and windloading, on the overall performance of the antenna system. Hopefully this short newsletter item will encourage others involved in computational electromagnetics to make contact with colleagues involved in numerical analysis of structures and we can look forward to increased cooperation between workers in the two fields, to our mutual benefit.

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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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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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HIGHLIGHTS

OF THE

8TH REVIEW OF PROGRESS IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

16-20 MARCH 1992

- **Meeting on Canonical Problems**

- **A CAEME Posters and Software Demonstration**

- **Vendor booths** will be set up in the Hermann Hall Ballroom and will be manned 2 - 6 PM Tuesday 17 March. Vendor booth space will also be available in 101Spanagel on Wednesday 18 March.

- **Wine and Cheese Buffet 1600 - 1800** Tuesday 17 March in Hermann Hall Ballroom.

- **Committee and User Group Meetings** will be held at 5:30 PM Wednesday 18 March.

- **Eight short courses** are offered this year on 16 through 20 March.

Full-day offerings are	1. "Time Domain Modeling of Guiding & Radiating Structures with TLM" 2. "Using GEMACS to Solve Practical Problems" 3. "Electromagnetic Microwave Design"
Half-day courses are	4. "An Introduction to FDTD & Its Applications" 5. "Signal Representation & Model-Based Parameter Estimation Applications in Computational EM" 6. "Antenna Radiation in Natural Environments: Special Topics" 7. "UTD and its Practical Applications" 8. "The 3D MMP Code for Computational EM on PC's"

(Full details are contained elsewhere in this Newsletter)

PRELIMINARY AGENDA

The Eighth Annual Review of Progress in Applied Computational Electromagnetics

NAVAL POSTGRADUATE SCHOOL
16 - 20 MARCH 1992

Pat Foster
Chairman, Technical Program Committee

MONDAY MARCH 16

0830-1630 **SHORT COURSE (FULL-DAY)**
"Time Domain Modeling of Guiding & Radiating Structures with TLM" by Wolfgang J.R. Hoefer

0830-1130 **SHORT COURSE (MORNING HALF-DAY)**
"An Introduction to FDTD & Its Applications" by Karl Kunz and Ray Luebbers

0830-1130 **SHORT COURSE (SPLIT FULL-DAY -- CONTINUES TUESDAY 1300)**
"Antenna Radiation in Natural Environments - Special Topics" by Robert Bevensee

1300-1630 **SHORT COURSE (SPLIT FULL-DAY -- CONTINUES TUESDAY 1300)**
"UTD & Its Practical Applications" by R.J. Marhefka

1300-1630 **SHORT COURSE (AFTERNOON HALF-DAY)**
"Signal Representation & Model-based Parameter Estimation Application in Computational EM" by E.K. Miller and G.J. Burke

1800-2030 **CONFERENCE REGISTRATION** Ingersoll Lobby

1600-1800 **BOARD OF DIRECTORS MEETING** 122 Ingersoll
(Members are invited to observe)

1830 **BOARD OF DIRECTORS DINNER**

TUESDAY MARCH 17

0715 **CONFERENCE REGISTRATION** Ingersoll Lobby

0730 **ACES BUSINESS MEETING** President Stan Kubina 122 Ingersoll

1300-1630 **SHORT COURSE (SPLIT FULL-DAY -- FIRST PART MONDAY 0830)**
"Antenna Radiation in Natural Environments - Special Topics" by Robert Bevensee

1300-1630 **SHORT COURSE (SPLIT FULL-DAY -- FIRST PART MONDAY 1300)**
"UTD and Its Practical Application" by R.J. Marhefka

SESSION 1: MOMENT METHOD THEORY **Moderator: Allen Glisson**

0800 "Electromagnetic Scattering by Bodies with Complete or Partial Material Coatings of Varying Thickness"
A.W. Glisson, P.M. Goggans and A.A. Kishk University of Mississippi

0820 "CLASP - A New, General-purpose Method of Moments Scattering Code"
P. Kirby, D.W. Lizius, A.J. Marrison, J.G. Morgan and J.C. Wood Culham Laboratory, U.K.

0840 "Hybrid Optics/Numerical Approach to Electromagnetic Scattering"
C.D. Sillence British Aerospace, U.K.

0900 "Realistic Feed Region Models for Use in the Numerical Analyis of Wire Antennas"
D.J. Janse van Rensburg and D.A. McNamara University of Pretoria

SESSION 2: GENERAL MULTIPOLE EXPANSION **Moderator: Robert Bevensee**

0920 "On the Application of Line Multipoles in the MMP-Program"
P. Leuchtmann and F. Bomholt Swiss Federal Inst. of Tech. Zurich

0940 "Iterative and Block Iterative Solutions of Overdetermined Systems of Equations in the MMP Code"
Ch. Hafner and N. Kuster Swiss Federal Inst. of Tech. Zurich

1000 **BREAK**

TUESDAY MARCH 17

SESSION 2: "GENERAL MULTIPOLE EXPANSION" (CONT)

1010 "Automatic Expansion Setting for the 3D-MMP Code""
P.Regli — Swiss Federal Inst. of Tech. Zurich

1030 "FD Schemes, Particles, Cellular Automata and Other Exotic Features of the 3D MMP Graphics"
Ch. Hafner — Swiss Federal Inst. of Tech. Zurich

SESSION 12: TRANSMISSION LINE MODELING

Moderator: Lloyd Riggs

1050 "Developments in the Transmission Line Modelling (TLM) Method"
C. Christopoulos and J.L. Herring — University of Nottingham, U.K.

1110 "An X-Windows Previewers for GTEC Input Data"
M.E.G. Upton and S.J. Kubina — Concordia University

1130 "The Application of Transmission Line Matrix Modelling to a Microwave Heating Applicator"
I.J. Dilworth — University of Essex, U.K.

1150 Introduction to Canonical Problems: **Moderator: Hal Sabbagh**

1220 **LUNCH**

SESSION 4: CAEME

Moderator: Magdi Iskander

1320 "Reflections on the First CAEME Book and a Description of Future Directions"
M. Iskander — University of Utah

1340 "Role of Computational Tools in the Learning Cycles of a Practicing Engineer"
S. Sanzgiri, P. Green and R. Smith — Texas Instruments

1400 "Simple Techniques for Effortlss Desk-Top Production of Computer Movies to Help Students Visualize Time-Varying Phenomena in Electromagnetics"
F.E. Vermeulen, F.S. Chute and E. Sumbar — University of Alberta

1420 "A Computer Algebra Approach to LaPlace's Equation"
J.M. Crowley — Electrostatic Applications

SESSION 5A: CODE APPLICATIONS (Hermann Hall Ballroom)

Moderator; James K. Breakall

1400-1800 **POSTERS**

Paper 1 "The Effect of Modeling Resolution on Antenna Pattern Sensitivity Using GEMACS V5.0"
J.A. Evans and H.F. Bascom — Decision-Science Applications

Paper 2 "Validation of the Cross Section and Glint Evaluation System"
M.T. Husar and A.J. Terzuoli, Jr. — Air Force Institute of Technology

Paper 3 "Wide Band Optimization of Yagi Arrays Using NEC"
R.W. O'Connor and J.P. Scherer — Randtron Systems

Paper 4 "A Comparison of Solutions for Wires Over Ground"
G.J. Burke — Lawrence Livermore National Lab.

Paper 5 "Element Impedance Considerations in Array Design"
C.J. McCormack and R.L. Haupt — U.S. Air Force Academy

Paper 6 "Extending NEC to Model Wire Objects in Infinite Chiral Media"
G.J. Burke — Lawrence Livermore National Lab
E.K. Miller — Los Alamos National Laboratory
A.K. Bhattacharyya — Physical Science Laboratory

Paper 7 "Electromagnetic Modelling of a Warship at HF Frequencies"
J. McLachlan, Y. Antar, S. Kubina and S. Kashyap — Dir. Maritime Combat Systems, Ottawa

Paper 8 "Benchmark Calculations with CLASP"
P. Kirby, D.W. Lizius, A.J. Marrison, J.G. Morgan, D.I. Shepherd and J.C. Wood — Culham Laboratory, U.K.

TUESDAY MARCH 17

SESSION 5A: CODE APPLICATIONS (CONT)

Paper 9 "The Regular Tetrahedron - A Canonical Scattering Problem"
A.J. Mackay — DRA (RSRE) U.K.
P. Kirby and D.W. Lizius — Culham Laboratory, U.K.

Paper 10 "An Introduction to the Three-Dimensional Frequency-Independent Phased Array (3D-FIPA)"
J.K. Breakall — Penn State University

Paper 11 "Time-Harmonic 2-D Electromagnetic Field Solutions Using Matlab"
J.E. Lebaric and D. Kajfez — University of Mississippi

Paper 12 "Electrostatic Field Inside a Split Cylinder - A Matlab Approach"
D. Kajfez and Y. Wu — University of Mississippi

Paper 13 "Synthesis of Sum and Delta Beams for Continuous Circular Aperture for Monopole Processing"
M.A. Hussein, K.B. Yu and B. Noble — G E Research & Development Center

SESSION 5B: CAEME (POSTERS) AND SOFTWARE DEMONSTRATIONS

Moderator: Magdy Iskander

1400-1800 **POSTERS AND DEMONSTRATIONS**

Paper 1 "A Transmission-Line Laboratory Exercise Using Computer Simulations to Verify Measurements"
M.E. McKaughan — U.S. Coast Guard Academy

Paper 2 "Visualization of Radiation Effects from Simple Charged Particles"
R. Cole and C. Brune — University of California

SESSION 5C: MMACE

Moderator: Robert Jackson

Paper 1 "The MMACE Program: Status and Agenda"
R.H. Jackson — Naval Research Laboratory

1400-1800 **POSTERS**

1400-1800 **VENDOR BOOTHS**

SESSION 6: MEETING ON CANONICAL PROBLEMS

Moderator: Hal Sabbagh

1600-1800 **WINE AND CHEESE BUFFET** — Hermann Hall Ballroom

WEDNESDAY MARCH 18

0800 **ACES BUSINESS MEETING** — 122 Ingersoll

SESSION 7: ANTENNA AND MICROWAVE CIRCUITS

Moderator: Darko Kajfez

0830 "CG-FFT Analysis of Two Dimensional Fresnel Zone Plate Antennas"
Y.G. Guo and S.K. Barton — University of Bradford, U.K.

0850 "Finite Cylindrical Cavity Resonators"
R.A. Speciale — General Dynamics

0910 "A Study of Edge Diffraction on a Grounded Dielectric Sheet by a Computational Method"
J. Watkins — King's College, London

0930 "Spectral Domain Analysis of Printed Transmission Lines in Multi-layered Substrate and Superstrate Configuration""
J.R. Souza — Pontifical Catholic University of Rio de Janeiro, Brazil

0950 "On the Calculation of the Electromagnetic Field in Planar Structures by Spectral Domain Techniques"
A. Vilcot, S. Tedjini and P. Chazon — LEMO, Grenoble, France

1010 **BREAK**

1030 "Electromagnetic Fields - A Menace to Society?"
Dr. I. Gyuk, — INVITED SPEAKER
Dept. of Energy

WEDNESDAY MARCH 18

SESSION 8: LOW FREQUENCY APPLICATIONS
Moderator: O. Mohamed

1110 "A Hybrid Method for the Computation of 2D Eddy Currents in Ferromagnetic Materials"
A. Nicolet, A. Genon, P. Dular, F. Delince and W. Legros
University of Liege, Belgium

1130 "On the Development of the Combined Eddy Current Code"
Z. Cheng, S. Gao, C. Ye and P. He
Baoding Transformer Works,
Baoding, P.R. China

1150 "Electrostatic Qualification of High and Very High Voltage Insulators"
A.M.I. Morega and P. Minciunescu
Duke University

1210 "Hybrid Calculation of the Magnetic Vector Potential and Impedance for a Coil in the Air"
D.D. Derkacht, L.D. Philipp, D.J. Lynch and A. Mahmood
Washington State Univ. at Tri-Cities

1230 **LUNCH**

1330 "The Finite Element Analysis of the 50 Cycle Induction Furnace"
Q. Zhang, Y. Qiu, D. Hou and S. Chen
Xi'an Jiaotong University, P.R. China

1350 "Time Domain Analysis of the Magnetic Field Penetration into Stratified Conductive Shields, Using FEM"
C.V. Bala, O. Craiu and M.I. Morega
Polytechnic Institute of Bucharest

1410 **BEGINNING OF PARALLEL SESSIONS** **(122 INGERSOLL AND HYATT REGENCY)**

SESSION 9: HF APPLICATIONS (Hyatt Regency)
Moderator: C.E. Ryan

1430 "RCS Prediction Validation of the Simulated Radar Image Code"
D.A. Stanley and A.J. Terzuoli, Jr.
Air Force Institute of Technology

1450 "Far Zone Scattering by a Flat Plate with Higher Order Effects"
R.J. Marhefka
Ohio State University

1510 "Electromagnetic Scattering By Two Dimensional Periodic Bodies"
K.J. Harker
SRI International

1530 "Screening Properties of the Inclined Strip Grating"
E.E. Kriezis and D.P. Chrissouldis
Aristotle University of Thessalonika,
Greece

1550 **BREAK**

1610 "Comparisons of GO, 1st Order PO, and Numerical Integration of Wagner Surface Fields for the Skywave Scattered by an Electrically Large Gaussian Shaped Ridge"
R.H. Ott and G.J. Burke
Lawrence Livermore National
Laboratory

1630 "Statistics of RadarCross Sections Calculated From Geometrical Optics"
W.B. Gordon
Naval Research Laboratory

1650 "Space Stations ACS Antenna Pattern Analysis"
S.U. Hwu
Lockheed Engineering & Sciences Co

1710 "Geodesics on Convex Surfaces for a GTD/UTD Program"
P.R. Foster
Microwave & Antenna Sys, Malvern,
U.K.

SESSION 10: ELECTROMAGNETIC COMPATIBILITY (122 Ingersoll)
Moderator: Frank Walker

1410 "Investigating Electromagnetic Interference using Symbolic Mathematical Software"
K. Slattery
INVITED SPEAKER

1430 "Numerical Techniques for EMI Source Modeling: A Review of Progress"
T.H. Hubing
University of Missouri-Rolla

1450 "E^3 Modeling and Simulation Tool"
D. Millard, J. Woody and R. Herkert
Georgia Tech

WEDNESDAY MARCH 18

SESSION 10: ELECTROMAGNETIC COMPATIBILITY (CONT)

1510 "Finite Element Analysis Technique for EMC Applications: Lessons Learned"
D.S. Dixon, M. Obara and N. Schade — Naval Underwater Systems Center

1530 **BREAK**

1550 "Optimizing EMI Shield Design with Numerical Techniques"
C.E. Brench — Digital Equipment Co.

1610 "The Use of Finite Element Methods and Closed Form Solutions for Electromagnetic Shielding Employing Conductive Composites"
J. Masi — Western New England College

1630 "Application of the Intrasystem EMC Analysis Program (IEMCAP) for Complex System Modeling and Analysis"
A.L.S. Drozd and G.L. Brock — Kaman Sciences

1650 "Full Wave Calculation of Emissions from Radiating Structures"
S. Daijavad and B.J. Rubin — IBM T J Watson Research Centre

1800 **HAPPY HOUR (NO HOST)** — LA NOVIA TERRACE — HERMANN HALL

1900 **ACES AWARDS BANQUET** — LA NOVIA ROOM — HERMANN HALL

THURSDAY MARCH 19

SESSION 11; FINITE DIFFERENCE TIME DOMAIN (PART 1)

Moderator: Karl Kunz

0800 "Finite and Infinite Elements Applied to Electromagnetic Scattering"
M.S. Towers, J.A.R. Macnab and A. McCowen — University of Wales, Swansea, U.K.

0820 "Transient Scattering from Arbitrary Bodies"
D.A. Vechinski and S.M. Rao — Auburn University

0840 "Finite Element Solvers for Radar Cross-Section (RCS) Calculations"
B. Petitjean, R. Lohner — The George Washington University
C.R. DeVore — Naval Research Lab. Washington

0900 "RCS of Cubes, Strips, Rods and Cylinders by FDTD"
C.W. Trueman, S.J. Kubina — Concordia University
R.J. Luebbers, K.S. Kunz — Penn State University
S.R. Mishra and C. Larose — Canadian Space Agency

0920 "The Analysis of Pulse Propagation in Linear Dispersive Media Using the Finite-Difference Time-Domain Method"
F.J. German and G.K. Gothard — Auburn University

0940 "Finite Difference-time Domain Solution of the Maxwell Equations for the Dispersive Ionosphere"
L.J. Nickisch — Mission Research Corp
P.M. Franke — University of Illinois

1000 **BREAK**

SESSION 3: INVERSE SOLUTIONS

Moderator: Andrew J. Terzuoli, Jr.

1015 "Target Discrimination Based on High-Range-Resolution (HRR) Transient-Radar Returns Computed from Triangular-Patch Aircraft Models"
L.S. Riggs — Auburn University
C.R. Smith — Redstone Arsenal

1035 "Scattered/Internal Intensity for Dielectric Objects with Gaussian Beam Illumination"
E.S.M. Khaled, S.C. Hill and P.W. Barber — Clarkson University

1055 "Solution of Inverse Scattering Problems Using a Method of Moments Approach"
D.C. Jenn — Naval Postgraduate School

THURSDAY MARCH 19

SESSION 3: INVERSE SOLUTIONS (CONT)

1115 "Asymptotic Scattering Center Model and Numerical Solution for Scalar Scattering by Two Soft Cylinders"
R.W. Scharstein — University of Alabama

1135 "Time and Frequency Domain Evaluation of Asymptotic Methods for Computing the Electromagnetic Scattering from Jet Engines"
D.J. Andersch, J.L. Fath and A.J. Terzuoli, Jr. — Air Force Institute of Technology

SESSION 13: FINITE DIFFERENCE TIME DOMAIN (PART 2) — Moderator: Karl Kunz

1155 "A Dedicated VLSI Architecture for Finite-Difference Time Domain Calculations"
J.R. Marek, M.A. Mehalic and A.J. Terzuoli, Jr — Air Force Institute of Technology

1215 "FDTD Calculations of Microwave Absorption in the Human Head"
P.J. Dimbylow — National Radiological Protection Board, U.K.

1235 **LUNCH**

1330 "Computational Trade-offs Associated with the Use of Higher-Order Interpolation Functions in Finite Element Modeling"
A.F. Peterson — Georgia Institute of Technology

1350 "An Efficient Finite Element Analysis of Microwave Cavities and Waveguides Using Edge Elements"
L. Pichon and A. Razek — Laboratoire de Genie Electrique de Paris

1410 "Finite Difference Solution of Dielectric Waveguides Containing Arbitrarily Nonlinear Material"
J.R. Souza — Pontificial Catholic University of Rio de Janeiro, Brazil

1430 "Electromagnetic PIC Modelling in Arbitrary Geometry"
J.W. Eastwood and W. Arter — Culham Laboratory, U.K.

1450 **BREAK**

SESSION 14: MATHEMATICAL METHODS AND COMPUTER ISSUES — Moderator: Pat Foster

1510 "Programming a Portable GUI"

L.W. Henderson — The Ohio State University

1530 "A Graphical Language Interpreter for the Input of Geometrical Data"
A. Genon, A. Nicolet, N. Bamps and W. Legros — University of Liege, Belgium

1550 "Using Commercial CAD Packages to Interface with 3-D EM Modeling Codes"
T.H. Hubing and G.K. Bhat — University of Missouri-Rolla

1610 "Parallelization of the Numerical Electromagnetic Code - Basic Scattering Code (NEC-BSC) for the Intel IPSC/2 and IPSC/860 Hypercubes"
P.R. Work, S. Suhr, G.B. Lamont and A.J. Terzuoli, Jr. — Air Force Institute of Technology

1630 "Virtual Memory Implementation of a 2-D Finite Element Eddy Current Simulation Program on a Personal Computer"
D.E. Madle, A. Mahmood, Q.H. Nguyen, L.D. Philipp and D.J. Lynch — Washington State Univ. at Tri-Cities

1650 "Implementation of EM-WAVETRACER in the Data Transport Computer"
C.F. Lee and R.L. Utzschneider — Wavetracer Inc.

FRIDAY MARCH 20 SHORT COURSES

0830 **SHORT COURSE (FULL-DAY)**
"Using GEMACS to Solve Practical Problems" by Buddy Coffey

0830 **SHORT COURSE (FULL-DAY)**
"Electromagnetic Microwave Design" by James C. Rautio

0830 **SHORT COURSE (MORNING HALF-DAY)**
"The 3D MMP Code for Computational Electromagnetics on PC's" by Ch. Hafner

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**'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 payable to "The Applied Computational ELectromagnetics Society" or "ACES", for the indicated amount.

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- __ Time Domain Modeling of Guiding and Radiating Structures with TLM (full-day 16 March)
- __ Using GEMACS to Solve Practical Problems (full-day 20 March)
- __ Electromagnetic Microwave Design (full-day 20 March)
- __ An Introduction to FDTD and its Applications (half-day 16 March)
- __ Signal Representation and Model-based Parameter Estimation Applications in Computational Electromagnetics (half-day 16 March)
- __ Antenna Radiation in Natural Environments - Special Topics - Special Topics (split-days, morning 16 March and afternoon 17 March)
- __ UTD and its Practical Applications (split-days, afternoons 16 and 17 March)
- __ The 3D MPP Code for Computational Electromagnetics on PC's (half-day, morning 20 March)

ACES reserves the right to cancel a course at any time with full refund.

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- ☐ **Time Domain Modeling of Guiding and Radiating Structures with TLM** (full-day16 March)
- ☐ **Using GEMACS to Solve Practical Problems** (full-day 20 March)
- ☐ **Electromagnetic Microwave Design** (full-day 20 March)
- ☐ **An Introduction to FDTD and its Applications** (half-day, morning 16 March)
- ☐ **Signal Representation and Model-based Parameter Estimation Applications in Computational EM** (half-day, afternoon 16 March)
- ☐ **Antenna Radiation in Natural Environments - Special Topics** (split-days, morning 16 & afternoon 17 March)
- ☐ **UTD and its Practical Applications** (split-days, afternoon 16 & 17 March)
- ☐ **The 3D MPP Code for Computational Electromagnetics on PC's** (half-day, morning 20 March)

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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.

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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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D. Kajfez, softcover, 295 pages, 1986,
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CONTENTS

Ch. 6. Signal flow graphs. Graphical interpretation of linear equations, simplifying flow graphs, Mason's rule, error correction for the automatic network analyzer.

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D. Kajfez, softcover, 351 pages, 1988,
ISBN 0-930071-03-4.

CONTENTS

Ch. 9. Noise. Noise sources, noise models for microwave active devices, source transformations (Hillbrand and Russer's approach). Noise factor in terms of correlation matrix, noise measure.

Ch. 10. Transistor amplifiers. Conditions of passivity and activity, scattering matrix for complex normalization, simultaneous match of a two-port, circle mapping. Stability, balanced amplifier, nonlinear effects.

Ch. 11. Nonlinear oscillators. Van Der Pol's equation, relaxation and quasiharmonic oscillations, output power. Injection locking, large-signal Fourier analysis, Kurokawa's device and load line, load pulling, Wagner's device line measurement.

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Ad deadlines are same as Newsletter copy deadlines.

Place ads with Paul Elliot, Newsletter Editor, ARCO, 1250 24th St. NW, Suite 850, Washington, D.C. 20037 USA. The editor reserves the right to reject ads.