APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

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TABLE OF CONTENTS

OFFICERS' REPORTS

COMMITTEE REPORTS

TECHNICAL FEATURE ARTICLE -

PERSPECTIVES IN CEM

TUTORIAL

EDITORIAL

BOOK REVIEW

ANNOUNCEMENTS

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ACES NEWSLETTER AND JOURNAL COPY INFORMATION

Issue	Copy Deadline
March	January 13
July	May 25
November	September 25

For further information on the ***ACES JOURNAL,*** contact Prof. Duncan Baker, address on page 2.

For the ***ACES NEWSLETTER*** send copy to Ray Perez 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 any version of MICROSOFT-WORD and ASCII files on both IBM and Macintosh disks. On IBM disks we can also read WORDPERFECT and WORDSTAR files. If any software other than MICROSOFT WORD has been used on Macintosh Disks, contact the Managing Editor, Richard W. Adler BEFORE submitting a diskette. If it is not possible to send a Macintosh disk then the hardcopy should be in Courier font only for scanning purposes.

NEWSLETTER ARTICLES AND VOLUNTEERS WELCOME

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

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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.

APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

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James K. Breakall	1995	Ray J. Luebbers	1996	Duncan C. Baker	1997
Dr. Pat Foster	1995	Harold A. Sabbagh	1996	Edmund K. Miller	1997
Frank E. Walker	1995	W. Perry Wheless, Jr	1996	Andrew F. Peterson	1997

OFFICER'S REPORTS

PRESIDENT'S STATEMENT

ACES is known by the company it keeps, so it is no surprise that a number of our members have been recognized by other technical societies. This year the IEEE conferred the status of Fellow to the following ACES members: Linda Katehi, Adalbert Konrad, Ray Luebbers, and Ronald Pogorzelski. All ACESesians join me in congratulating these people for their outstanding achievements.

Ray Luebbers and his committee have put together an excellent program for the Eleventh Annual Review, one which embraces 'low frequency' CEM to 'high frequency' CEM. The subject matter to be discussed ranges from the traditional scattering and radiation problems, so typical of ACES past, to optimization techniques in applied electromagnetics. This area has been of interest to designers of electrical machines, but we see it is being applied to hyperthermia and superconducting accelerator magnets.

I am pleased to see ACES embrace all aspects of computational electromagnetics, for there is no single 'natural' milieu of CEM for ACES. The problems of CEM are many and varied. If one has an interest in solving Maxwell's equations, he should be at home at any frequency, in any environment.

You will note that Ken Siarkiewicz, a long-time dedicated supporter of ACES, has put together an interesting session entitled 'Research and Engineering Framework for CEM'. Ken then did himself proud by releasing $10,000 of MMACE (millimeter-wave, microwave advanced computational environment) funding so that ACES could properly support this session. This tells me two things: first, that Ken is a pretty good man to have on your side, and secondly, that ACES is increasingly being viewed as the preeminent vehicle to expose issues in computational electromagnetics.

ACES is reaching this stature because of the dedication of its members, especially those who volunteer to do its work. When you publish next, think about the ACES Journal or Newsletter as the publication of choice. When you wish to give your profession extracurricular support, consider working for ACES. A lot of people have, and a lot more will.

Enjoy the Eleventh Annual Review.

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SECRETARY'S REPORT

A meeting of the ACES Board of Directors was held by teleconference on 26 October 1994. Participants were: R. W. Adler, Duncan Baker, Jim Breakall, Pat Foster, Ray Luebbers, Ed Miller, Andy Peterson, Hal Sabbagh, Frank Walker, and Perry Wheless. This report is not intended to rehash the minutes of the meeting, but merely to point out some highlights which might be of special interest to the membership.

1. Dick Adler reported that the past two annual conferences have been especially good to ACES from a financial viewpoint, with revenue from the 1994 conference increasing by 18% and there was a 17% increase in attendance.

2. Dick Adler also reported that ACES now has VISA, MasterCard, American Express, and Discover Card capability, so that members may elect to pay their membership fees and registrants for the conference can pay their registration fees using one of these credit cards.

3. It was noted that many new names are turning up in CEM in connection with both NECLIST and the electromagnetics UseNet user group on the Internet. We would like to identify an ACES member with the time and interest to cultivate these apparent newcomers to the field of CEM for membership in ACES.

4. The following motion was passed, which imposes term limits on members of the ACES Board of Directors: *Directors of the Applied Computational Electromagnetics Society may serve only two consecutive three-year terms. Former Directors will become elligible to run for office again after an absence of one year from the Board.*

5. Robert M. Bevensee, Chair of the Historical Committee, has authored *The History of ACES 1985-1994.* We all thank Bob for this fine piece of work on behalf of the Society, and you may expect to see the final manuscript in the *ACES Newsletter* in due time.

6. Pat Foster and Tony Brown reported that the ACES U.K. Chapter has formalized its constitution and is growing in membership. The Chapter is sponsoring a one-day meeting which includes a slate of paper presentations. Interest in Europe is apparently increasing, and a number of European ACES members are visiting the U.K. meeting(s). Visitors are welcomed by the U.K. Chapter, which is the focal point for ACES in the region.

7. Ray Luebbers reports that all is going very well in preparation for the ACES '95 conference in Monterey. Preliminary plans are to continue the popular combined vendor exhibits/poster papers/wine & cheese party on Tuesday afternoon. Please see the full conference agenda which appears elsewhere in this *Newsletter.*

8. Several active members of the COMPUMAG community will be attending ACES '95. Members of the ACES Board of Directors and the ACES Publications Committee will seek to forge a more active cooperative relationship between ACES and COMPUMAG during the course of the conference.

9. There were numerous committee reports. For the most part, the written committee reports were published in the last *Newsletter* (vol. 9, no. 3, November 1994).

This was the first Board of Directors meeting to be conducted by teleconference. The sense of the Board was that the meeting was efficient and effective, and that teleconferencing is a practical alternative for the conduct of ACES business. The annual Board of Directors meeting and Meeting of Members at the conference will continue unchanged.

Submitted by:
W. Perry Wheless, Jr.
ACES Secretary
13 January 1995.

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 on Wednesday 22 March 1995 , in 102 Glasgow Hall at the Naval Postgraduate School, Monterey, CA. The meeting is scheduled to begin at 7:30 AM PST for purposes of:

1. Receiving the Financial Statement and Treasurer's Report for the time period ending 31 December 1994.
2. Announcement of the Ballot Election of the Board of Directors.
3. Summary of the activities of incorporation.
4. Modifications to the Bylaws that have been approved by the Board of Directors at the March 1994 meeting in Monterey, CA. The proposed change would create a new section, Section 4, under Article 7 and deal with specific committee meeting and reporting requirements, as follows:

ARTICLE 7. COMMITTEES

SECTION 4. SPECIFIC COMMITTEE MEETINGS AND REPORTING REQUIREMENTS

All Committee Chairs (for both Permanent and Membership Activity Committees) shall convene their Committees with sufficient frequency to appropriately consider and act on all Committee business; each Committee shall have a minimum number of annual meetings stipulated in its Charter. Meetings can be by telephone or in person. Official meeting reports shall be submitted to the Board of Directors for publication in the ACES Newsletter. A minimal formal report of "no activity" may be acceptable in warrantable cases. The Secretary will forward all reports accepted by the Board to the ACES Newsletter Editor-in-Chief for publication in the next Newsletter.

By order of the Board of Directors
Perry Wheless, Secretary

ANNUAL REPORT 1994

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 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 1994, the paid-up membership totaled 450, with approximately 32% of those from non-U.S. countries. There were 15 students, 65 industrial (organizational) and 370 individual members. The total membership has decreased by 7% since 1 January 1994, but non-U.S. membership has increased by 22%.

Perry Wheless, Secretary

ANNOUNCEMENT ON DUES INCREASE

In accordance with a 5-year financial plan adopted by the Board of Directors in July 1992, for the purpose of maintaining ACES as a financially solvent non-profit corporation, the annual membership dues will increase by $5, effective 1 April 1995, and will increase by an additional $5 each year.

MEMBERSHIP RATES EFFECTIVE 1 APRIL 1995

AREA	INDIVIDUAL SURFACE	INDIVIDUAL AIRMAIL	ORGANIZATIONAL (AIRMAIL ONLY)
US & CANADA	$70	$70	$120
MEXICO,CENTRAL & SOUTH AMERICA	$73	$75	$120
EUROPE FORMER USSR TURKEY SCANDINAVIA	$73	$83	$120
ASIA, AFRICA MID EAST, PAC RIM	$73	$90	$120

1994 FINANCIAL REPORT

ASSETS

BANK ACCOUNTS	1 JAN 1994	31 DEC 1994
MAIN CHECKING	24,711	43,650
EDITOR CHECKING	2,196	2,373
SECRETARY CHECKING	2,889	3.952
SAVINGS	304	311
CREDIT CARD	0	5,035
CD #1	11,420	11,776
CD #2	11,420	11,776
TOTAL ASSETS	$52,940	$78,872

LIABILITIES:	0
NET WORTH 31 December 1994	$78,872

INCOME

Conference	87,579
Publications	5,910
Membership	28,294
Software	2,440
Interest & misc.	5,166
TOTAL	129,389

EXPENSE

Conference	49,630
Publications	21,039
Software	846
Services (Legal, Taxes)	1,472
Postage	14,492
Supplies & misc.	15,981
TOTAL	103,460

NET INCREASE FOR 1994	$25,929

In 1994 we enjoyed a net gain of $24,879. This year the net increase was $25,929, which came from increased conference income. Even though membership/subscription fees increased by $5 each, income from memberships dropped 3%, due to a 7% drop in membership numbers.

Andrew Peterson
Treasurer

PERMANENT STANDING COMMITTEES OF ACES INC.

COMMITTEE	CHAIRMAN	ADDRESS
NOMINATIONS	Stan Kubina	Concordia U/ECE Dept. 7141 Sherbrooke St. West, Montreal, Quebec, CANADA , H4B 1R6
ELECTIONS	Doug Werner	Penn State U/ARL P.O. Box 30 University Park, PA 16804
FINANCE	Andrew Peterson (Acting)	Georgia Institute of Technology School of ECE Atlanta, GA 30332-0250
WAYS & MEANS	Frank Walker	Boeing Defense and Space Gp. P.O. Box 3999, MS 82-11 Seattle, WA 98124-2499
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AWARDS	David Stein	Consultant PO Box 169 Linthicum Heights, MD 21090

MEMBERSHIP ACTIVITY COMMITTEES OF ACES INC.

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SOFTWARE EXCHANGE	Randy Jost	SRI International 12510 Cliff Edge Dr. Herndon, VA 22070
SOFTWARE PERFORMANCE STANDARDS	Donald Pflug	Rome Laboratory/ERST 525 Brooks Rd. Griffiss AFB, NY 13441-4505
AI & EXPERT SYSTEMS	Wayne Harrader	Ball Communications PO Box 1235 Broomfield, CO 80020
HISTORICAL	Robert Bevensee	Boma Enterprises PO Box 812 Alamo, CA 94507

ACES PUBLICATIONS COMMITTEE

There are several items of good news and a little bad news from Publications this time around.

Things are running smoothly with the *ACS Newsletter*. Ray Perez has done a commendable job of establishing regular 'departments', and that approach seems to be holding up well. However, unsolicited contributions (articles, that is) to the *ACES Newsletter* from the members have been less than we would like to see, and there is room for considerable improvement in that area. The Department Editors have an advantage over the *ACES Journal* with regard to stirring up articles on short notice, because the *ACES Newsletter* items don't have to go through the peer review process and can be somewhat more informal in format. The Editors are having to work too hard for material now, though, considering that ACES has hundreds of members practicing CEM!. Most, if not all, have an interesting study, experience, or observation which would make a good report to the *ACES Newsletter*. We urge you to convert your article ideas into hardcopy and get them in the mail!

The new format guidelines instituted by Duncan Baker with the *ACES Journal* have changed the appearance of the publication (most seem to think for the better) and have cut the page requirements for a given amount of material by approximately one-third. This has the effect of cutting the publications cost to ACES, or freeing up pages so that more papers can be published, according to your point of view. The *ACES Journal* was allocated 515 pages for publishing papers in 1994. Thanks mostly to Duncan's format work, we actually published about 450, and so the budgetary request of Publications for 1995 and 1996 is to hold the line at 515 for the next two years. For 1995 and 1996, we plan to continue with three Journal/Newsletter issues each year, which allows us to save a substantial amount of postage by consolidating the mailings.

We have made changes to encourage and favor ACES members in the *ACES Journal* (for example, members get twelve free pages for their papers versus a limit of eight for non-members) but, again, the contributions from ACES members have been disappointing in number. We have acted to address a perception that many non-members were 'taking advantage of ACES' to effectively build up their resumes at our expense. Now the membership needs to respond by thinking of the *ACES Journal* first when it comes to submitting your next refereed paper. Several people have told me they started going elsewhere when the available pages were inadequate in past years and there were some relatively long delays with the *ACES Journal*. These problems have been substantially rectified at this point, so you are invited to come back 'home'. While we emphasize availability and service to ACES members, we are working on all fronts to secure high-quality papers that are informative and helpful to our readers.

So. basically, the good news is that opportunities have expanded in ACES publications, while holding costs flat, and the bad is that the membership is not availing itself of these opportunities very well. If we can help with your publishing questions and needs, feel free to call on us at any time!

W. Perry Wheless, Jr.
ACES Editor-in-Chief / Publications Chair
e-mail wwheless@ua1vm.ua.edu

ACES NOMINATION'S COMMITTEE

This year the terms of Board members Jim Breakall, Pat Foster and Frank Walker expire. Their service to our society over the years is much appreciated. Jim Breakall and Frank Walker are not able to let their names stand for another term and they will try to redirect their available time to other important areas of ACES activity. We are fortunate that Pat Foster has agreed to let her name stand as one of the candidates for another term of office.

In addition, Adalbert Konrad and Todd Hubing have agreed to let their names be put forward as candidates. All have exceptional talents and enthusiasm to offer our society in the role as members of the Board of Directors.

Thus, by a mail ballot, you will be asked to make a selection of the three candidates that you favor for the three positions that become available this year. There is also provision on the ballot for write-in candidates. Please give it some thought and **do** exercise your vote. It keeps our society healthy and progressive. The Nomination's Committee also welcomes suggestions for candidates for next year's election. There is always a pressing need to identify members who are prepared to devote some time to the many important aspects of ACES work that needs to be promoted, organized and carried out in order to maintain our leading role in Computational Electromagnetics and of service to our community.

Happy New Years to you all!

Stan Kubina
Chairman

SOFTWARE PERFORMANCE AND STANDARDS COMMITTEE

A set of antenna pattern and isolation measurements has been completed on the Rome Laboratory Transformable Scale Aircraft-Like model (TSAM). TSAM is a specialized aircraft-like test article constructed at Rome Laboratory to provide antenna measurements on a platform of controlled complexity and variable configuration in support of CEM code validation. Current measured data includes principal radiation pattern cuts and antenna isolation at selected frequencies of each of six monopole antennas mounted at various TSAM fuselage locations for the full-up TSAM and fuselage-only TSAM. It is planned to make such measurements available to ACES members through a suitable ACES mechanism.

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A REPORT ON 1994 IEEE / SAIEE 8TH SOUTH AFRICAN SYMPOSIUM ON ANTENNAS AND PROPAGATION AND MICROWAVE THEORY AND TECHNIQUES

The local South African Chapter of the IEEE and the South African Institute of Electrical Engineers jointly sponsored this symposium in Stellenbosch, South Africa on October 3, 1994. 49 papers/posters were presented. It was held concurrently with three other IEEE sponsored symposia from Oct 3-Oct 4, on the campus of the University of Stellenbosch:

> CONSIG-94, the seventh symposium on theoretical and practical work in communications and signal processing, sponsored by the IEEE Signal Processing Chapters of South Africa.
>
> SS&C-94, the first symposium on small satellites and control theory and practice, jointly sponsored by the IEEE Control, and Aerospace and Electronic Systems Chapter of SA.
>
> COMPSYS-94, the first symposium on computer systems, sponsored by the IEEE Computer Chapter of SA.

All told, 427 delegates attended the symposia, with 132 attending AP/MTT, 172 COSMIG, 49 SS&C, and 74 COMPSYS. This year was our engineering faculty's 50th birthday, and the symposia were hosted as part of the celebrations. The symposia overlapped with the annual Stellenbosch arts & Crafts Festival, and a number of delegates enjoyed some of the entertainment on offer, including street festiivals and musical performances.

The AP/MTT Symposia have their roots primarily in the upsurge in defence spending in South Africa in the 1980's, although papers presented at this and previous symposia have addressed a variety of other areas, including electromagnetic propagation in mines, rain attenuation characteristics, new HF propagation models, and optical systems to mention only a few, and a substantial amount of basic research on computational electromagnetics has also been reported. The first symposium was held in 1993, and subsequent symposia were held in 1986, 1988, and 1990. Since 1990 the symposium has been an annual event. A more detailed history of the symposia can be found in a companion report that I have written for the IEEE AP Magazine. Since the first symposium in 1983, computational electromagnetics has been a topic of great interest at these conferences, and increasingly CEM methods are being routinely used for various electromagnetic problems, although it is notable that the South African AP/MTT industry has still not widely embraced CEM tools.

A variety of well-known figures in the AP community have been invited speakers, including Peter Clarricoats, Ed Miller and Jim James. This year, we invited Ted van Duzer, who presented a talk entitled "Superconducting Analog and Digital Microwave Electronics".

As mentioned above, a report on the Antennas and Propagation activities in general has been submitted to the IEEE AP Magazine, and I would like to highlight the Computational Electromagnetics (CEM) activities in this article. The main centres of CEM activity in the country at present are the Universities of Stellenbosch, Pretoria and the Witwatersrand, with perhaps the widest range of CEM problems currently being addressed as part of the activities of our antenna and electromagnetics group at Stellenbosch, headed by John Cloete.

Our Stellenbosch group consists of John, Keith Palmer and myself on the faculty, with at present seven full-time doctoral tudents (of whom four will have graduated when this report is published), four full-time Master's students, and workshop and computer support. Our CEM interests centre on antenna applications, but also include RCS predictions and recently the theoretical characterization of artificial (chiral) media, and we use a wide range of discrete computational methods, viz. MoM, FEM/BEM and FDTD. In addition, theoretical work is in progress on diffraction theory. CEM oriented papers that were presented included: error estimates for FEM/BEM work (Frans Meyer and myself); the RCS of microstrip patches (Caroli Scholtz and John Cloete); ground penetrating radar (GPR) antennas (Johann van Tonder and John Cloete); the computation of chiral parameters using the MoM (Isak Theron, myself and John Cloete); and pattern prediction for the radiation patterns of the VHF antennas of our department's micro-satellite SUNSAT - due for launch as auxiliary payload by NASA in early 1996 (Nico-Jan Bornman and

Keith Palmer). The FEM/BEM error estimate work is especially interesting because for the first time, we have beenable to make quantitative predictions of errors for a full-wave electrodynamic formulation. This has also been combined with a mesh-adaptive approach. The GPR work is of very considerable interest and application to the mining industry here - using the Sommerfeld formulation, GPR antennas are now being simulated with a view to increasing the effectiveness with which the ground penetrating beam is launched. This work is beind done in cooperation with Mike Inggs' Remote Sensing Group at the University of Cape Town. The computational chiral media work is in progress and is closely related to other theoretical work on the constitutive parameters of chiral media by John Cloete and Roger Raab (Univ. of Natal). The work promises to permit the accurate prediction of chiral media parameters, and is backed up by fabrication and measurement facilities. The error estimate, GPR and computational chiral work is all doctoral-level research. Other CEM work in progress at Stellenbosch is a combined mode-matching and method-of-lines procedure (Petrie Meyer); this work is part of the microwave group's efforts.

The group at the University of the Witwatersrand consists of Andre Fourie, Derek Nitch and Ofer Givati. They have been putting most of their efforts into a new object-oriented version of NEC2, with additional facilities. They presented work on the fast sparse iterative method for NEC2, and compared this with other well known iterative methods, especially the conjugate gradient method. Andre Fourie's presentation on this won them a prize. They have also been involved in antenna placement studies on aircraft and the design of biconical antennas, and presented papers on this work.

The University of Pretoria group, led by Duncan Baker (who is very well known in ACES circles, and is presently serving as Editor-in-Chief of the Journal) and Johann Joubert, reported work on model based parameter estimation (de Beer and Baker), Prony's method (Roberts and McNamara - the influence of Ed Miller's visit to South Africa in Feb-March this year is obvious)!, and microstrip-waveguide interconnects (Hildebrand and McNamara). There is also some interesting work on radar target recognition in progress at Pretoria that was reported at the CONSIG symposium. (This work is being done mainly by Wimpie Odendaal, recently returned from a post-doctoral stint at Ohio State, and Liesbeth Botha of the pattern recognition group at Pretoria). This work is measurement, not CEM, based. They are fortunate to have an excellent compact range at their disposal. Derek McNamara and Danie Janse van Rensburg were previously at the University of Pretoria and both were very active in the CEM community; both emigrated to Canada during the year and were sorely missed at this symposium.

As mentioned, the level of industry participation was very impressive. Work reported by industry was almost entirely on antennas or microwave devices; the former is covered in detail in the companion IEEE AP Magazine report. An exception was Stellenbosch based start-up companies Nabla-E (Andre Bezuidenhout) and Lambda-F (Marius Conradie), who reported work on HF and HF antennas, with extensive use of NEC2, and won a prize for one of their presentations.

There was also an impressive number of exhibitors, mainly in the hardware field. Hewlett Packard were present in force and via local agents, High Performance Systems, provided generous financial support for the symposium. Local companies Avitronics and Plessey-Tellumat backed up their formal presentations with an impressive display of antennas.

A full program listing all the papers and authors' addresses may be obtained by e-mail from me (at davidson@firga.sun.ac.za); I still have some copies of the 249-pg A5 format proceedings available fairly cheaply proceeds to the benefit of the local AP/MTT chapter!

I would like to thank everyone involved in the steering committee for their sterling work in organizing this symposium. The AP/MTT steering commitee comprised PW van der Walt (Chairman), myself, Willie Perold, Garth Milne, Petrie Meyer, Howard Reader and Neels Britz. The AP/MTT technical program committee consisted of myself (chairman) and John Cloete. The Proceedings were edited by Johann de Swardt.

In conclusion, this is an excellent opportunity to invite overseas authors to consider participating in the technical program at future symposium, or at least consider attending. From next year, the symposium proceedings will be registered as an official IEEE document. For some years, we had problems regarding copyright which precluded this, but these have now finally been resolved. South Africa is well and truly back on the map nowadays and our country has a lot to offer aside from symposia. There is, of course, the Kruger National Park, our famous game reserve the size of Israel, but the country also has great beaches, mountains, wine farms, etc.

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MODELER'S NOTES

Gerald J. Burke

Modeler's Notes for this issue will cover NEC–4 developments, a revised NEC package for the Macintosh and a performance report on the Power Macintosh. There has yet to be any actual modeling discussed here, but I have not heard from anyone with experiences, good or bad, and the modeling that I have been doing lately has not produced anything of general interest. Some good news on NEC–4 is that the question of availability has finally been resolved. The Army and Navy have agreed that it no longer is Military Critical Technology and is only subject to export restriction. U.S. citizens (or "U.S. Persons") in this country can now obtain it directly from us (contact: G. J. Burke, L-156, Lawrence Livermore National Labs., P.O. Box 5504, Livermore, CA 94550) by signing an agreement not to distribute it further and accepting the collaboration agreement for release as a "code in development." Foreign requests must still be submitted by the requesting country's embassy through U.S. Army HQDA (DAMI-CIT) and directed to Commander, USA ISEC, ASQB-OSE-TP (Attn.: Sandy Daniel), Fort Huachuca, AZ 85613-5300. I do not know if they will be any more liberal in considering such requests, but the code is certainly well behind the state of the art in computational modeling by now.

A minor problem has been found in the double precision version of NEC4.1 that should be corrected in codes already in use. This came from a discovery that when a loop was generated with the GR command to use symmetry and modeled at successively lower frequencies, the double precision NEC–4 failed at a considerably higher frequency than double precision NEC–3. The problem was traced to the value of 2π used in the Fourier transform of the azimuthal modes in subroutine FBLOCK. The value was entered to eleven places, but without a "D0", so it was truncated to single precision. This value is critical for small loops modeled with symmetry, so it should be made double precision with a few more digits added, making the statement at line 93 of subroutine FBLOCK: PHAZ=6.2831853071796D0/NOP. Single precision values for 2π in several other places in the NEC4D code can also be changed to double, but FBLOCK is the only point where it has been found to be critical. Subroutine CONSET was intended to set constants used throughout the code, but it has not been used consistently. I do not like to use common blocks in routines like Bessel functions that should stand alone, but some of the geometry routines should get constants from COMMON/CONSTN/ set by CONSET, and I will try to clean this up.

In the July 94 Newsletter some running times were given for NEC–2 compiled with the Absoft MacFortran II compiler and the older MacFortran/020. Previously I had been using the 020 compiler since it compiles much faster than the newer MacFortran II. However MacFortran II produces significantly faster running code, particularly when optimized for a Mac Quadra. We have now set up NEC–2 and NEC–4 packages compiled with MacFortran II for people using Macs who do not have a Fortran compiler. These packages include the source code and executable files for single and double precision, 300 and 600 segments maximum, and compiled for a 68020/30/40 or optimized for 68040. The plotting programs (NECPLOT, ZPLOT and PATPLT) are still compiled with MacFortran/020 since I have not yet set up a version of DIGLIB for the MacFortran II compiler. The codes can be compiled for other segment limits on request. The single precision code for 1200 segments requires 12.2 MB of memory, so it will run on a Mac with 16 MB total memory.

Since the 7/94 column I have upgraded my Macintosh Quadra 650 with a Power Macintosh Upgrade Card from Apple, and now have some hard numbers for the NEC running times estimated before. The upgrade card is available for around $499 by mail order, which seems like a bargain for the performance boost it offers. Power PC accelerators for various Macintosh models are also available from third-party vendors at a considerably higher price, and they can offer a higher clock speed and the option to use 64-bit RAM if you have the money to load them up. But the price of accelerators can be almost as much as for a new Power Mac. The upgrade card just doubles the clock speed of the motherboard, so the 33 MHz Quadra 650 becomes a 66 MHz PPC. Apple has included a 1 MB cache on the card to help overcome the bottleneck of the processor accessing memory on the motherboard.

Unlike my previous experience with an accelerator, the installation of the PPC upgrade card went smoothly, and as an Apple product it comes with Apple's blessing to open the cover to install it (but not to install RAM). The card just plugs into the PDS slot. Then you install a software patch to the system, turn on the card in the control panel and restart. The card can be turned on and off from the Control Panel, and you then have to shut down and restart for the change to take effect. In the PPC mode the time to start up when the Mac is first turned on increased to 64 sec. from 34.5 sec. for the Quadra, and the memory required by the System went from 3077 KB for the Quadra to 4375 KB for the PPC. The startup time with the card installed but turned off was 38 sec. Of course these times depend on a number of factors, such as the inits installed.

Being able to switch between PPC and Quadra modes seems like a good thing at this time, with lots of 68K software still in use. The PPC system, either with the upgrade card or a new Power Mac, will run 68K software in emulation, but it is slower than on a Quadra and the emulation does not include a FPU. Typesetting a moderate sized document in the Textures TEX program from Blue Sky Research was about fifty percent slower in emulation on the 66 MHz Q650/PPC than running in Quadra mode at 33 MHz. Blue Sky does have a new Version 1.7 of Textures with native PPC code, but I have not ordered it yet. The time on a Quadra 650 is probably about four times faster than on a typical Mac II, so it is still quite usable in either Quadra or PPC mode. For word processing or drawing programs it probably will make little difference whether the code is native or emulated, except for heavy-duty users. However, the situation is different for programs that use floating point arithmetic. Since the 68K emulation in the PPC system does not include the FPU, running NEC for 68K on the PPC will cause an immediate crash. There is a shareware program called Software FPU ($10 fee, John Neil & Associates, P.O. Box 2156, Cupertino, CA 95015) that will emulate a FPU on 68K systems that do not have one, and thus can provide an emulation of an emulated FPU on PPC systems. For usable speed you need to send in $20 and get the native PPC version of Software FPU, and it still is not fast enough for practical modeling work. Solving a 100 segment problem with the NEC2S code compiled with MacFortran II for 68K systems took 583.6 sec. to fill the matrix and 370 sec. to factor on the Q650/PPC with the PPC-native Software FPU. This is 500 times slower in filling and 1500 times slower in factoring than with native PPC code. But Software FPU does permit the use of the old utilities, such as plotting programs, until they are converted to PPC code. Running code compiled specifically for a 68040 (–N40 option) with MacFortran II will still cause a crash with Software FPU.

The best results are obviously obtained with native PPC software. So far I have bought native versions of Mathematica, Fortran and Stuffit, and they seem to provide the expected factor of 4 to 8 increase in speed over the Quadra 650. Running Mathematica version 2.2.2, the time to plot Bessel functions $J_n(x)$ for orders 0 through 5 and x from 0 to 20 was 12.4 sec. on a Mac 8100/80, 14.4 sec. on the Q650/PPC, 125.8 sec. on the Quadra 650 and 291.3 sec. on a Mac IIci. The time for the Simplify command to operate on a fairly complicated expression was 4.4 sec. on the 8100/80, 5 sec. on the Q650/PPC, 26.7 sec. on the Quadra 650 and 191 sec. on the Mac IIci. Also Mathematica started up faster, taking 8 sec. and 10 sec. to start the Front End and Kernel, respectively, on a Mac8100/80, 6 sec. and 18 sec. on the Q650/PPC, 7 sec. and 21 sec. on the Quadra 650 and 21 sec. and 47 sec. on a Mac II ci. The new Stuffit Deluxe Version 3.5 running on the Q650/PPC was only about twenty percent faster than the old one on the Quadra 650, but more than twice as fast as the old version running in emulation on the PPC. These were times to stuff or expand and delete the original file, so over half of the stuffing time was disk activity.

For a Fortran compiler Absoft Corporation seems to be the choice at this time. Their Power Macintosh F77 SDK (Software Development Kit) sells for $699 or $499 to present users of MacFortran II. Absoft released their Fortran compiler for the Power Macintosh shortly after Apple started selling Power Macs, and it seems to be a good product and relatively bug-free considering its recent origins. Language Systems is shipping a "late-beta" version of their PPC compiler and expect to start shipping the final version on January 16. The price of $695 includes their PPC and 68K compilers which run in MPW. An article in MacWeek in May 1994 had said that Motorola would release a Fortran compiler for the Power Macs in July 94 for a price of $349, and that they would take advantage of their inside knowledge to optimize the code. However, the compiler has yet to appear. All that I could get from Motorola was that they still have plans for a Power Macintosh compiler, but they would not say what those plans are. Absoft plans to release a Fortran 90 compiler, developed together with Cray Research, sometime this year and also has Fortran compilers for DOS and Windows NT.

The Absoft Power Macintosh F77, like their MacFortran II for 68K Macs, runs in the Macintosh Programmer's Workshop (MPW) which includes an editor and many utilities such as Catenate, Compare and Search. MPW may take a little getting used to for regular Mac users. The commands are UNIX-like, with lots of –a –b –c options, but every command can also be generated with a dialogue box that includes all of the options and generates the command line as boxes are checked. The command can then be executed from the dialogue box or pasted into the worksheet and executed from there. The documentation for MPW is offered at an extra cost, but is not needed for most users. The Absoft manual includes a summary of the most commonly used commands, and MPW has a very good help package. The SDK includes the compiler, debugger, libraries and various examples of code to access the Macintosh Toolbox routines. There is also a make-file builder, which is needed since the compiler cannot handle large codes in a finite amount of RAM unless the subroutines are split into separate files. Even when split the Linker takes about 18 MB to link NEC, so you need enough RAM in the Mac. The compiler accepts ANSI Standard Fortran 77 and also includes a number of extensions for compatibility with VAX/VMS, IBM and other popular Fortrans. It includes Structure and Pointer statements and a provision to pass arguments by value, since these are needed to access the Mac Toolbox.

As a first test of the compiler I tried compiling NEC–2. The compilation went smoothly, although it takes about 30 minutes for the Power Mac, compared to 10 minutes with the older MacFortran II on the Quadra 650. Absoft is working on reducing the compilation time, so this may be improved in the next release. No changes in the code were needed, such as substituting for the DREAL function as Dick Adler has reported with some DOS compilers. The optimization bug encountered in the MacFortran II that required a –z option for subroutine HINTG (see 11/94 Newsletter) does not occur in the Power Mac F77. The only bug encountered in compiling NEC–2 was in the Open statement with a null file name, OPEN(UNIT= *n*, FILE='') that, as in MacFortran II, can be used to obtain a dialogue box for opening files. It gives the dialogue box all right, but if you click CANCEL it hangs the system, requiring a restart. There is a subroutine STDFIL in the Examples folder that gives a dialogue box in which CANCEL works correctly. Absoft will fix this problem, but they said that it may take a while since it cannot easily be patched. NEC–2 seems to run all of the examples correctly and at an impressive speed as will be discussed later

The next project was to compile NEC–4, and this revealed a more serious bug in the compiler. The single precision NEC4S compiled without any error messages and correctly ran the examples that did not use the Sommerfeld ground model. However, cases with ground produced the message

STRAC: AN ERROR OCCURRED IN FILLING THE INTERPOLATION TABLES, IR,IZ= *nn nn*

This was from from subroutine STRAC that does an iterative solution for the angle of a ray passing through the air-ground interface between a source and evaluation point. The problem was traced to inaccurate values being returned by the SQRT function for complex arguments with a small imaginary part. When the imaginary part of the argument is about 10^{-3} of the real part the result of SQRT has a relative error of 10^{-5} and the relative error in the small imaginary part is 0.02, which is considerably worse than single precision ought to be. For arguments with smaller imaginary parts the square root becomes real. As a result the iterative solution in STRAC was unable to converge to the requested relative error of 10^{-5}, resulting in the error message. This same error would occur in NEC–3, but not in NEC–2. Sometime in the past two years I have received a call from someone with the same error message as they were installing NEC–3, and they reported that it went away with double precision. It would be interesting to know what compiler they were using, since it was well before the Power Macs came out. The only answer that I could give then was that it should not happen, and my records are not good enough to trace the call. In single precision there was an easy way around the problem, since the Absoft compiler has an option –N2 to "use double precision transendentals." Using this option gave accurate square roots for single precision and codes seemed to run a little faster with –N2 than without it. When compiled with –N2 the single precision NEC–4 ran all of the examples correctly, including ground.

Next I tried compiling the double precision NEC4D, and again it compiled without problems and ran the examples without ground correctly. However, some of the ground cases produced results of NaN (Not a Number). Again the problem was traced to the SQRT function. For small imaginary parts, less than about 10^{-8} of the real part, the result became inaccurate, but also in some cases returned an imaginary part that printed as NaN which propagates through the solution. If you take a complex number like DCMPLX(1.D1, 1.D−14) and increment the real part in steps of 1.D−15 the square root gives about 23 valid (but not too accurate) results followed by 2 NaNs in a repeating pattern. One way around this would be to write your own square root function. For the small imaginary parts an accurate result can be obtained from the square root of the real part followed by one iteration. But hopefully Absoft will fix SQRT soon.

Table 1. Times in seconds for NEC2S/D to fill and factor the impedance matrix. Total is the time printed at the end of the output and included computation of currents but no radiated fields.

Computer	Prec.	No. Seg.	Fill	Factor	Total
Mac Q650	S	300	34.28	30.48	67.32
Mac Q650	S	600	124.63	280.07	412.37
Mac Q650/PPC	S	300	9.00	4.80	15.27
Mac Q650/PPC	S	600	32.63	104.63	139.72
Mac Q650/PPC	S	1200	105.90	1072.43	1185.75
Mac 8100/80	S	300	6.37	2.92	9.80
Mac 8100/80	S	600	23.45	80.83	105.75
Mac 8100/80	S	1200	74.07	783.63	862.93
Mac Q650	D	300	41.63	35.17	79.57
Mac Q650	D	600	148.70	285.95	442.60
Mac Q650/PPC	D	300	9.42	8.05	18.80
Mac Q650/PPC	D	600	33.63	138.57	175.18
Mac Q650/PPC	D	1200	—	—	—
Mac 8100/80	D	300	6.80	5.85	13.52
Mac 8100/80	D	600	24.85	91.15	117.65
Mac 8100/80	D	1200	82.25	933.73	1021.90
DEC-3000/400	S	300	4.26	2.52	7.06
DEC-3000/400	S	600	15.44	32.17	48.39
DEC-3000/400	D	300	4.94	4.28	9.59
DEC-3000/400	D	600	36.77	679.78	718.61

Running times for NEC–2 in single (S) or double (D) precision for wire models with 300, 600 and 1200 segments are shown in Table 1 for several computers. In each case the model was constructed from a straight wire on the z axis with length of 1λ, radius of $10^{-3}\lambda$ and 10 segments. A GM command was used to make nine more copies of this wire with a lateral displacement of 0.2λ in the x direction to get 100 segments. Then a second GM command with a displacement of 0.2λ in the y direction made two copies for 300 segments, five copies for 600 segments, etc. The description in the July 94 Newsletter was not quite correct, and the configuration does have a small effect on the fill and factor times. The Mac codes were compiled with Absoft MacFortran II, version 3.2 with –N40 option for the Quadra 650 and with the Power Macintosh F77 compiler for the Q650/PPC and Power Mac 8100/80. The –N9 option for frequent interrupt checks was not used, since it slows down the code somewhat, and the –O optimization was used in all cases. I could not run the 1200 segment double precision case on my Quadra 650/PPC since it did not have enough RAM. The slow speed for double precision 600 segments on the DEC Alpha is apparently due to page faulting, and I need to have a talk with our system manager.

The PPC card is seen to produce about a 4 to 6 fold increase in speed over the Quadra 650 with the greatest increase for factoring the matrix with 300 segments. However, when the order of the matrix is doubled to 600 the factoring time increases by a factor of 21.8 on the Q650/PPC and by 27.7 on the Mac 8100/80, rather than the expected factor of 8. From 600 to 1200, and presumably higher if you have enough RAM, the factoring time increases at a rate closer to N^3. The large increase in factoring time from 300 to 600 segments may be related to memory access time, since if the 1 MB cache on the PPC upgrade card is available for data the entire 300 × 300 complex matrix could be sucked into the cache. The 8100 comes with a 256 KB cache and can be upgraded to 512 KB, but I do not know how much was in the one used here. Scaling the factor and fill times would indicate that the Mac 8100/80 should run a 2000 segment problem in about 1 hour and 16 minutes, and the new 8100/100 should cut that to about one hour.

The difference between the Q650/PPC and 8100/80 is somewhat greater than the difference in the clock speeds for both filling and factoring, as might be expected with the RAM on a separate board from the processor card. The October or November MacWorld had a report that a problem in the version of the 601 PPC processor used on the upgrade card prevented most applications from using the transcendental functions on the FPU, resulting in slower performance. If that was the case it should show up in slower fill times on the Q650/PPC, which is not apparent. I did not know that the FPU had transcendental functions, but if that is the reason for the wrong results from SQRT, Intel might be very interested in hearing about it.

As mentioned before, the Mac codes used for Table 1 were compiled without the option –N9 for "frequent Command-. checks." This produces the fastest code, but if you want to stop the run before it finishes you probably will have to reset the Mac, since it only checks for interrupts during I/O operations. If the code is compiled with the –N9 option then execution can easily be terminated by typing Command-. and the code will also run in the background while another operation, such as editing, is going on. Real multitasking on a Mac! Once the code is compiled with –N9, the frequency of interrupt checking can be change by running a utility on the executable file, but 10/60 second checks provides good response in using an editor or word processor and results in about 10 to 15 percent slower NEC speed. When I ran NEC while simultaneously typing as fast as I could in an editor it slowed the NEC run by about another 10 percent.

Another factor of interest is the size of the program. The code for a RISC processor would be expected to be larger than for CISC since multiple operations would be needed for the missing processor instructions. However, the 600 segment NEC–2 for the PPC required 3.47 MB and 6.42 MB for single and double precision, respectively, while the 68K code required 3.5 MB and 7 MB. The Power Mac had virtual memory set for 1 MB more than the installed RAM as recommended. This allows programs to run in less memory, since the system has the freedom to do some swapping if needed. A good feature of the PPC compiler is that it sets the memory requirement of the executable file during linking, while with the 68K compiler you have to set it by trial and error. The disk space taken by the PPC NEC–2 was 432 KB and 448 KB for single and double precision, compared to 480 KB and 488 KB for the 68K code.

A comparison of speeds of the Q650/PPC and a Mac 7100/66 would be interesting, but I will have to wind this up to meet the shortened deadline. Certainly the computation speeds available from the Power Macintoshes, and probably similar speeds from Pentium systems, make it possible to do some serious modeling work on affordable PCs.

Finite-Difference Time-Domain Methods for Helicopter Antennas and EM Field Penetration*

Invited Paper

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Abstract

The application of the finite-difference time-domain (FDTD) method to helicopter antennas and electromagnetic penetration are presented in this paper. The computed input impedance and gain of an HF towel-bar antenna mounted on the surface of the Apache helicopter are compared with available measurements. Also, penetration into a partially conducting/partially composite helicopter airframe is examined. A preprocessing geometry program used in generating the FDTD geometry by using solid surface helicopter geometries is also presented.

I. Introduction

The Advanced Helicopter Electromagnetics (AHE) Program was initiated at Arizona State University on January 1, 1990, to develop numerical, analytical and measurement methods for the analysis of helicopter electromagnetics. The numerical methods pursued under the AHE program include the Finite-Difference Time-Domain (FDTD) method [1] and the Moment Method (MM) [2]. The AHE program uses computer codes written using the MM, such as the Numerical Electromagnetics Code (NEC), Finite Element Radiation Model (FERM) code, and Electromagnetic Surface Patch (ESP) code [2]. In this paper, the AHE program research conducted using the FDTD method is reviewed and several applications of the method in modeling antennas and penetration are outlined.

Two of the most critical steps in modeling radiation by antennas mounted on helicopters are the antenna feed modeling and the accurate representation of the helicopter structure. Different ways to model the feed of a monopole mounted on a ground plane were described in [3]. One approach is to force the four tangential components of the magnetic field surrounding the feed of the monopole to a time function. An alternative approach is to use the four radial electric fields at the feed point as described in [4].

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The complex helicopter structure is modeled by generating a discrete mesh suitable for use by an FDTD computer code that uses a cubic grid. The discrete FDTD model of the complex geometry was generated by applying a staircase (stepped) approximation to the solid surface helicopter model. An interactive program, GEOM [12, 13, 14], was developed at Arizona State University (ASU) through the AHE program to automatically generate discrete cubical FDTD models of arbitrary geometries. The geometry data is then used by an FDTD computer code for the analysis of electromagnetic radiation, interference and interaction problems.

II. Applications

Areas of interest for the application of the FDTD method are prediction of antenna radiation characteristics and electromagnetic penetration into helicopters. These areas play an important role in the design of modern airframes and in the design of reliable communication systems on complex structures. These selected areas provide the reader with a general overview of the potentials and capabilities of the versatile and easy to use FDTD method.

A. Radiation Characteristics

The AHE Program used the FDTD method initially to analyze radiation by monopole and waveguide aperture antennas mounted on finite ground planes [3] and pyramidal horns with and without material on their inner walls [5]. The same approach used in the above papers was extended to study radiation by monopole antennas mounted on the NASA scaled helicopter [1] and HF loop and inverted-L antennas mounted on simplified structures [6, 7] and on the surface of the Apache helicopter [8]. In all the above referenced cases, the modeling of the complex helicopter geometry was accomplished using GEOM.

GEOM takes as its input an export file from the Super-3D visualization package [9]. This export file is generated when the structure is viewed on Super-3D. GEOM translates the original geometry into a discrete form by applying a staircase approximation to the surfaces of the original structure. The GEOM program then generates two output files. The first serves as the input file to the FDTD code. The second file is used to view the discrete model using Super-3D. GEOM requires the user to specify the frequency of operation, the number of cells per wavelength and the electrical parameters of each medium (permittivity, electric conductivity, permeability and magnetic resistivity) filling the grid. Thirteen different media can be specified by using different Super-3D color attributes. This feature of the program is utilized in the following section to analyze penetration into a composite helicopter structure. Finally, surfaces and wires can be selectively set to different media. A flow chart of the steps followed in using the GEOM program is shown in Figure 1.

The FDTD method, with the recently introduced Berenger Perfectly Matched Layer (PML) absorbing boundary conditions [10], was used to analyze HF antennas on the airframe of the AH-64 Apache helicopter [8]. The antenna of interest is an experimental 14′ (4.267 m) long towel-bar operating in the HF band (2-30 MHz). The solid surface geometry of the AH-64 Apache helicopter is illustrated in Figure 2. Toward the tail section of the helicopter the experimental 14′ loop antenna is shown on the port side. A 24′ long loop antenna, which can be configured both as open- and short-circuited to the helicopter vertical stabilizer, is mounted on the starboard side of the helicopter's tail boom.

Using a cubic cell size of 7″ (0.1778 m) and the GEOM code, an FDTD mesh of the helicopter was generated and is shown in Figure 3. A Rayleigh pulse with frequency components in the HF band (2-30 MHz) and with no DC component was used along with the radial E-field feed model for the antenna excitation. The input voltage and current at the antenna feed point were computed and the input impedance over the HF band was calculated. The FDTD computed results are compared with measurements performed on the Apache helicopter by the Naval Air Warfare Center (NAWC), and scale (10:1) measurements performed on a generic helicopter model at Arizona State University in Figure 4.

The reference planes of the scale measurements and FDTD predictions were adjusted to align the peaks of the input resistance with those of the NAWC measurements. The small discontinuities in the input resistance of the scale measurement at approximately 3.3 MHz intervals are the result of cable ringing due to the extreme mismatch between the cable and the antenna. FDTD prediction of the input resistance exhibits small sharp resonance peaks at approximately 9 and 27 MHz which are due to coupling with the 24′ antenna on the starboard side of the helicopter. The 24′ antenna was shorted to the helicopter at the feed for this prediction. Similar evidence of coupling is not present in the NAWC or scale measurements because the 24′ antenna was loaded during the measurements. When the passive element on the scale model was shorted to the fuselage at the feed, similar coupling characteristics were observed. Another interesting characteristic of the predicted input impedance results are the broad resonance peaks around 8.5 and 27 MHz. These resonance peaks are due to airframe resonances of the Apache helicopter. Figure 5 compares the FDTD prediction to the NAWC in-flight measurement of the yaw plane gain pattern for the 14′ towel-bar antenna at 24.13 MHz. Similar computed patterns in other planes also compare well with measurements.

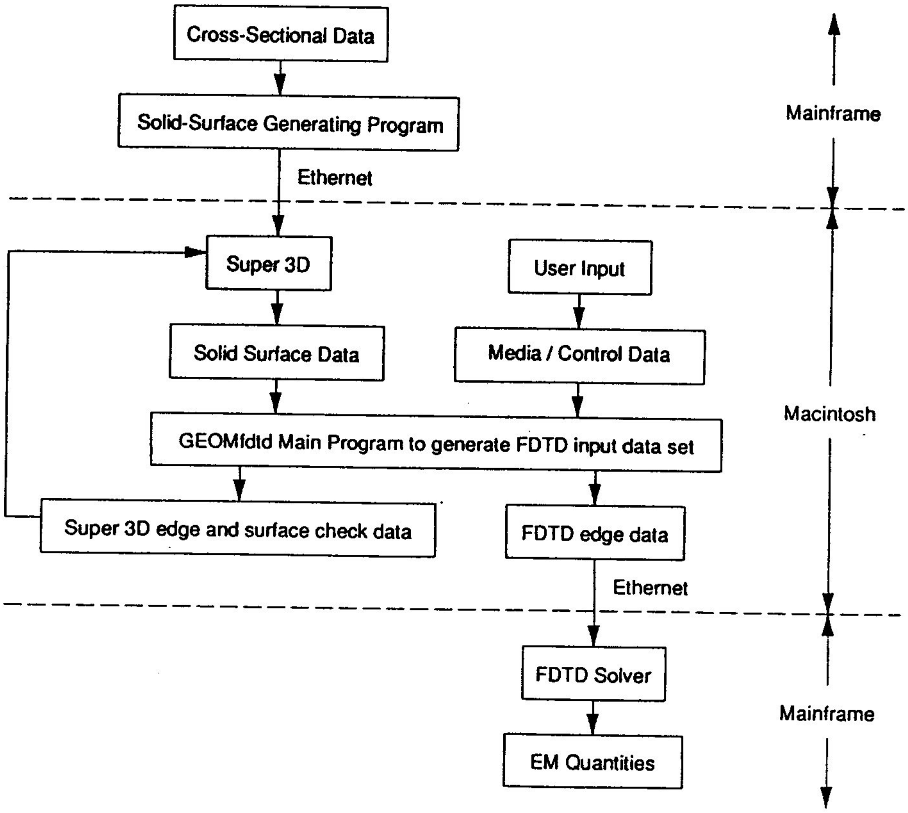

Figure 1: Systematic flowchart for the FDTD part of GEOM.

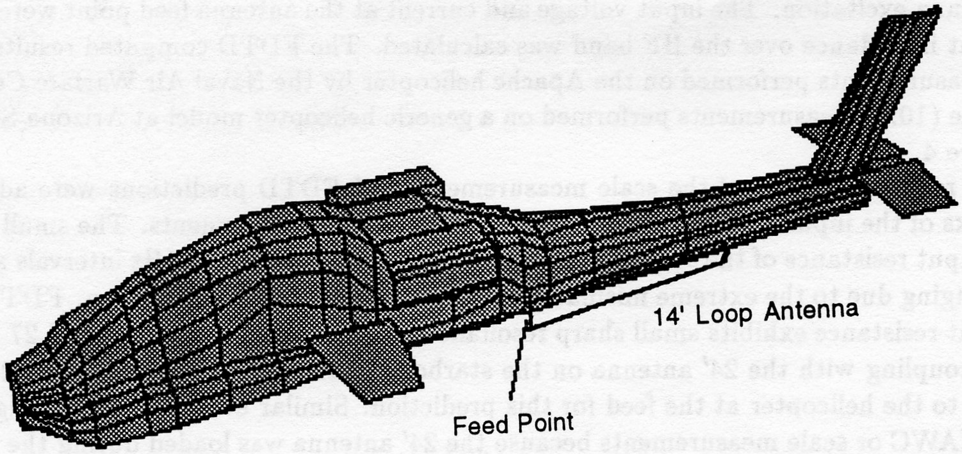

Figure 2: The geometry of the Apache helicopter. A 14′ loop antenna is shown on the tail section.

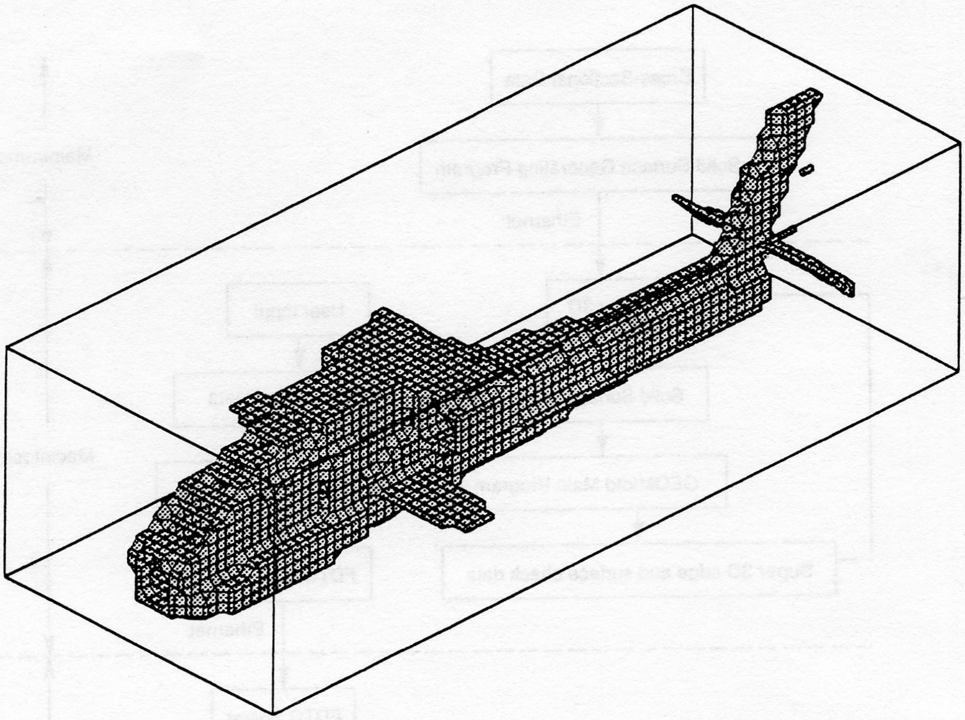

Figure 3: Staircase approximation of the Apache helicopter.

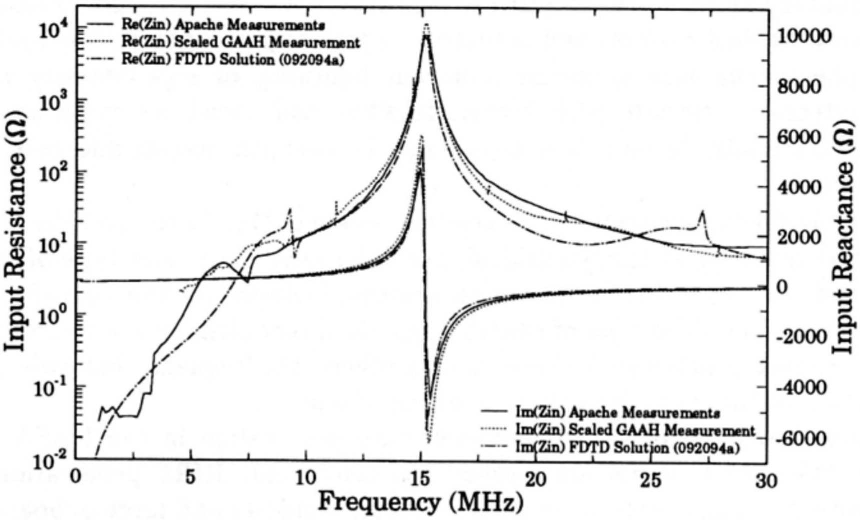

Figure 4: Comparison of the 14′ HF loop antenna's input impedance, measured on the Apache helicopter, a 10:1 scaled model of a generic helicopter, and the FDTD predictions.

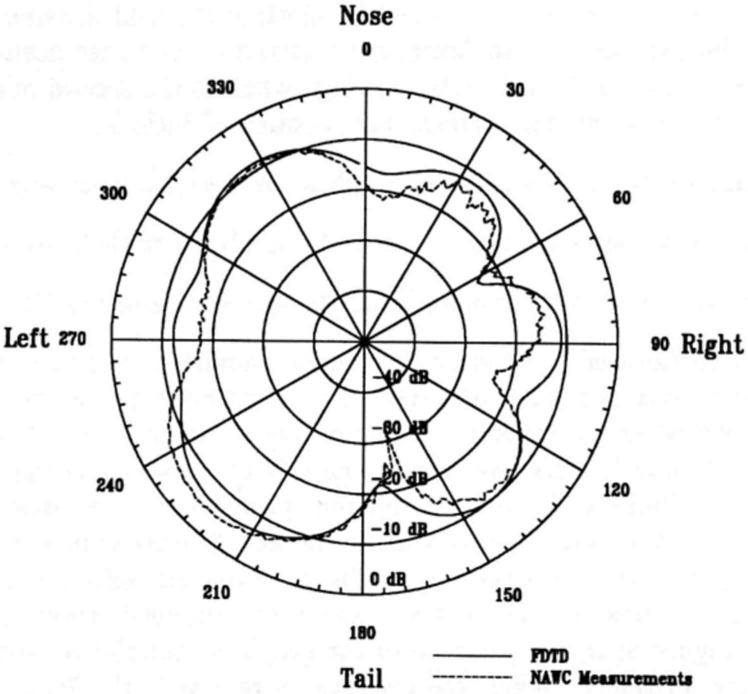

Figure 5: Measured and FDTD predicted yaw-plane, E_ϕ, gain pattern at 24.13 MHz of the 14′ loop antenna on the Apache helicopter.

B. Electromagnetic Penetration

Modern military and civilian aircraft use digital systems to control life-critical functions such as the engines, sensors, fuel systems and actuators. These digital flight control systems are vulnerable to external phenomena such as cosmic radiation, lightning, or high-intensity radiated fields (HIRF). Modern integrated circuits with higher densities and speed are more sensitive to HIRF. Also, composite materials, despite their advantages in strength, weight and cost, provide less shielding than aluminum.

The level of field penetration is dependent, among other factors, on the structure of the aircraft, the size and material at the windshield, the thickness, shape and type of material of the aircraft fuselage and the type of communication systems installed on the aircraft. The field penetration level also depends on the type of electromagnetic threat striking the aircraft. Possible factors that can have significant influence include, among others, the frequency bandwidth, maximum intensity, and direction of the incoming electromagnetic threat.

Numerical analysis of electromagnetic wave penetration in the NASA scale helicopter using the finite-difference time-domain method was conducted. HIRF penetration in helicopters occurs mainly through large apertures (e.g., the cockpit window) and large onboard antennas (e.g., high-frequency loop and inverted-L antennas). The helicopter airframe shown in Figure 6 was partially conducting/partially composite. Graphite composite material ($\sigma = 10^4$ S/m and $0.5''$ thickness) was used to simulate the helicopter windshield. The effect of removing the graphite material and changing the direction of the incoming threat was examined by investigating the level of the penetrating fields inside the helicopter fuselage compared to those outside the airframe.

A plane wave traveling in the y-direction with vertical polarization (E_z and H_x components) is incident on the composite helicopter airframe. The amplitude of the incident electric field is 1 V/m. Three parametric cases were examined by plotting the field distribution in the interior and exterior of the helicopter at two horizontal cross sections. The first horizontal cross section was taken toward the bottom of the helicopter fuselage whereas the second one was taken toward the top of the helicopter. The three parametric cases examined include:

a. The windshield windows are made of graphite and the incidence angle is horizontal.

b. The windshield windows are removed and the incidence angle is horizontal.

a. The windshield windows are removed and the incidence angle is 25° above horizontal.

The GEOM code was used to generate the staircase model of the helicopter. For this application 20 cells per wavelength were used at 500 MHz. The resulting staircase approximation is illustrated in Figure 7. At 500 MHz the thickness of the graphite composite ($0.5''$) is smaller than the the FDTD grid used. A subcell model was used to specify the presence of the graphite material.

The E_z field distribution of the three different parametric cases, over a horizontal cross section toward the bottom of the helicopter airframe, are illustrated in Figure 8. These were normalized with respect to the amplitude of the incident electric field and were plotted in dB [$20 \cdot \log_{10}(E^{total}/E^{inc})$]. Figures 8(a), (b), (c) correspond to parametric cases (a), (b), (c), respectively. As illustrated in Figure 8(a), the presence of the graphite material reduces the wave penetration into the helicopter airframe. When the graphite is removed, the level of internal fields inside the helicopter cavity increases, as illustrated in Figures 8(b) and (c). Note that the level of the penetrating fields is higher when the wave strikes the helicopter at normal incidence. The three parametric cases examined indicate high intensity fields toward the tail section of the helicopter. This is the area where usually HF antennas are mounted, and it is expected that the induced fields would affect onboard communication systems.

A second horizontal cross section was taken toward the upper part of the helicopter fuselage. This cross section includes parts of the graphite composite windshield. The field distribution of the E_z electric field component along this cross section is illustrated in Figure 9. Again the same three parametric cases are examined. With the presence of the graphite composite windshield the field penetration inside the helicopter airframe is reduced. When the graphite material is removed, significant field penetration inside the airframe occurs. Also, with the graphite material removed the field intensity at the aperture/airframe interface is very high. These high intensity fields are expected to have a significant effect on electronic circuits in the vicinity of the cockpit window. A second area of high field intensity is the region toward the tail section of the helicopter where there is a sharp discontinuity in the helicopter airframe. This discontinuity separates the main airframe from the tail section of the helicopter. Again, these high intensity fields are expected to have a significant effect on large HF antennas mounted on the tail section of the helicopter.

The field intensity of the remaining field components is also available from the FDTD program. These results can be examined interactively using TECPLOT, a commercially available software [11]. As shown by the previous two examples, the level of penetrating fields depends on the material used on the windshield window and the incidence angle of the incoming threat. Other factors that affect the field distribution inside and outside the helicopter fuselage are the shape of the helicopter, material used in the airframe, frequency of the incoming threat, type of communication systems installed on the aircraft, and size and type of apertures on the helicopter airframe. All of these factors can be examined through computer simulation of HIRF penetration using the FDTD method.

III. Conclusions

Using the GEOM program, discrete helicopter models were generated from surface models for FDTD analysis of antenna radiation characteristics and electromagnetic penetration. The modeling of an experimental HF loop antenna on the surface of the Apache helicopter is demonstrated and computations of the input impedance and gain patterns of the antenna are compared with measurements. The coupling effect between two HF antennas mounted simultaneously on the Apache helicopter is evident in the predicted input impedance.

Numerical simulation of electromagnetic field penetration into a partially conducting/partially composite NASA helicopter model was also performed. The helicopter windshield was first modeled as graphite material and the effect of removing the graphite on the level of the penetrating fields was investigated. The effect of changing the plane wave incidence angle on the level of the penetrating fields was also examined. These are some of the factors affecting penetrating fields in the helicopter airframe and the field distribution in the vicinity of the helicopter. Other factors, including the frequency of the incoming wave, the composition of the airframe cavity, the structure of the helicopter fuselage, etc., will be examined in the future.

IV. Acknowledgements

The authors would like to thank the participating industry and government members of the AHE program for their interest and support of this project. The participating members include Boeing Helicopters, McDonnell Douglas Helicopter Co., Rockwell International, United Technologies - Sikorsky Aircraft Division, NASA Langley Research Center, CECOM/NASA Joint Program, U.S. Army Research Office, U.S. Army Electronic Proving Ground and U.S. Naval Air Warfare Center.

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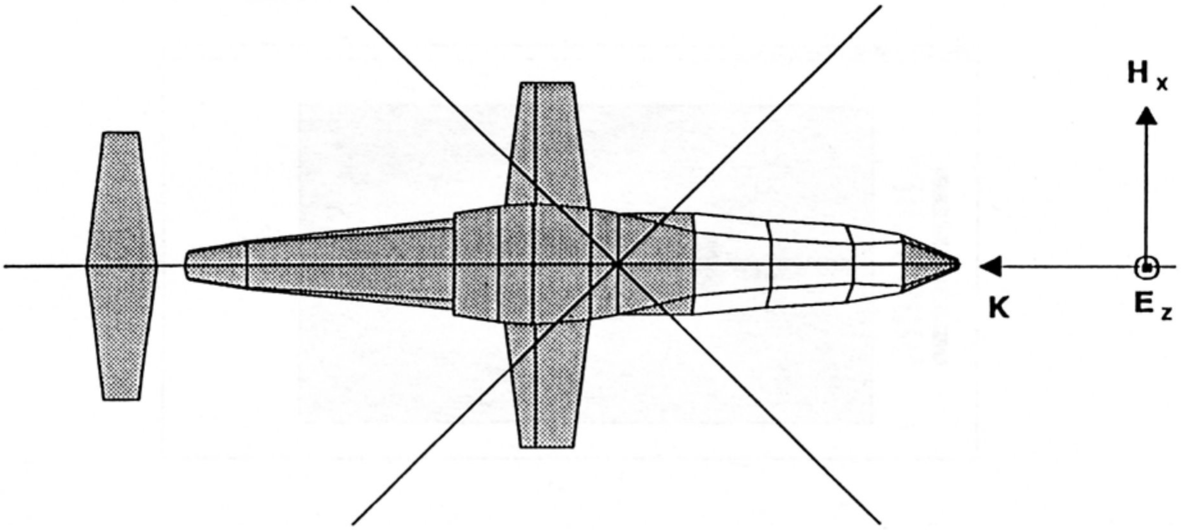

Figure 6: Partially conducting/partially composite NASA helicopter model at 500 MHz.

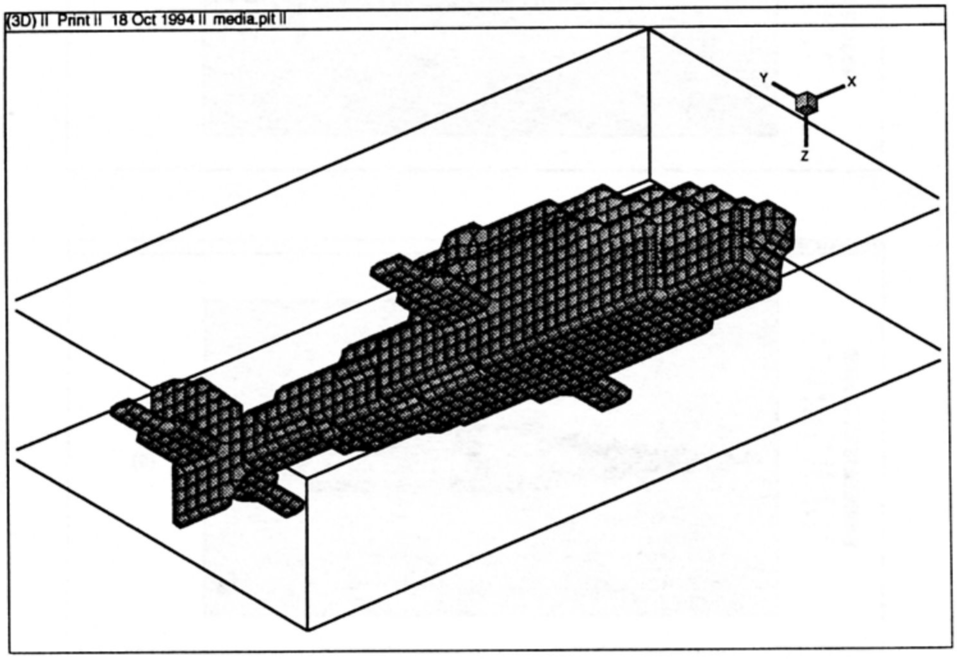

Figure 7: Staircase approximation of the NASA helicopter model at 500 MHz using 20 cells pe wavelength.

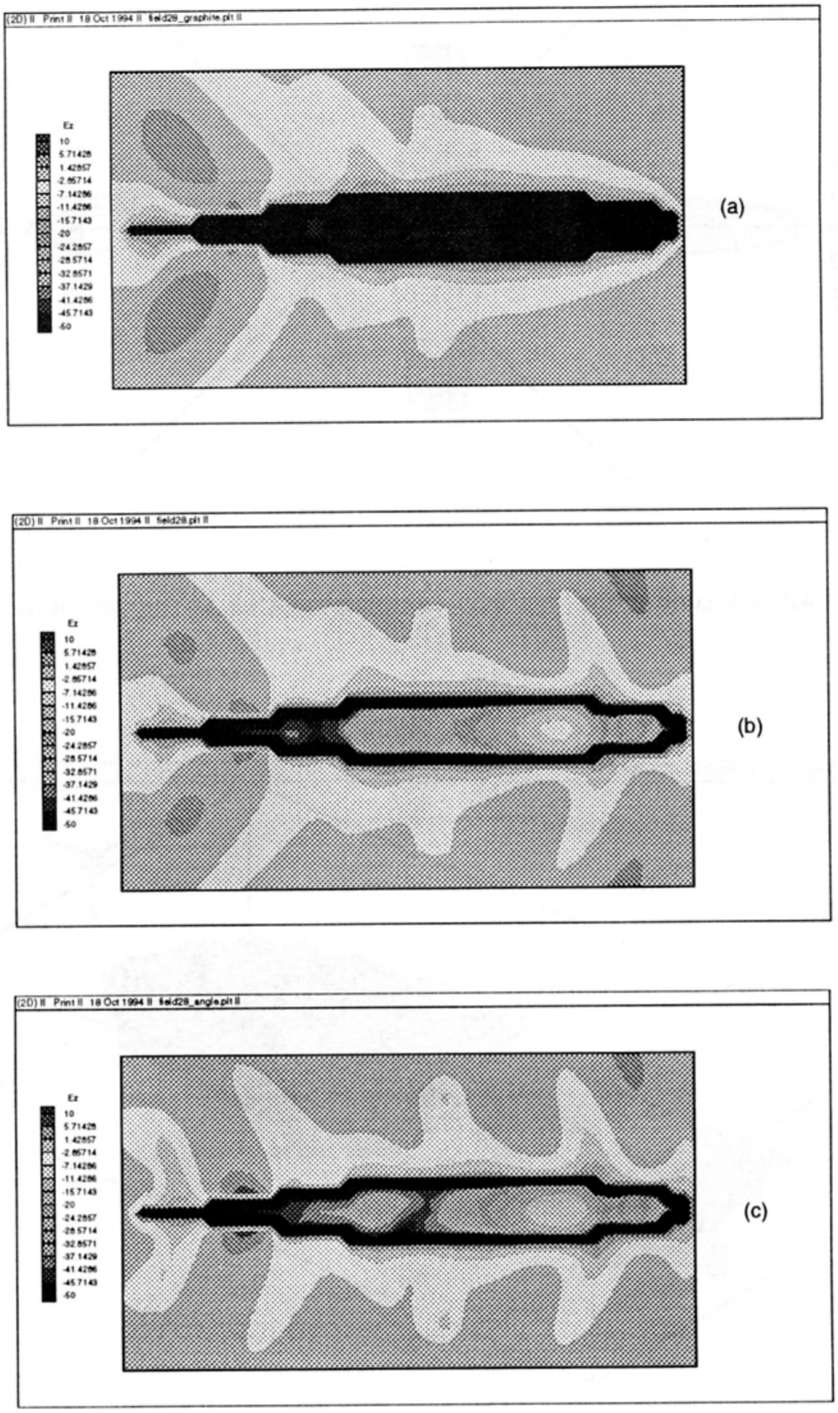

Figure 8: Normalized gray scale E_z electric field distribution over a bottom cross section at 500 MHz. (a) With graphite and at horizontal incidence, (b) without graphite and at normal incidence, (c) without graphite and at an incidence angle 25° above horizontal.

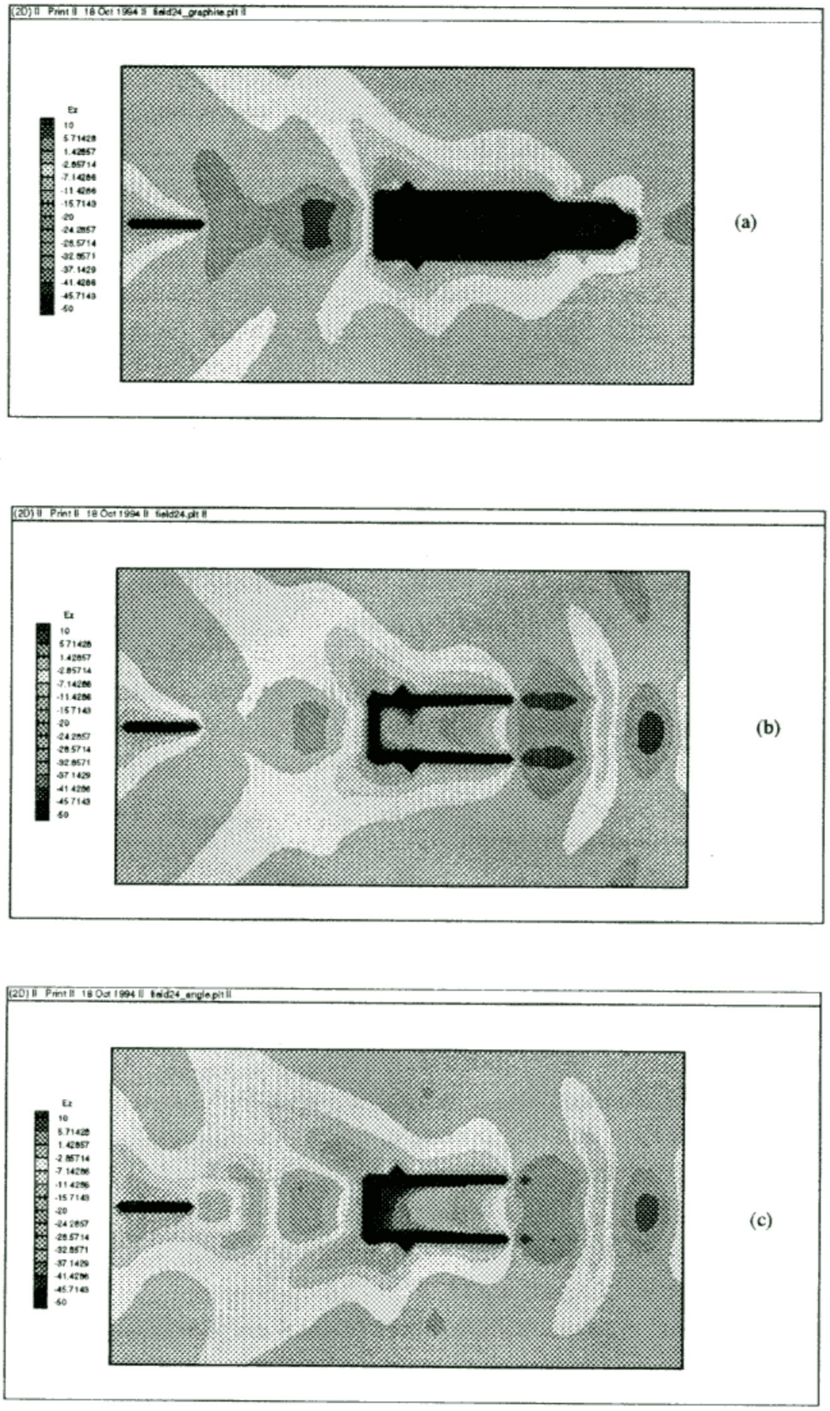

Figure 9: Normalized gray scale E_z electric field distribution over a top cross section at 500 MHz. (a) With graphite and at horizontal incidence, (b) without graphite and at normal incidence, (c) without graphite and at an incidence angle 25° above horizontal.

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QUANTITATIVE ASSESSMENT OF THE COMPARISON OF ELECTROMAGNETIC CALCULATIONS WITH EXPERIMENTAL DATA

by

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Introduction

In the November 1994 issue of the ACES Newsletter, Ed Miller [1] argued that, when comparing electromagnetic calculations with experimental data, often only qualitative statements are made regarding the degree of the agreement between the two sets of data. In addition, different authors compare different features of the two curves (eg : null position, impedance errors) which leads to inconsistency when comparing the performances of different numerical methods.

The authors have also been concerned with this problem and have investigated whether various figures of merit can be applied to assess quantitatively the overall agreement between numerical modelling results and experimental data in the general field of electromagnetics. The experimental set-up is described in Reference [2].

To give an example of the problem that one is often faced with, refer to Figure 1 which shows the variation with frequency of the normalised current flowing in a wire placed within a resonant cavity. The full line represents experimental data whilst the dotted line represents the results from a Transmission-Line Modelling (TLM) simulation. What can we say about the agreement between the two curves ? There looks like reasonable agreement but what do we mean by "reasonable"? Visually, most of the peaks of the experimental data are reproduced in the calculation, but there are discrepancies between the positions and amplitudes of some of the peaks. One of the reasons for such discrepancies is that the numerical calculation uses a rectangular mesh, which is not the most appropriate for describing the cylindrically shaped wire. This problem can be compensated for by using what is known as a "resonance error correction" [3] . If this correction is introduced into the calculation, then the comparison between the corrected numerical calculation and experimental data looks like Figure 2. Comparing this figure with Figure 1, it could be argued that the corrected numerical calculation offers better agreement with experiment than when no resonance error correction is incorporated. However, this visual comparison is not conclusive and it would be far more satisfactory if a quantitative measure of the improvement can be obtained.

In References [4] and [5], correlation methods were applied to the evaluation of TLM applied to experiments in a screened room and the transmission of electromagnetic energy through a cavity. An outline of this technique is described below.

Correlation Methods

Suppose that $\{x[n]\}$ and $\{y[n]\}$ are two sets of data samples. The normalised cross-correlation function , $\{R_{xy}[p]\}$ is defined by :

$$R_{xy}[p] = \frac{\sum_{n=1}^{N-p} x[n]\, y[n+p]}{\sqrt{\sum_{n=1}^{N} (x[n])^2 \sum_{n=1}^{N} (y[n])^2}} \tag{1}$$

$$0 \leq p \leq N-1$$

with a similar formula for $p < 0$.

The maximum of $\{R_{xy}[p]\}$, R_{max}, is referred to as the cross-correlation coefficient. The correlation function has the following properties :

(A) If $x[n] = y[n+s]$, then $R_{max} = 1$ at shift $p = s$.

(B) If $x[n] = y[n]$, then the cross-correlation function becomes the autocorrelation function, $R_{xx}[p]$ which has a maximum value of 1 at zero shift $p = 0$. In this case, the autocorrelation function is *symmetric* about $p = 0$.

The above properties have lead us to define the following three figures of merit to compare numerically derived and experimental data:

(1) Maximum Value of Cross-Correlation, R_{max}

The closer to 1 this value, then the more similar are the two curves.

(2) The Degree of Asymmetry of $\{R_{xy}[p]\}$, S_{rms}

This is defined by

$$S_{rms} = \frac{1}{N}\left[\sum_{p=1}^{(N/2)-1}(R_{xy}[p] - R_{xy}[N-p])^2\right]^{\frac{1}{2}} \tag{2}$$

where it should be noted that, in the calculation of the correlation functions, the Fast Fourier Transform (FFT) method is being used, which assumes an underlying periodicity of the curves such that $R_{xy}[-p] = R_{xy}[N-p]$. If $x = y$, then $R_{xy}[p]$ is identical to the autocorrelation function which is symmetric about $p = 0$; hence the more similar are x and y, then the closer S_{rms} is to zero.

(3) RMS Difference Between the Auto-Correlation Function of the Experimental Curve and the Cross-Correlation Function for the Experimental Data and Numerical Calculation, D_{rms}.

This is defined by

$$D_{rms} = \left[\frac{1}{N}\sum_{p=1}^{N}(R_{xx}[p] - R_{xy}[p])^2\right]^{\frac{1}{2}} \tag{3}$$

If $x = y$, then from property (B) above, D_{rms} is zero.

Application of Correlation methods

If we apply the above three figures of merit to the curves in Figure 1 and 2, then we obtain the results in Table 1 :

Table 1 Cross-Correlation Between Numerical and Experimental Curves

	R_{max}	S_{rms}	D_{rms}
No Resonance Correction used in Numerical Model	0.962	0.037	0.028
Resonance Correction used in Numerical Model	0.984	0.021	0.018

It can be seen that when the resonance error correction is incorporated into the calculation, then R_{max} is closer to 1 and S_{rms} and D_{rms} are both closer to zero compared with the case where no such correction is made. From our discussion in the previous section, this suggests that the incorporation of resonance error correction into the calculation does indeed improve the agreement between the TLM calculation and the experiment ; this finding confirms the conclusions reached by the visual comparison made earlier.

Discussion

(1) The correlation methods that have been described in this article, have weighted all parts of the current/frequency curve equally. However, one can perform transformations on such curves to accentuate certain features. For example, if the comparison of peak positions are deemed to be more important than peak heights then one could compare figures of merit that have been derived from correlations of first or higher order derivatives of the current/frequency curves. Alternatively, a combination of first and second order derivatives could be used. If it is desired to compare the absolute values of the numerically derived and experimental curves, then one should not normalise the numerically derived data as has been done in Equation (1) ; in this case, if the experimental data are still normalised , then the correlation coefficient could be greater than 1 ; the closeness of the correlation function to 1 would give an indication of the overall similarity of the two curves being compared from the point of view of both shape and absolute value. In fact, one can envisage various figures of merit being available, each one tailored to compare specific features of two curves.

(2) It is important to assess the significance of any comparison, for example by quoting a standard deviation for any figure of merit that is calculated ; this will depend on the signal to noise ratio of the experimental data. The experimental data analysed in this article are reproducible in that experimental curves taken on different occasions are practically identical. In the case of lower signal to noise ratios, where the experimental curves are not so repeatable, the improvement observed in the illustrated example may not be deemed significant.

Conclusion

When modelling electromagnetic fields and comparing with experiment, it is argued that it is important to validate numerical calculations as much as possible using quantitative factors rather than just relying on visual inspection. This work is being pursued by the authors in the area of Electromagnetic Compatibility (EMC) although the methods suggested in this article could be applied to any situation where one is comparing numerical calculation with experiment or comparing different numerical calculations.

We would appreciate feedback from the applied electromagnetics community, regarding the potential usefulness of using figures of merit, based on correlating experimental data with the results from numerical modelling calculations, so that these techniques may be developed further through collaboration.

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Figure Captions

Figure 1 : Effect of a resonant cavity on a signal passing through it. The solid line is experiment and the dashed line is TLM <u>without</u> resonance error correction.

Figure 2 : As for Figure 1, except that now the dashed line is TLM <u>with</u> resonance error correction.

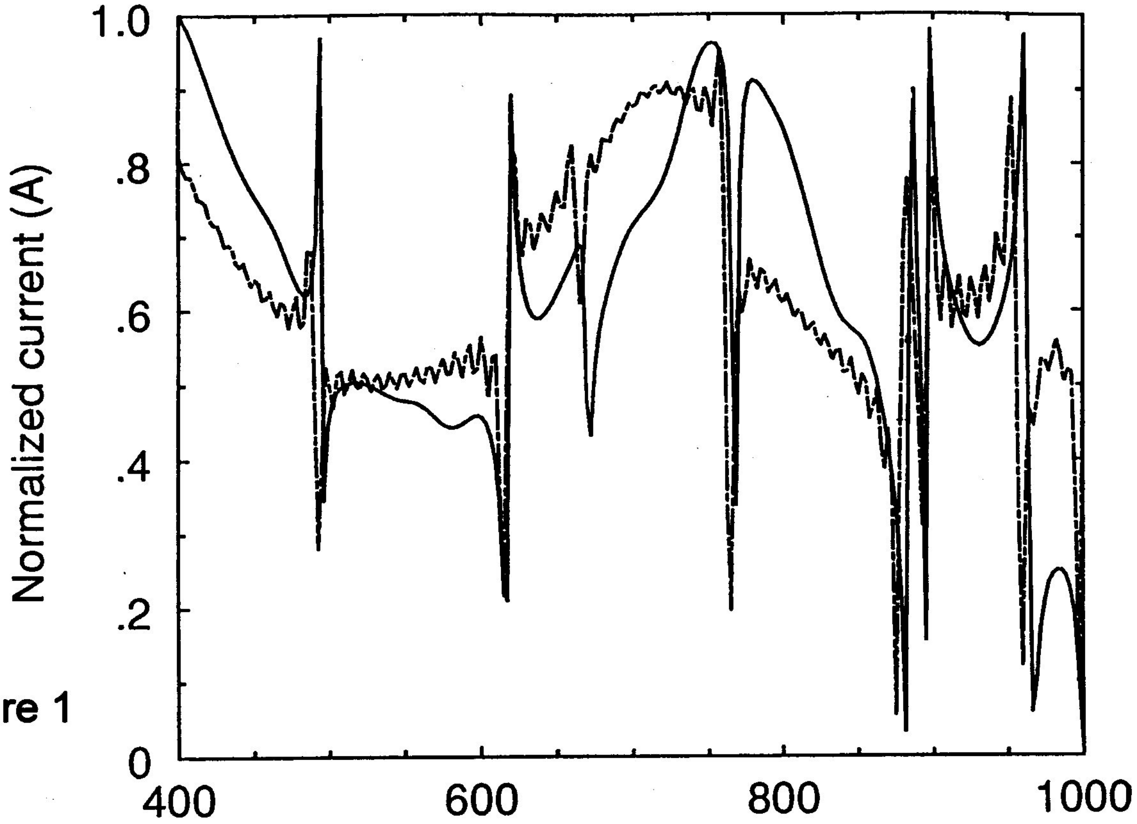

Figure 1

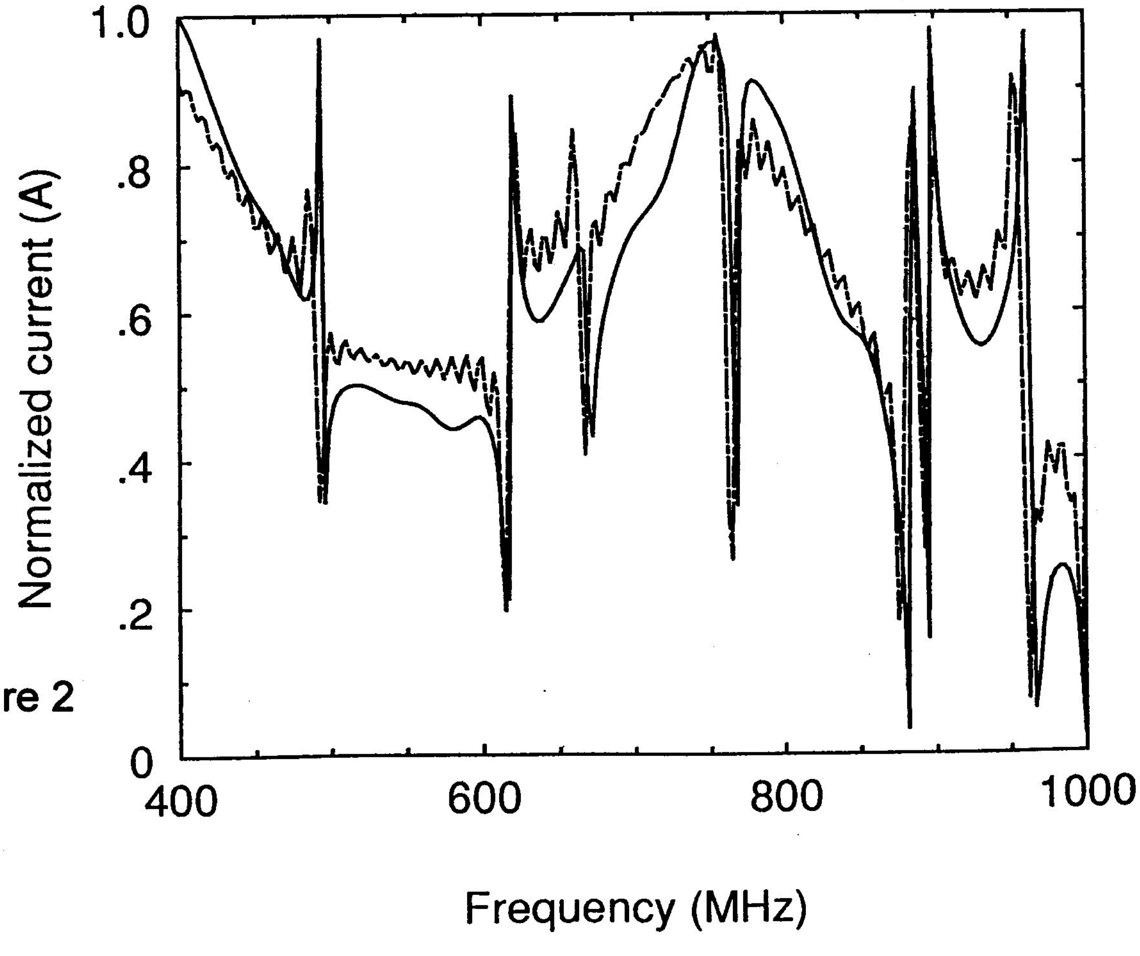

Figure 2

The Practical CEMist
- practical topics in communications -

Perry Wheless, K4CWW

This installment of The Practical CEMist considers an often-asked question, namely "is there any substantial difference in results from modeling HF wire antennas near real ground with NEC2 or NEC3?" The answer is the usual, disconcerting "it depends". The antenna considered here is a pyramid, or small vertical half rhombic (VHR), representative of an antenna type which is in use at a considerable number of amateur radio stations. This VHR antenna is an excellent test case. because it involves a counterpoise wire just 5cm above the ground and two ground stakes. The ground stakes, in particular, give us a good opportunity to see a illustrative circumstance where the results from NEC3 modeling are clearly superior to those from NEC2.

When two codes give different results, it is usually difficult to resolve which is superior because pattern measurements on full-sized HF antennas are seldom available. This paper contains actual measured data and by overlaying measurements with NEC2 and NEC3 results in the pattern plots, the reader is afforded a rare opportunity to make comparisons. Also, the reader will note that the ground parameters, ε_r and σ, were measured at the antenna range when the pattern measurements program was conducted.

Mike Fanning (WA4QHI) is a Design Engineer with Motorola Transmission Products Division, where he is responsible for design and development of high-speed and subrate digital telecommunications gear. He attended the University of Alabama, where he received both the B.S. and M.S. degrees in Electrical Engineering. Mike is active in various facets of amateur radio. He holds an Amateur Extra class license as well as a U.S. patent. Interested readers can contact Mike Fanning at phone 205-430-7032, or by mail at Motorola Transmission Products Division, 5000 Bradford Drive, Huntsville, AL 35805.

In the last issue, I mentioned that we were looking forward to being able to work with the new antenna design optimization software from Paragon Technology, Inc., State College, PA. Progress has been made on that front and, as of this writing, a pre-release copy of NEC-WIN- has been secured, installed on ye olde PC, and run through a test drive. I am now quite optimistic that we will be able to give you a first peek at the capabilities of this innovative product through an application paper in the next *ACES Newsletter*. I would like to again thank Todd Erdley of Paragon for his continued interest in ACES, and for his cheerful cooperation by making the software available to us. If you care to discuss the NEC-WIN product with Todd directly, he can be reached at 814-234-3335.

ACES has many talented Practical CEMists as members, and this department of the *ACES Newsletter is* intended to serve as an outlet for you to share your expertise and experiences in practical aspects of applied computational electromagnetics. I check the mailbox every day! Please submit article manuscripts directly to:

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In the immortal words of Bartles & James, "Thank you for your support."

PRACTICAL CHARACTERIZATION OF A HIGH-FREQUENCY VERTICAL HALF RHOMBIC

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Abstract - Selected radiation pattern characteristics of the commercially available Barker & Williamson model AC-1.8-30 antenna are investigated experimentally and numerically above finite ground in the high frequency range (3-30 MHz). Numerical solutions are presented from both NEC-81 version 2.2 running on a 80386-based PC, and NEC3 running on an IBM 3090 mainframe computer. Basic limitations of NEC2 are discussed, and comparison of NEC2, NEC3, and measured data are presented in graphic form via antenna pattern displays.

INTRODUCTION

Design and analysis of wire antennas using personal computer-based numerical methods is attractive from the viewpoint of convenience, since field measurements of wire antennas (particularly at frequencies below 5 to 7 MHz) can be impractical due to the large amount of real estate required for accurate pattern characterization. Today, there are several commercially available analysis tools (MININEC, ELNEC, YAGI-NEC) available for the experimenter and radio amateur to model antenna behavior. Most packages generate pattern data and input impedance information for wire antennas in free space or over a simple ground plane. For many elevated antenna applications, inexpensive PC based numerical codes are more than adequate to yield useful and accurate data. However, many hf wire antennas are in close proximity to finite ground, and generally have other geometric anomalies (ground stakes, support masts, guy wires, etc.) introduced during actual deployment. These anomalies can affect pattern modeling in various ways, depending on location, alignment, and metallic content. Finite ground parameters (dielectric constant and conductivity) also affect pattern analysis, and different codes treat finite ground analysis with various degrees of accuracy.

The original version of NEC was developed as a refinement of the Antenna Modeling Program (AMP) by Lawrence Livermore Laboratory under the joint sponsorship of the Naval Ocean Systems Center and the Air Force Weapons Laboratory. In the years since its introduction to the military, several versions of NEC have become available on platforms ranging from PCs to workstations to mainframes. The best PC-based version of NEC available at the time this research was conducted [1] was NEC-81, version 2.2, or simply NEC2. NEC2 is a user-oriented computer code utilizing the method of moments for the analysis of the electric and magnetic response of antennas and other metal structures [2]. It provides a numerical solution of integral equations for the currents induced on a structure by source excitation at the structure, or by incident field remote excitation away from the structure. An inherent limitation of NEC2 is that it does not take into account structure elements that penetrate into finite earth through the air-earth interface. Consequently, much of the NEC2 pattern analysis is in error due to the program's inability to properly compensate for the effect of the ground rods being placed two feet into the ground.

In order to more accurately predict antenna pattern characteristics, the mainframe based NEC3 was chosen for further analysis and refinement. NEC3 also features an improved Sommerfeld/Norton treatment of imperfect ground planes which allows for more realistic characterization of metallic objects penetrating the ground. All NEC3 runs were executed on The University of Alabama's IBM 3090 mainframe.

A popular antenna in the amateur community is the longwire, and one form of longwire antenna is that of the nonresonant rhombic, which provides directional gain in the direction opposite the feed point of 5 to 12 dBd [3]. Since the wavelength of radiation in the hf spectrum is relatively long (10 to 100 meters) and a rhombic antenna is typically 1 to 5 wavelengths on a side, full rhombics are almost always constructed horizontally above ground. A logical alternative to the individual who does not have the necessary room to construct a full horizontal rhombic antenna is to reduce the area required for installation by cutting the rhombic in half and rotating the assembly into the vertical plane. In this case, it is possible to reduce the overall surface area drastically, as the antenna can be placed so that the legs are terminated at ground level in a relatively small installation space. The remaining interior angle of the rhombus is mounted vertically away from the ground as high as practically possible. The distant ends of the antenna are grounded and tied together by a single counterpoise wire, and the whole structure is fed through a 9:1 balun. This configuration is commonly known as a Vertical Half Rhombic (VHR), although an alternative description would be a "balanced-feed, loaded pyramid". The VHR chosen for this study is the Barker & Williamson model AC-1.8-30 which is designed primarily for broad-band amateur use in confined areas. The B&W VHR configuration is depicted in Figure 1. Antenna wire is stranded #14 AWG, and the center support for this study was a 10.7 meter fiberglass pole. The axis of the antenna is along a precise East-West line, with the balun feed at the East end and the termination network at the West end.

The pattern measurements for this particular study were carried out using Eyring's Broadband Antenna Test System (BATS) at its Cedar Valley, Utah test range. BATS is a computer-controlled, integrated test system which incorporates the capability for airborne pattern measurements of antenna power gain. The test system is referenced to standard dipoles [4] for obtaining hf pattern profiles with an overall accuracy on the order of 1dB. The BATS configuration and methodology is described in references [5] and [6], with details on the antenna measurement beacon in [4]. Test site ground parameters ε_r (dielectric constant) and σ (conductivity) are measured for each pattern profile as described in reference [7].

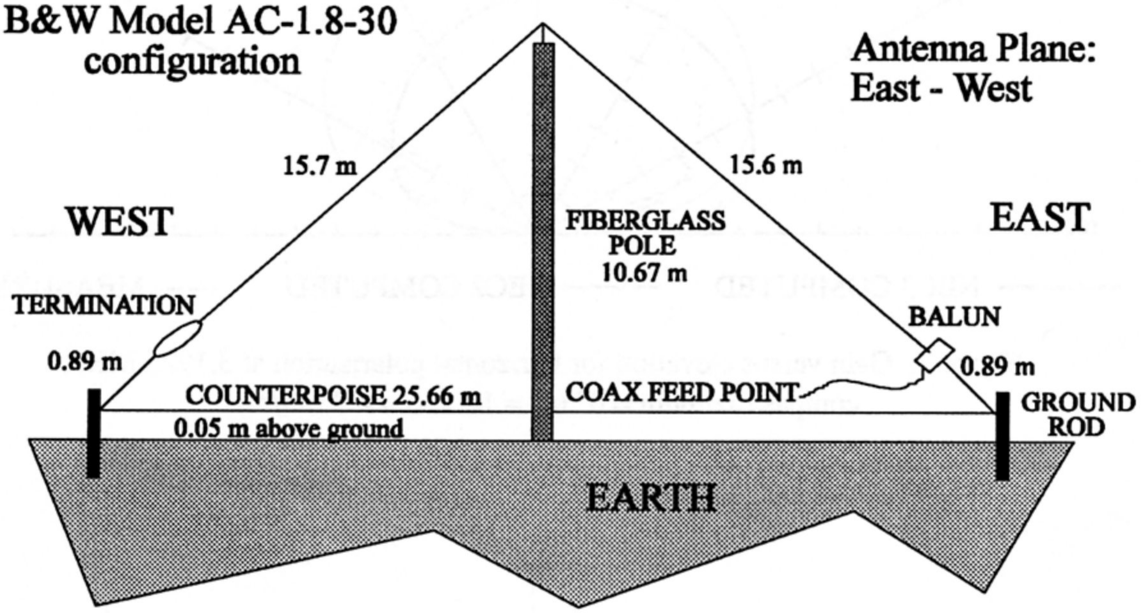


Figure 1. Antenna geometry

COMPARISON OF COMPUTED AND MEASURED PATTERNS

Measured radiation pattern profiles were acquired at the Eyring test facility at frequencies of 3.195, 10.12, 19.0475, and 22.9015 MHz. NEC2 and NEC3 pattern data was then generated and plotted on a PC via the BATS software. Both NEC2 and NEC3 plots have been compensated for efficiency.

Figures 2-4 are gain versus elevation pattern profiles at respective frequencies of 3.1925, 10.12, and 19.0475 MHz. The measured data was derived from airborne flyovers along a North-South course (perpendicular to the axis of the antenna). The polarization attitude was horizontal, with the measurement beacon radiator aligned parallel to the VHR axis. High winds aloft are evident in figures 3 and 4, which were measured four days earlier than the figure 2 pattern. The NEC3 predicted patterns closely emulate the measured data in all three instances, while the PC-based NEC2 patterns exhibit worse-case errors of ~5 dB.

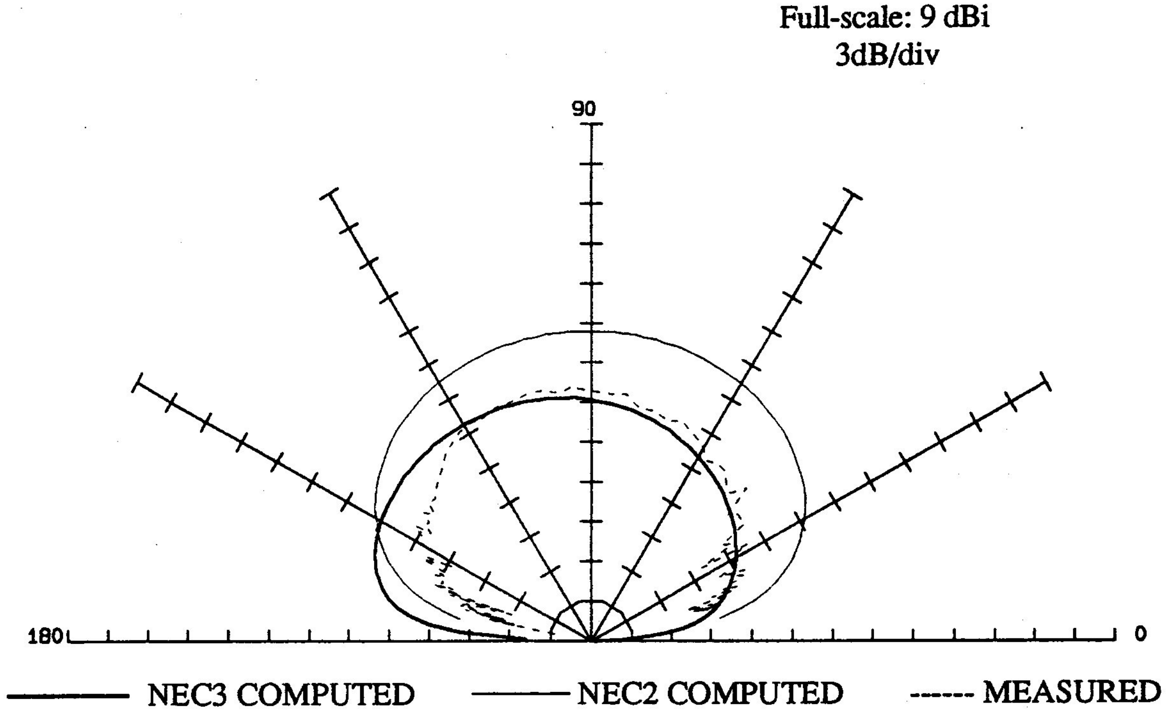


Figure 2. Gain versus elevation for horizontal polarization at 3.1925 MHz, compass azimuth = 0° ($\varepsilon_r = 18.5$, $\sigma = 4.3$ mS/m).

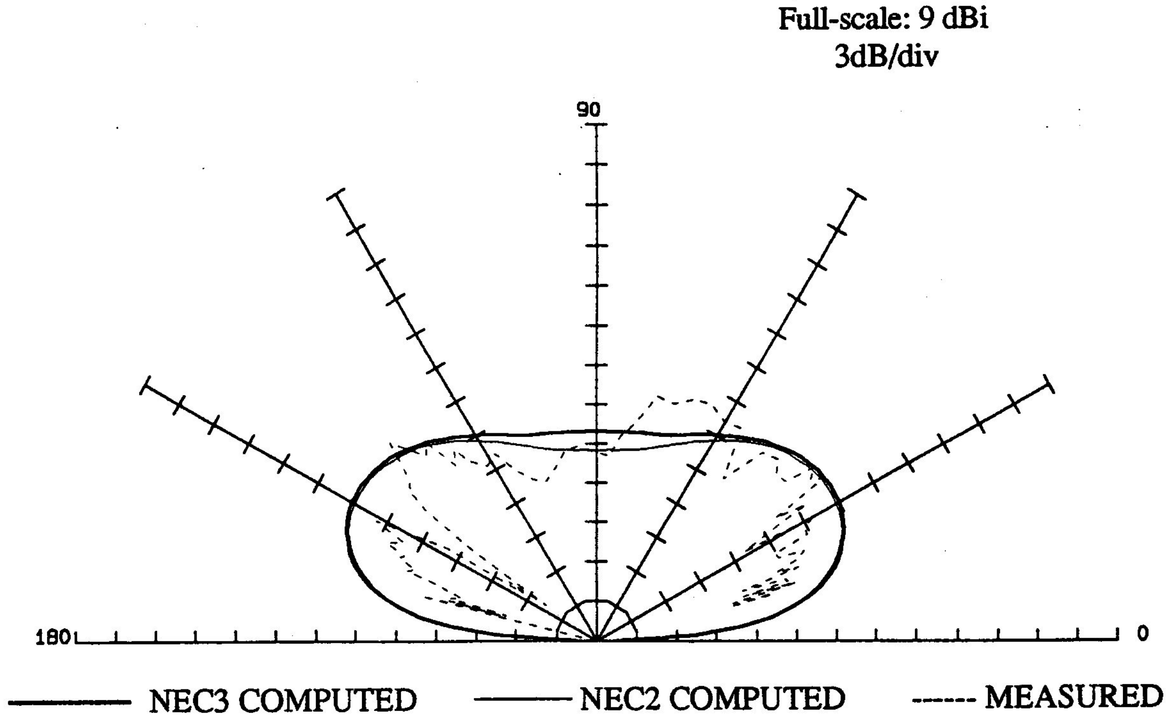
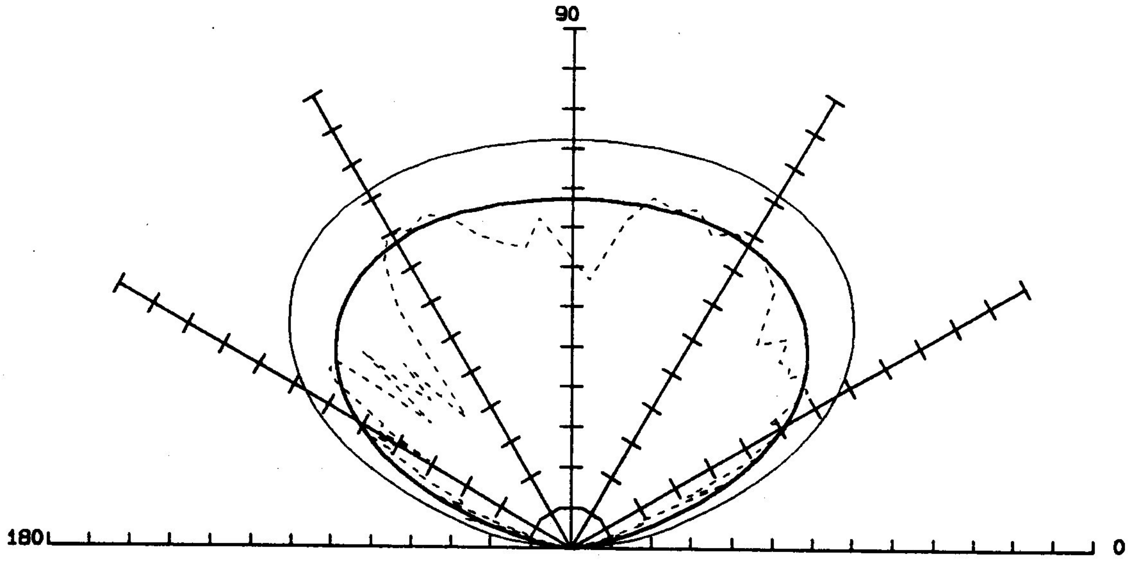


Figure 3. Gain versus elevation for horizontal polarization at 10.12 MHz, compass azimuth = 0° ($\varepsilon_r = 8.7$, $\sigma = 6.7$ mS/m).

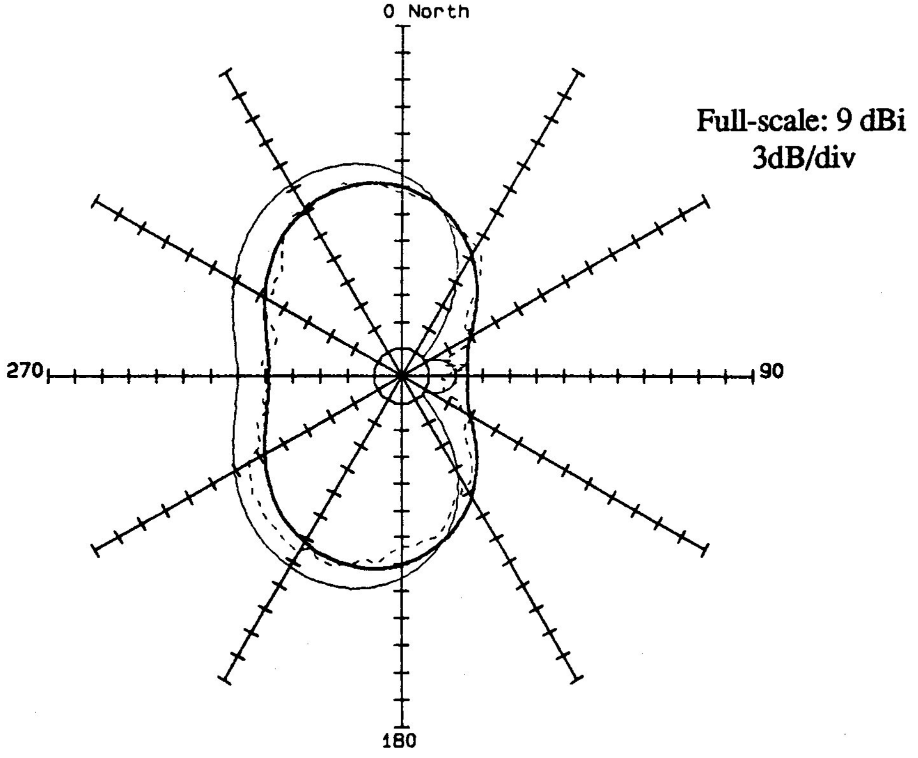
Full-scale: 9 dBi
3dB/div



——— NEC3 COMPUTED ——— NEC2 COMPUTED ------ MEASURED

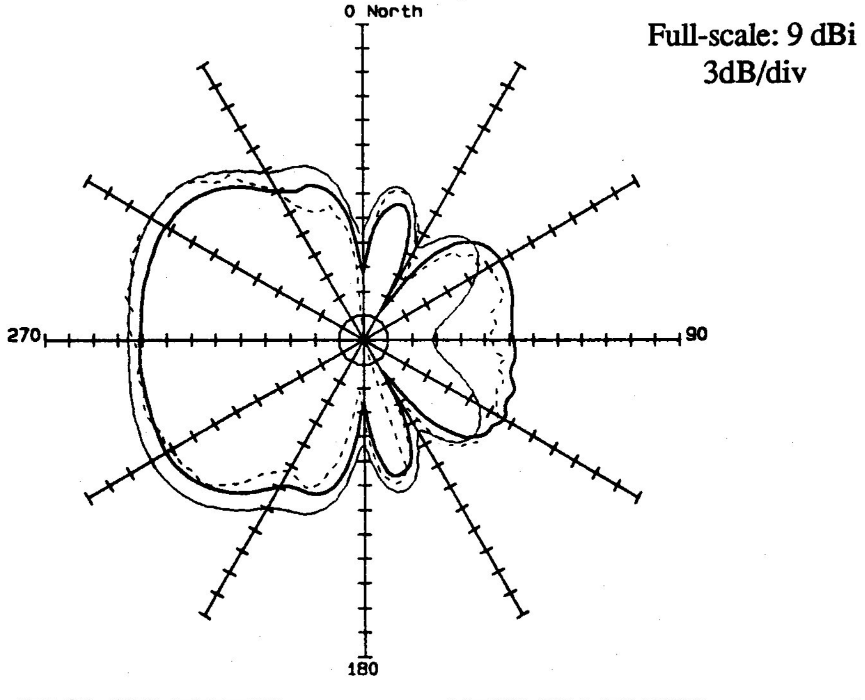
Figure 4. Gain versus elevation for horizontal polarization at 19.0475 MHz, compass azimuth = 0° ($\varepsilon_r = 7.8$, $\sigma = 8.9$ mS/m).

Figures 5-11 present seven gain versus azimuth pattern profiles (involving various values of elevation angle θ above the horizon). Figures 5-9 are vertical polarization cases, while the polarization is horizontal in figures 10 and 11. The NEC3 predicted patterns for figures 5-7 are notably more successful than NEC2 in the minor lobe regions. Also, figure 7 depicts a case where the overall pattern size from NEC2 is unacceptable while the NEC3 results correlate well against measurements. Although neither code predicts the back lobe in figure 8, the NEC3 pattern size is far superior to the NEC2 analysis. In the case study of figure 9, NEC3 afforded only modest improvement over the NEC2 results in the minor lobe region.



——— NEC3 COMPUTED ——— NEC2 COMPUTED ------ MEASURED

Figure 5. Gain versus azimuth for vertical polarization at 10.12 MHz, 5° elevation ($\varepsilon_r = 10.0$, $\sigma = 8.0$ mS/m).



——— NEC3 COMPUTED ——— NEC2 COMPUTED ------ MEASURED

Figure 6. Gain versus azimuth for vertical polarization at 22.9015 MHz, 10° elevation ($\varepsilon_r = 6.3$, $\sigma = 8.5$ mS/m).

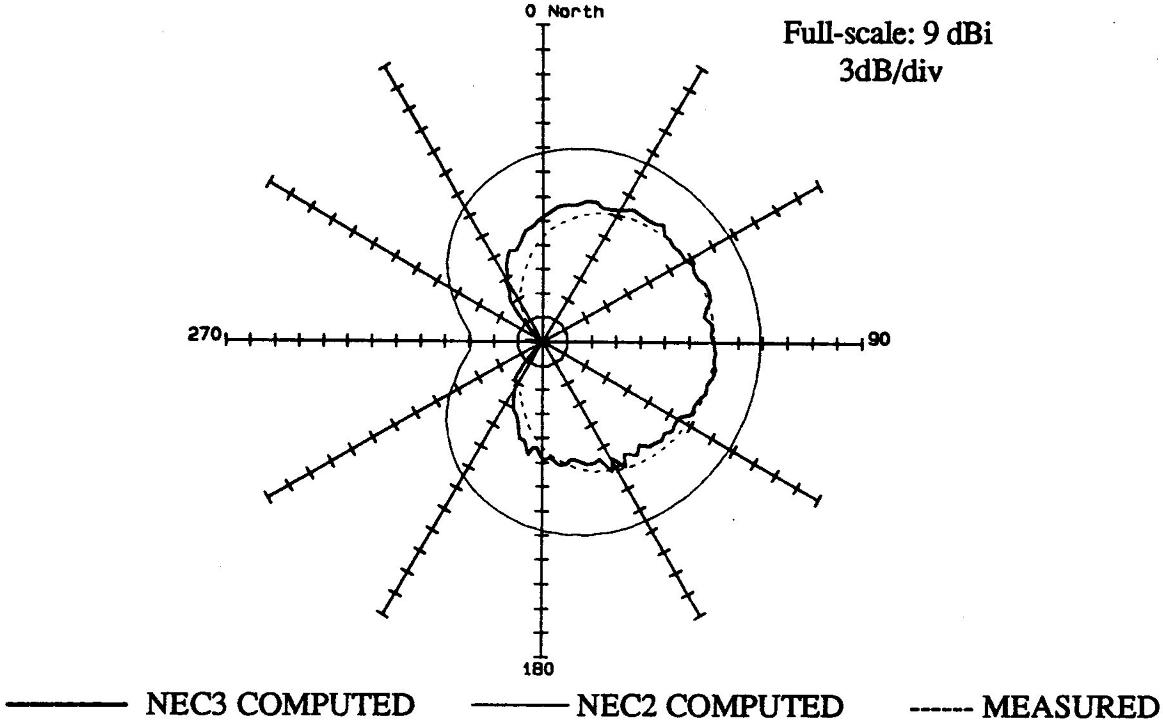


Figure 7. Gain versus azimuth for vertical polarization at 3.1925 MHz, 20° elevation ($\varepsilon_r = 18.5$, $\sigma = 4.3$ mS/m).

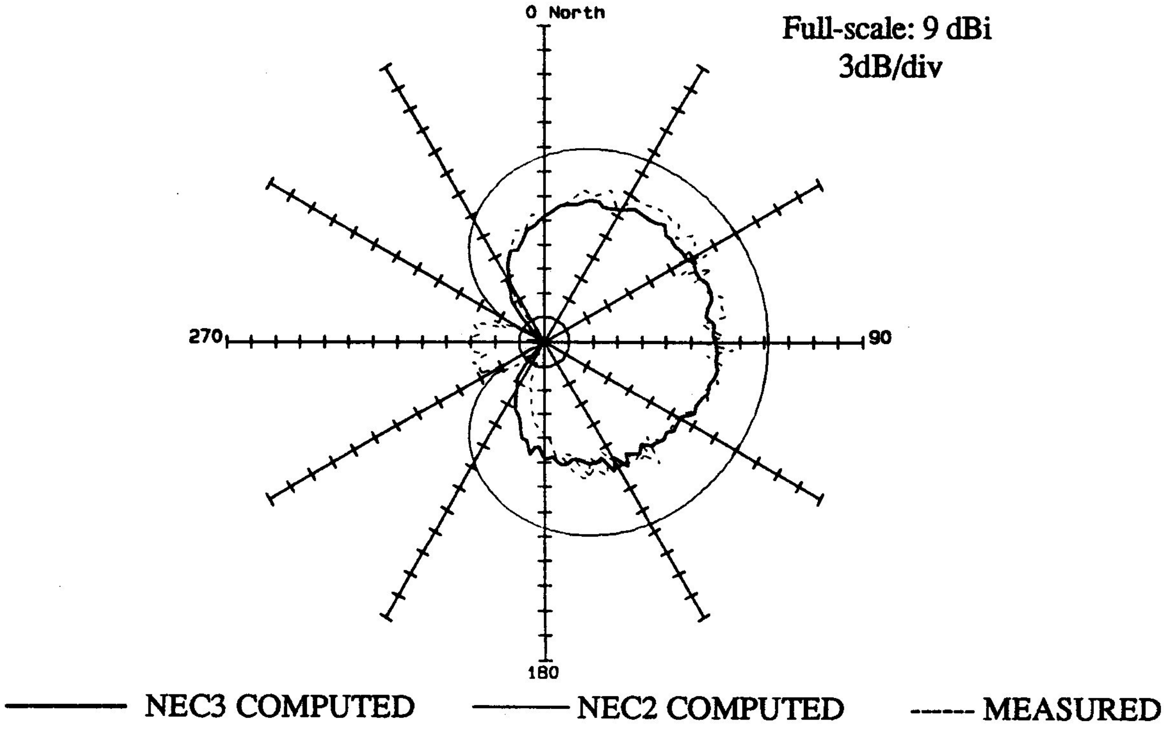


Figure 8. Gain versus azimuth for vertical polarization at 3.1925 MHz, 40° elevation ($\varepsilon_r = 18.5$, $\sigma = 4.3$ mS/m).

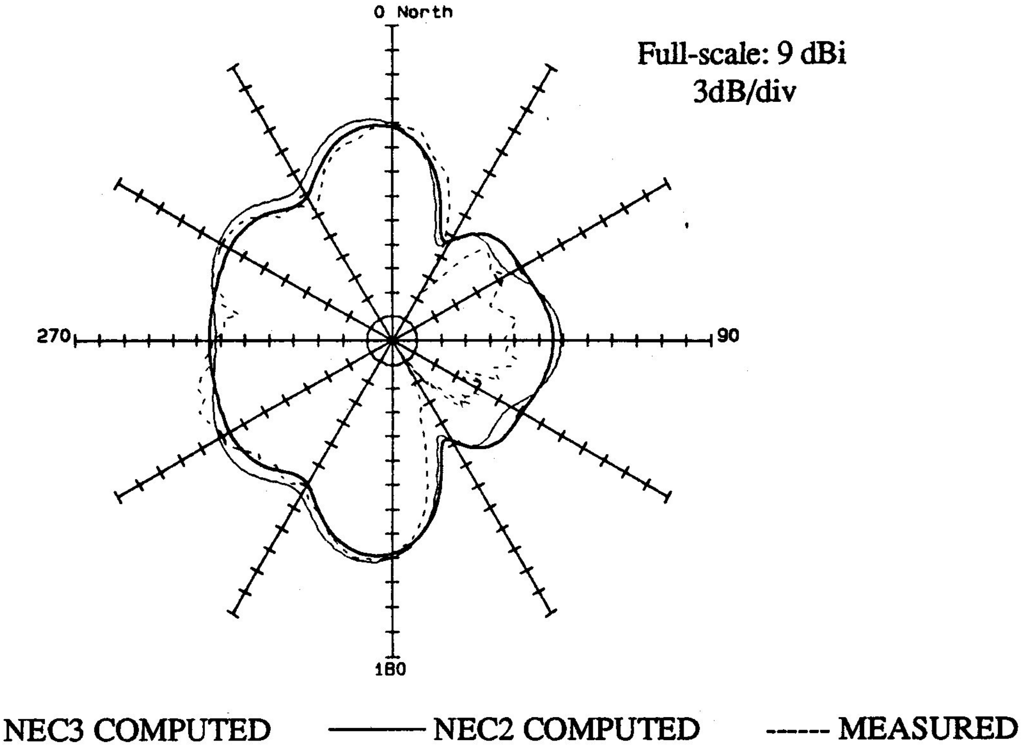


Figure 9. Gain versus azimuth for vertical polarization at 19.0475 MHz, 30° elevation ($\varepsilon_r = 8.9$, $\sigma = 10.8$ mS/m).

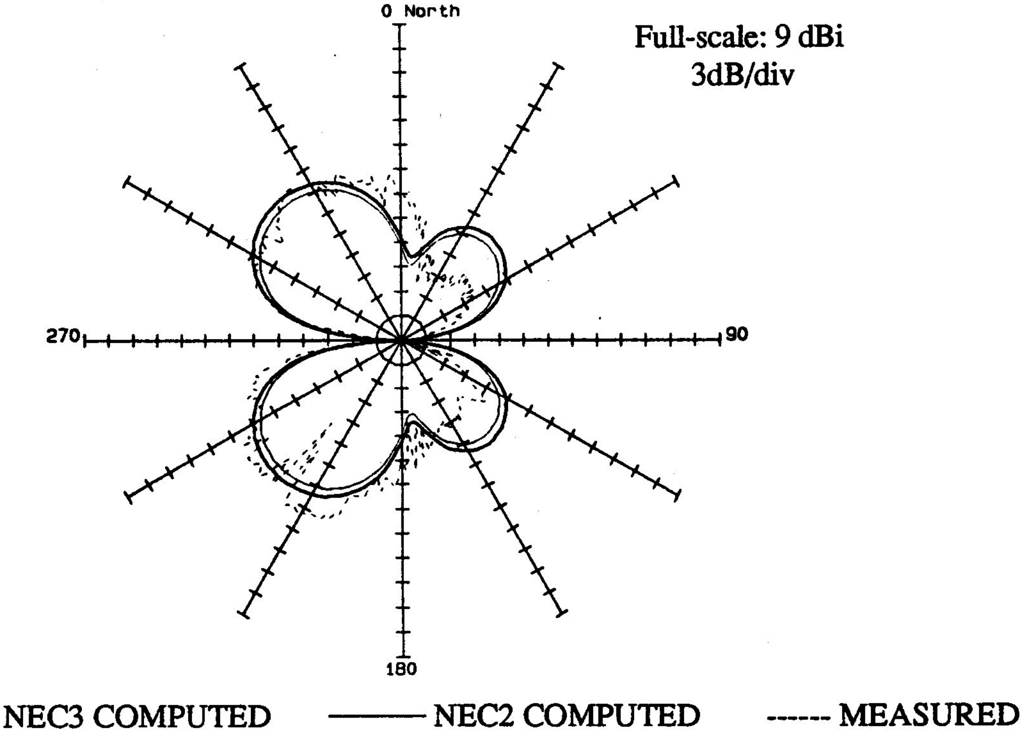


Figure 10. Gain versus azimuth for horizontal polarization at 10.12 MHz, 30° elevation ($\varepsilon_r = 8.7$, $\sigma = 6.7$ mS/m).

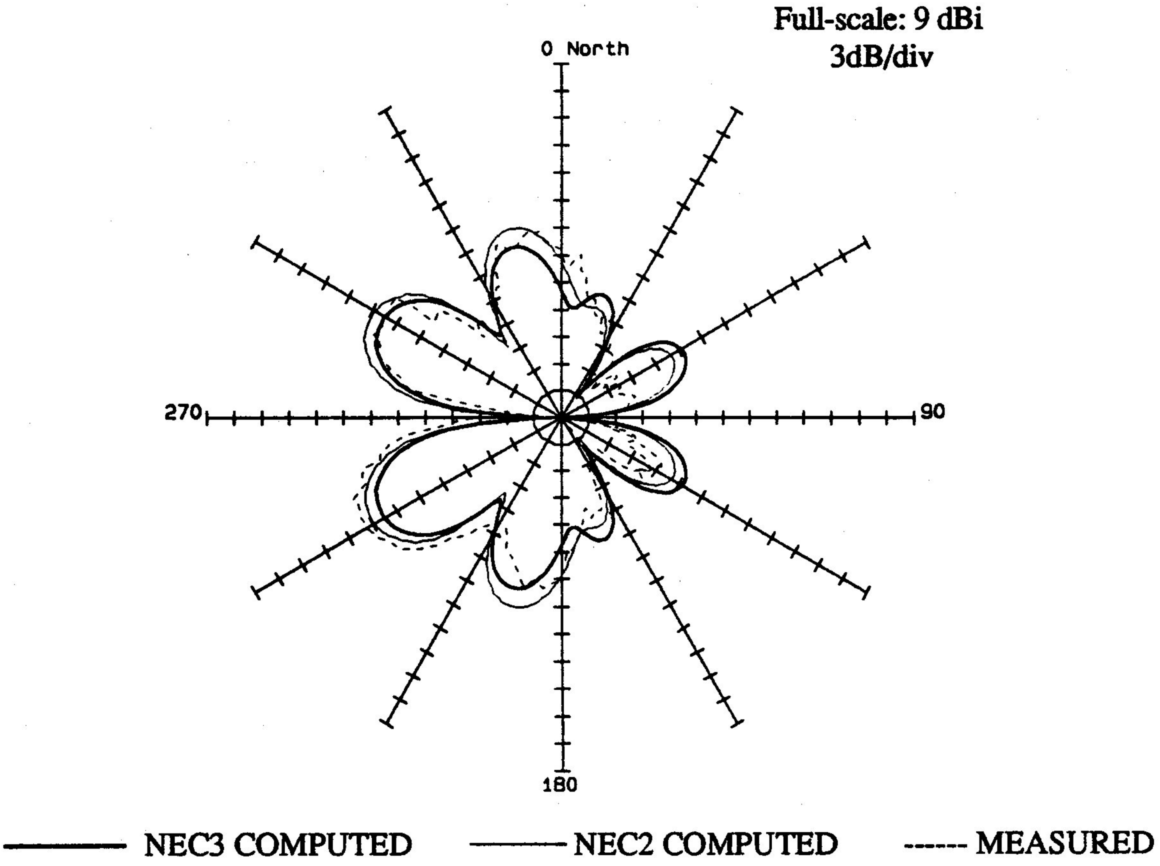


Figure 11. Gain versus azimuth for horizontal polarization at 19.0475 MHz, 30° elevation ($\varepsilon_r = 8.9$, $\sigma = 10.8$ mS/m).

CONCLUSIONS

A specific case study has been utilized to compare and contrast the accuracy and reliability of NEC2 and NEC3 radiation pattern predictions for hf wire antennas in close proximity to finite ground and with ground stakes extending into the earth. NEC3 shows more consistent modeling of pattern size and minor lobe structure in all calculated runs, while the NEC2's inability to adequately deal with ground stakes is reflected in the elevation plots and in lower frequency azimuth plots. Both models do an adequate job predicting azimuth plots, but overall accuracy is better with NEC3. For commercial design and manufacture of antennas, a NEC3 model can be developed that is good enough to require only a modest pattern measurement series at a few discrete frequencies. New intermediate frequency pattern behavior may then be predicted numerically with a high degree of confidence. Conversely, in less rigorous applications (such as amateur radio antenna analysis) NEC2 can be utilized to reliably predict a relative azimuth profile. Signal magnitude may be off on the order of 3 to 5 dB, but the overall shape of the major lobes and nulls should be sufficient for generating an overall operational profile of the antenna.

ACKNOWLEDGMENTS

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Tutorial Article

Development and application of finite element methods for electromagnetic scattering problems has been ongoing for more than thirty years. Currently there are mature finite element codes available commercially that are being applied in diverse areas including waveguide problems, RCS, printed circuits, and EMI modeling. However, research continues in many fundamental areas including automatic mesh generation, higher-order elements, and absorbing boundary conditions (ABCs) for open region problems.

Historically, node-based finite element formulations were first pursued extensively for electromagnetic scattering applications. However, there are several significant drawbacks of this approach including spurious solutions associated with the lack of enforcement of a divergence condition, difficulties in treating-edge conditions, and difficulties in easily handling boundary conditions at interfaces. While these issues have been pursued by many researchers with some success, edge-based finite elements introduced within the past ten years have provided an attractive alternative that fundamentally avoids the above difficulties. Jin-Fa Lee and Zolten Cendes were among the first researchers to apply and develop this approach for electromagnetic scattering problems. Dr. Lee has continued to pursue a number of fundamentally important issues in applying finite elements to printed circuits, optical problems, and waveguide discontinuities. In addition, he continues to pursue important areas associated with developing finite element CAD tools for these applications including automatic mesh generation. In the following tutorial article on *Tangential Vector Finite Elements* (edge elements), Dr. Lee presents at a "systems level", some recent work by his research group at Worcester Polytechnic Institute on automatic mesh generation a vector-space formulation of edge elements, and perfectly matched layer absorbing boundary conditions for open region problems.

I am pleased that Dr. Lee has contributed this article to the *ACES Newsletter*. Jin-Fa Lee was born in Taipei, Taiwan in 1960. He received the B.S. Degree from the National Taiwan University in 1982, and the M.S. and Ph.D degrees in electrical engineering from Carnegie Mellon University in 1986 and 1989, respectively. From 1988 to 1990 he was with ANSOFT Corp., where he developed several CAD/CAE finite element programs for modeling three-dimensional microwave and millimeter-wave circuits. From 1990 to 1991 he was a Post-Doctoral Fellow in the Electromagnetic Communications Laboratory at the University of Illinois at Urbana-Champaign. Currently, he is an assistant professor in the Department of Electrical Engineering at Worcester Polytechnic Institute. Dr. Lee's current research interests are analyses of numerical methods, couplings of active and passive components in high-speed electronic circuits, automatic mesh generations, and EM field propagation in linear and/or nonlinear media.

If you have ideas or suggestions for future tutorial articles, or would like to contribute a tutorial article to the newsletter, please feel free to contact me:

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I would greatly welcome suggestions and contributions.

TANGENTIAL VECTOR FINITE ELEMENTS AND THEIR APPLICATION TO SOLVING ELECTROMAGNETIC SCATTERING PROBLEMS

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1 INTRODUCTION

The problem of computing electromagnetic wave scattering, either in a semi-closed domain like a waveguide discontinuity, or in an open domain such as RCS calculations, has been a topic of much theoretical and practical importance. To address this issue, Finite Element Methods (FEMs) have been applied extensively. Furthermore, some recent breakthroughs are also helping the development of a user-friendly CAD/CAE environment for design engineers to simulate EM scattering problems on his/her computer. Of particular interest in this paper, closely tied with the research activities in the author's laboratory, are the *automatic mesh generation process* [3]; *tangential vector finite element basis functions* [9]; and, the *perfectly matched absorber (PMA) for use as an absorbing boundary condition* [1].

These research topics are the main subjects herein, and the paper is organized as follows: Section II describes some of the basic algorithms that are employed in the implementation of the automatic tetrahedral mesh generator developed at the Worcester Polytechnic Institute; a brief explanation of the *spurious modes* using the *Helmholtz decomposition diagram* is presented in section III; Section IV summarizes the famous *Whitney elements*, both 1-forms and 2-forms; the extension of the Whitney (edge) elements to higher-order vector finite elements which are free of spurious modes is discussed in section V; a preliminary result of a perfectly matched anisotropic absorber for use as an ABC in FEM application is included in section VI; and, finally, the author concludes and points out areas that in his opinion require intensive research efforts.

2 AUTOMATIC MESH GENERATION

Due to recent improvements in computer technology, in particular massively parallel machines, the size of engineering problems which are practical to analyze using the finite element method is dramatically larger than before. This makes it increasingly important to automate the mesh generation process, so that creation of a mesh does not become a bottleneck in the analysis of a product design. Furthermore, if mesh generation can be fully automated, then it becomes feasible to embed the entire finite element analysis (including the mesh generation) in a feedback loop in which the mesh can be selectively refined to ensure accurate numerical solutions.

For the purpose of automating the mesh generation process, triangles and tetrahedra have overwhelming advantages over other types of elements because they are simplices in 2 and 3 dimensions, respectively. *Delaunay tessellation* [4] is a convenient and proven way to automatically discretize any arbitrary problem geometry into a group of triangles and tetrahedra in two and three dimensions, respectively. Commercial software based upon the use of the Delaunay algorithm and its variants are now commonly employed in the finite element analyses with reasonably satisfactory results.

However, the standard *Delaunay* tessellation has several drawbacks. They are: the difficulties in resolving degenerate situation (more than four vertex points sharing the same circumsphere); the creation of slivery tetrahedra (tetrahedra that are almost *flat*); and, sometimes due to *bad* point distribution, *hot* spots (points that are connecting too many other points) are abundant. Herein, we present some techniques which deviate from the strict Delaunay tessellation aiming to circumvent the above mentioned difficulties in 3D mesh generation. The techniques that we use which enable us to fully automate the mesh generation process are mainly *face swapping algorithms*, and the *constrained gradient smoothing technique.*

2.1 Face Swapping Algorithm

In general, swapping the diagonal of two neighboring facets in 2D mesh generation can not be extended to 3D. However, there are a few local modifications in 3D based on the *swapping* concept which can be used to improve the quality of an existing mesh. Here, only the *2-to-3* modification and its counterpart *3-to-2* modification are discussed, although, many other similar swappings are also performed in the present implementation [7]. By performing the swappings, the 3D mesh is modified locally so that the overall quality measure of a set of neighboring tetrahedra is increased. It is also required that the outer surface of the set of tetrahedra is not changed. This is necessary to ensure that the swapping will not create an *invalid* tessellation. Shown in Fig. 1 is the *2-to-3* modification. Two tetrahedra having a common facet can be replaced by three tetrahedra which have a common edge connecting the two nodes not on the common facet. Thus the common facet is removed. The *3-to-2* modification is simply the opposite of the *2-to-3* modification.

2.2 Constrained Gradient Smoothing Technique

Although, Delaunay tessellation can be used to generate a FEM mesh automatically, it does not guarantee that *bad* elements are avoided. Particularly, in three dimensions, the occurrences of the *slivery* tetrahedra are frequent. The quality of the resultant mesh strongly depends on the given point distribution. Theoretically, there are three approaches to help ease this problem. They are: (i) to compute , *a-priori*, an optimal points distribution for a given problem geometry (too expensive and maybe too difficult); (ii) to adjust the location of the points in the *add-a-point* process

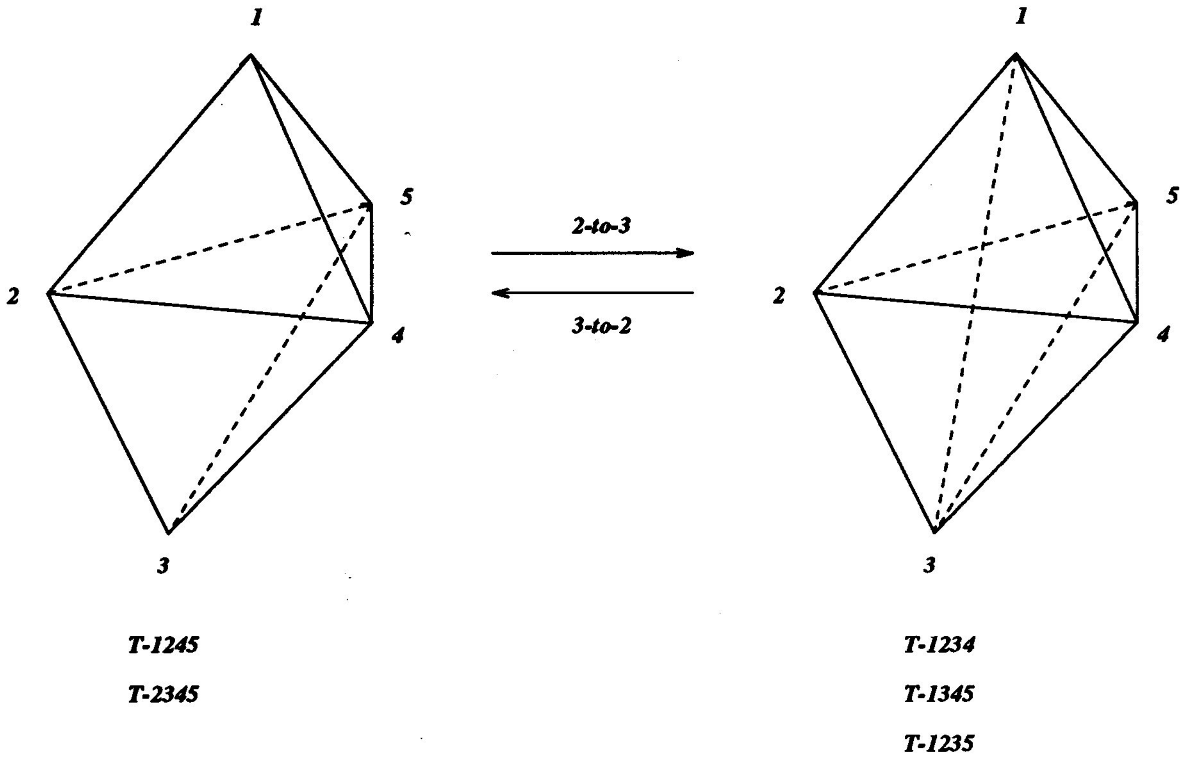


Figure 1: 2-to-3 and 3-to-2 triangular face swappings.

dynamically in the hope of generating a good quality tessellation; and, (iii) to move the mesh points to new locations after a FEM mesh is created in order to improve the mesh quality. The process of moving mesh points around to new locations but maintaining the topology of the mesh is referred to as *smoothing* in the literature [4]. In our implementation, we combine both the second and the third approaches. When a new point is added in the mesh refinement process, a local smoothing is performed which is then followed by a local face swapping procedure to result in a local optimal tessellation. Moreover, once the entire mesh is obtained, a global smoothing in conjunction with face swappings are employed to give a much better quality FEM mesh. However, unlike the most commonly used *Laplacian* smoothing [4] algorithm which simply places the point at the geometric center of its neighboring (connected) points, we formulate the mesh smoothing as a constrained optimization problem.

Quality Definition

For a given FEM mesh, its quality must be assessed in order to determine whether the mesh is satisfactory. Although the definition of mesh quality is not unique, and usually depends also on the solution procedures used for the FEM, nonetheless a *good* definition based upon engineering sense will serve as a useful tool in our discussion of mesh smoothing algorithms. The quality factor that is used in this work is defined as a normalized ratio of the in-radius R_{in} to the circum-radius R_{out} of a tetrahedron. In-radius and circum-radius are the radii of the inner-scribe sphere and the circum-scribe sphere, respectively. For an *ideal tetrahedron* $R_{out} = 3R_{in}$, therefore, we normalize the ratio of these two radii to range from 0 to 1. Consequently, the quality factor for a tetrahedron is defined as

$$Q = \frac{3R_{in}}{R_{out}}. \tag{1}$$

Mesh Smoothing

In the current approach, we formulate the *mesh* smoothing as a constrained optimization problem. Using the definition of the quality factor in the previous section, it can be stated as

For a mesh point P, find X, Y, Z such that

$$\mathcal{F}(X,Y,Z) = \max_{(x,y,z)\in S} \mathcal{F}(x,y,z) = \max_{(x,y,z)\in S} \Pi\, Q(T_i) \tag{2}$$

where $Q(T_i)$ is the quality factor for the tetrahedron formed by face i, and the point P. The constraints are set in such a way that the resultant mesh will always be a valid mesh, namely, there are no overlapping tetrahedra. Note that the derivatives of the objective function thus defined in Eq. 2 can not be evaluated analytically, and the exact optimal solution to Eq. 2 will be difficult to find. Therefore, we have adopted an *engineering* approach to come up with a satisfactory, not necessarily optimal, solution with affordable computation time.

Our approach starts by first calculating the radius of a constraint sphere S, centered at the current location of a point P, whose radius is the minimum distance of P to the side faces. In this way, it can be guaranteed that for all the points inside S, we will have a valid tessellation. Secondly, we find the search direction for optimization by applying finite differences to approximate the gradient of the objective function $\mathcal{F}$ at P. Finally, the optimal location which optimizes $\mathcal{F}$ along the gradient direction is obtained using a bisection method. Once the new/better location is identified, the point P is subsequently placed there.

2.3 Sample Mesh Results

Table I:

	Coax-to-Waveguide	Microstrip Filter
Q	# of Tetrahedra	# of Tetrahedra
$0.0 \leq Q(T) \leq 0.1$	19	62
$0.1 \leq Q(T) \leq 0.2$	13	360
$0.2 \leq Q(T) \leq 0.3$	30	1215
$0.3 \leq Q(T) \leq 0.4$	389	2883
$0.4 \leq Q(T) \leq 0.5$	1172	4060
$0.5 \leq Q(T) \leq 0.6$	3798	5334
$0.6 \leq Q(T) \leq 0.7$	8885	7236
$0.7 \leq Q(T) \leq 0.8$	11152	7743
$0.8 \leq Q(T) \leq 0.9$	7663	5784
$0.9 \leq Q(T) \leq 1.0$	2273	1618

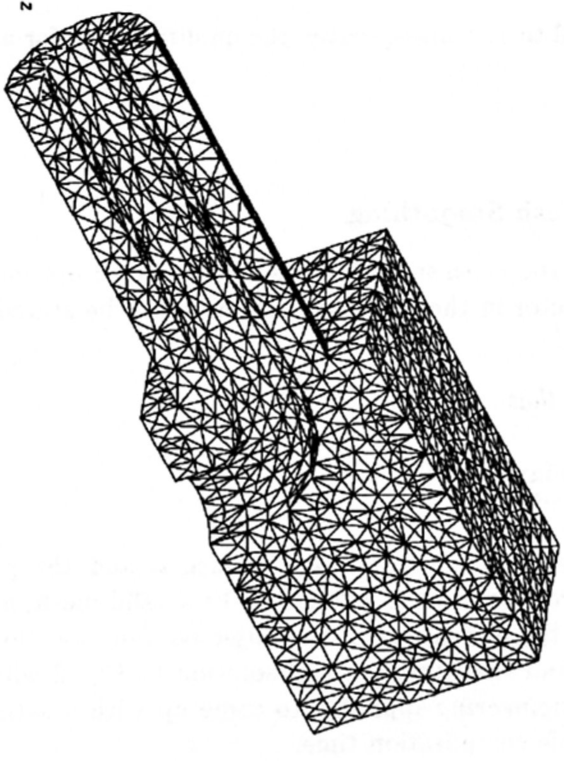


Figure 2: The FEM mesh for a coax-to-waveguide discontinuity.

In the present automatic mesh generation, the implementation starts by employing the Watson algorithm to construct a *minimum valid* tetrahedral mesh [3]. It is then followed by adding points in the mesh using a series of local swapping and smoothing operations until the problem domain is discretized sufficiently fine. Finally, a few iterations of global swapping and smoothing operations are performed to further improve the mesh quality. Two sample mesh results obtained by using this approach are shown in Fig. 2 and Fig. 3 for a coax to waveguide transition and a microstrip filter structure, respectively. Moreover, Table I summarizes the quality distribution of these two FEM meshes. Overall, the distributions show that the resultant meshes are more or less satisfactory.

3 MORE ON SPURIOUS MODES

It is well known that in modeling electromagnetic problems using vector finite element methods (FEMs), many formulations give spurious modes, or non-physical solutions. Furthermore, as observed by many previous authors, these spurious modes [19] do not satisfy $\nabla \bullet \epsilon\vec{E} = 0$ (or $\nabla \bullet \mu\vec{H} = 0$) which is required for physical solutions. In this paper, we will show that so long as the FEM formulation allows for a discrete Helmholtz decomposition, as described in more detail later, the numerical procedure will be stable and spurious modes will not occur. Moreover, for a stable FEM formulation, all the computed eigenmodes for microwave cavities with $k^2 \neq 0$, will satisfy $\nabla \bullet \epsilon\vec{E} = 0$, at least in the weak sense [11].

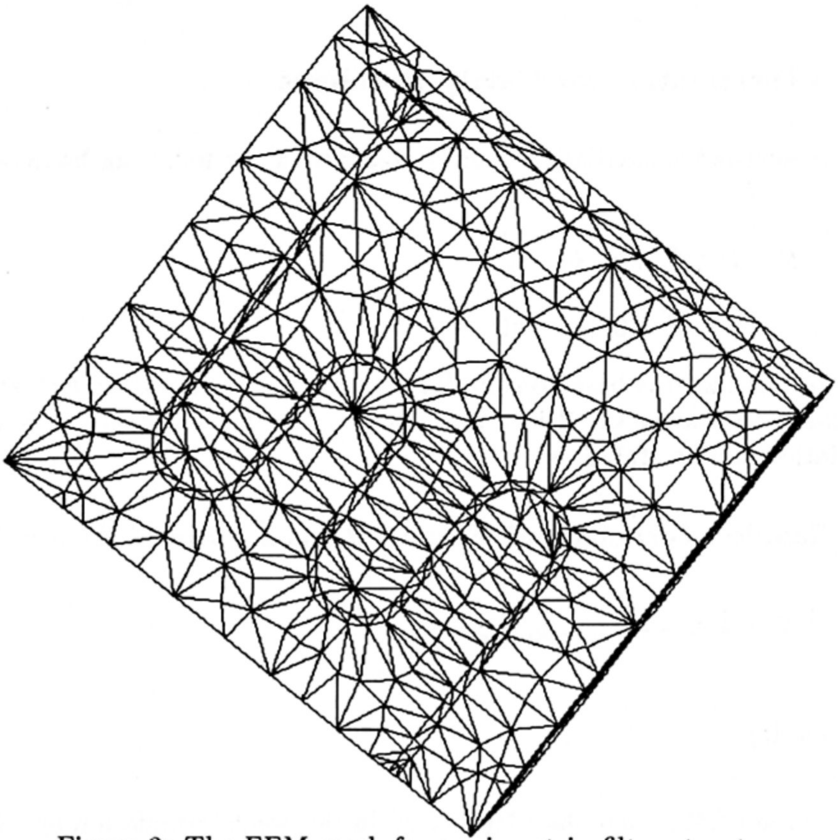


Figure 3: The FEM mesh for a microstrip filter structure.

To facilitate the discussion, the notations that will be employed throughout is given below.

3.1 Notation

Ω : problem domain.

Ω^h : a tetrahedral discretization of Ω with largest mesh size h, $\Omega^h = \{K_i\}$.

K_i : a tetrahedron belonging to the discretization Ω^h.

$L^2(\Omega)$ $= \{\phi \mid \int_\Omega \phi^2 d\Omega < \infty\}$

$\mathcal{L}^2(\Omega)$ $= \{\vec{v} \mid \int_\Omega \vec{v} \bullet \vec{v} d\Omega < \infty\}$

$\mathcal{P}_k(\Omega^h)$: the collection of piece-wise polynomial functions defined over Ω^h with orders at most k.

$\mathcal{H}(\text{curl}, \Omega)$ $= \{\vec{v}, \nabla \times \vec{v} \in \mathcal{L}^2(\Omega)\}$.

$\mathcal{H}_k(\text{curl}, \Omega^h)$ $= \left\{\vec{v} \mid \vec{v} \in \mathcal{H}(curl, \Omega^h) \cap \left(\mathcal{P}_{k+1}(\Omega^h)\right)^3, \nabla \times \vec{v} \in \left(\mathcal{P}_k(\Omega^h)\right)^3\right\}$.

r^h : the projection operator.

$\mathcal{H}^n(\Omega)$ $= \{u \mid \int_\Omega \mid \partial^\alpha u \mid d\Omega < \infty, \mid \alpha \mid \leq n\}$.

$\mathcal{V}^h$: a finite dimensional vector function space of vector fields defined over the discretization Ω^h.

$\mathcal{S}^h$: a finite-dimensional space of scalar functions defined over Ω^h.

3.2 Galerkin Formulation for Cavity Problems

In the analysis of microwave cavities, it usually starts with the following boundary value problem (B.V.P.):

$$\nabla \times \frac{1}{\mu_r} \nabla \times \vec{E} - k^2 \epsilon_r \vec{E} = 0 \quad in \quad \Omega$$

$$\hat{n} \times \vec{E} = 0 \quad on \quad \partial\Omega \tag{3}$$

The discussions in this paper is based on the E-field formulation, however, a straightforward modification can be made to analyze the H-field formulation. For the B.V.P. in Eq. 3, the corresponding Galerkin formulation can be stated as

Definition 1 (Galerkin Formulation) *Find $k \in R$ and $\vec{E} \in \mathcal{H}(curl, \Omega)$ such that*

$$< \frac{1}{\mu_r} \nabla \times \vec{E}, \nabla \times \vec{\Psi} > -k^2 < \epsilon_r \vec{E}, \vec{\Psi} >= 0 \tag{4}$$

$\forall \vec{\Psi} \in \mathcal{H}(curl, \Omega)$.

The application of the FEM is to replace $\mathcal{H}(curl, \Omega)$ in this weak formulation by a finite-dimensional subspace $\mathcal{V}$, or more precisely by a sequence of finite-dimensional subspaces $\mathcal{V}^h \subset \mathcal{H}(curl, \Omega)$ [16]. Over each space $\mathcal{V}^h$, the Galerkin procedure leads to the solution of a generalized eigenmatrix equation, with the dimension of $\mathcal{V}^h$. Ultimately, the Galerkin procedure for the B.V.P. Eq. 3 over a finite-dimensional subspace $\mathcal{V}^h$ can be formulated as
Find $k^h \in R$ and $\vec{E}^h \in \mathcal{V}^h$ such that

$$< \frac{1}{\mu_r} \nabla \times \vec{E}^h, \nabla \times \vec{\Psi}^h > - \left(k^h\right)^2 < \epsilon_r \vec{E}^h, \vec{\Psi}^h >= 0 \tag{5}$$

$\forall \vec{\Psi}^h \in \mathcal{V}^h$.

3.3 Discrete Helmholtz Decomposition

Theorem 1 *Assuming that for a chosen finite-dimensional subspace $\mathcal{V}^h \subset \mathcal{H}(curl, \Omega^h)$, the Helmholtz decomposition diagram (HDD) shown in Fig. 4 holds. Then it can be shown that*

$\forall \vec{E}^h \in \mathcal{V}^h$

$\exists s^h \in \mathcal{S}^h$ *such that*

$$\vec{E}^h = \nabla s^h + \vec{w}^h; \qquad \nabla s^h, \vec{w}^h \in \mathcal{V}^h \tag{6}$$

$$\begin{tikzcd}
 & & \nabla\times\mathcal{G}^h \equiv 0 & \\
\mathcal{V}^h \arrow[d, "\nabla\bullet"'] & \supset & \mathcal{G}^h = r^h(\nabla\mathcal{S}) \arrow[u, "\nabla\times"] & \nabla\mathcal{S} \arrow[l, "r^h"'] \arrow[d, "\nabla\bullet"] \\
\nabla\bullet\mathcal{V}^h & & \equiv & \nabla^2\mathcal{S}
\end{tikzcd}$$

Figure 4: Helmholtz Decomposition Diagram.

Equation 6 implies that

$$\mathcal{V}^h = (\nabla\mathcal{S}^h)\oplus(\nabla\mathcal{S}^h)^{\perp}. \tag{7}$$

Remarks:

- The projection operator r^h is defined as

  $$r^h : \mathcal{L}^2\left(\Omega^h\right) \longrightarrow \mathcal{V}^h \tag{8}$$

  namely, for a vector $\vec{v} \in \mathcal{L}^2(\Omega^h)$, we say $\vec{v}^h$ is its projection in $\mathcal{V}^h$ iff

  $$\left\langle \vec{v} - \vec{v}^h, \vec{w}^h \right\rangle \equiv 0, \quad \forall \vec{w}^h \in \mathcal{V}^h \tag{9}$$

  and write $\vec{v}^h = r^h(\vec{v})$.

Proof:

- Since $\vec{E}^h \in \mathcal{V}^h$ is a vector field, we can apply the Helmholtz theorem, and decompose $\vec{E}^h$ into a linear combination of solenoidal and irrotational fields. Namely,

  $$\vec{E}^h = \nabla s + \vec{w}, \quad \nabla\bullet\vec{w} = 0 \tag{10}$$

  Note, that in general, as a result of this decomposition, ∇s and $\vec{w}$ may no longer be in the subspace $\mathcal{V}^h$.

- Applying the projection operator r^h to both sides of Eq. 10, we have

  $$\vec{E}^h = r^h(\nabla s) + r^h(\vec{w}) \tag{11}$$

  In Eq. 11, we have already made use of the fact $r^h(\vec{E}^h) = \vec{E}^h$.

- From the Helmholtz decomposition diagram, it states that $r^h(\nabla s) \in \mathcal{G}^h$ and $\nabla \times \left(r^h(\nabla s)\right) = 0$. Therefore, we conclude that there exists a scalar function $s^h \in L^2(\Omega^h)$ such that

$$r^h(\nabla s) = \nabla s^h. \tag{12}$$

  Namely, when the Helmholtz decomposition diagram holds for $\mathcal{V}^h$, a gradient field will be mapped into a gradient field in $\mathcal{V}^h$.

- The collection of such functions s^h forms a finite-dimensional subspace $\mathcal{S}^h \subset L^2(\Omega^h)$, and we can write

$$\mathcal{V}^h = (\nabla \mathcal{S}^h) \oplus (\nabla \mathcal{S}^h)^{\perp}. \tag{13}$$

Note also, that in general, the projection of the solenoidal component $\vec{w}^h = r^h(\vec{w})$ is not necessarily solenoidal anymore. But, for certain vector FEMs (e.g. edge elements), the decomposition goes one step further and it becomes

$$\mathcal{V}^h = (\nabla \mathcal{S}^h) \oplus (\nabla \times \mathcal{F}^h) \tag{14}$$

which means that a solenoidal field will be projected to a solenoidal field in $\mathcal{V}^h$ as well. We shall elaborate on this point later.

3.4 $\nabla \bullet \epsilon \vec{E} = 0$ Condition

As shown in the previous section, a FEM formulation which satisfies the *Helmholtz Decomposition Diagram* also permits a discrete version of the Helmholtz decomposition. In this section, we will show that the existence of a discrete Helmholtz decomposition allows control over the divergence of the electric flux density, $\epsilon \vec{E}^h$. By picking $\vec{\Psi}^h = \nabla p^h$ in Eq. 5, with $p^h \in \mathcal{S}^h$, and use the fact that $\nabla \times \nabla p^h = 0$, we see that

$$k_i'^2 < \epsilon_r \vec{E}_i^h, \nabla p^h >= 0, \quad \forall p^h \in \mathcal{S}^h. \tag{15}$$

Equation 15 has two possible consequences:

1. $k_i' = 0$; (trivial solutions), and,
2. $< \epsilon_r \vec{E}_i^h, \nabla p^h >= 0, \quad \forall p^h \in \mathcal{S}^h$. This implies that $\nabla \bullet \epsilon_r \vec{E}_i^h = 0$, at least in the distributional sense.

Therefore, we conclude that for any FEM formulation, which satisfies the *Helmholtz Decomposition Diagram*, all of its non-trivial eigenpairs will satisfy $\nabla \bullet \epsilon_r \vec{E}_i^h = 0$, in the weak sense, and consequently, no spurious modes will occur.

4 WHITNEY ELEMENTS

In previous section, we have seen that a vector FEM formulation in which a discrete Helmholtz decomposition exists will be stable and free of spurious modes. There are such finite element formulations, the most widely adopted so far is the Whitney 1-forms or edge elements. The development of the edge elements, or more general the Whitney forms, started long before the finite element methods. The Whitney forms were defined original from a topological point of view, however, they also provide a natural discrete approximation of Maxwell's equations. The Whitney 0-forms and 3-forms, which are the usual scalar interpolations on the node and within the tetrahedron are familiar [17]. Therefore, let us focus only on the 1-forms and 2-forms.

4.1 Whitney 1-Forms and 2-Forms

In 1957, Whitney [18] described a family of polynomial forms on a simplicial mesh with the following properties:

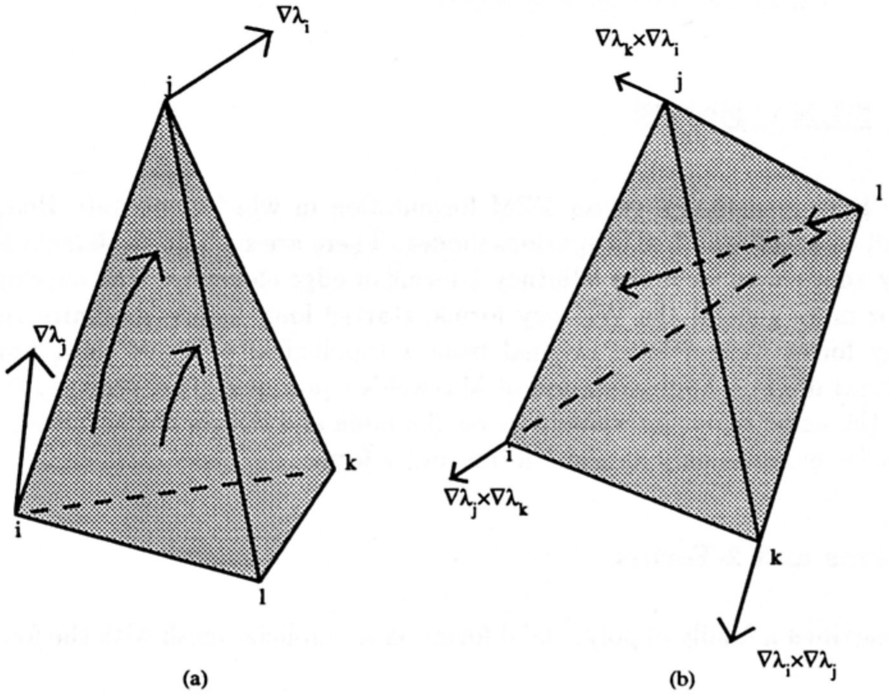
1. They are polynomials of, at most, the first degree on tetrahedra.
2. They "match" on the facets, in a sense to be clarified later.
3. They are uniquely determined from their integrals on p-simplices.

We say that two p-forms "match", or "conform", on a surface if they take the same values at any given set of p vectors tangent to the surface. In particular, Whitney elements of 1-forms require that the tangential components of the vector field, $\vec{u}$, be continuous, and for the Whitney 2-forms, the normal components of the field $\vec{u}$ must agree on both sides of the surface. Moreover, the Whitney elements are defined in such a way that p-forms are determined by integrals on p-simplices. Therefore, 1-forms are correctly represented with edge-variables, 2-forms by facet-variables, and so on. Whitney 1-forms are associated with mesh edges and thus can be physically interpreted as the circulation of the vector field $\vec{u}$ along a particular edge {i, j}. In the case of Whitney 2-forms, the facet variable, defined on facet {i, j, k}, is the integral of $\vec{u}$ across the facet. Consequently, it is the flux of $\vec{u}$ through facet {i, j, k}.

We now describe the basis functions that define the Whitney 1- and 2-forms. For the Whitney 1-forms, each edge in the tetrahedral mesh contributes an independent basis function. In other words, the degrees of freedom are defined on the edge. Thus, Whitney 1-forms are also called edge-elements [2]. As shown in Fig. 5(a), the corresponding vector field, $\vec{w}_{ij}$, attached to edge {i, j} is

$$\vec{w}_{ij} = \lambda_i \nabla \lambda_j - \lambda_j \nabla \lambda_i, \tag{16}$$

where the λ's are the bary-centric (or simplex) coordinates. Since $\nabla \lambda_j$ is orthogonal to facet {i,k,l} and $\nabla \lambda_i$ to facet {j,k,l}, the field turns around the axis k-l, its "central axis". It can be shown that the tangential part of $\vec{w}_{ij}$ is continuous across facets like {i,j,k}, and that its circulation is 1 along



(a) (b)

Figure 5: (a) 1-form $\vec{w}_{i,j}$, and (b) 2-form $\vec{w}_{i,j,k}$

edge {i,j} and 0 along all other edges [2]. Any vector field $\vec{u}$, can now be approximated by a linear combination of Whitney 1-forms as

$$\vec{u} = \sum_{\{i,j\}} u^{ij} \vec{w}_{ij}, \tag{17}$$

where u^{ij}, as mentioned earlier, is the *circulation* of $\vec{u}$ along edge {i,j}.

Similarly, as shown in Fig. 5(b), the vector field for the Whitney 2-forms (or facet elements) associated with a particular facet {i, j, k} can be written as:

$$\vec{w}_{ijk} = \lambda_i \nabla\lambda_j \times \nabla\lambda_k + \lambda_j \nabla\lambda_k \times \nabla\lambda_i + \lambda_k \nabla\lambda_i \times \nabla\lambda_j. \tag{18}$$

Now, instead of an axial field, we have a central field (the center is the fourth vertex) on each of the two tetrahedra which have facet {i,j,k} in common. It can be shown that the field has normal continuity, and its flux across facet {i,j,k} is equal to 1. Such fluxes relate to the degrees of freedom of the element. Any vector field $\vec{u}$, can then be approximated by a linear combination of Whitney 2-forms as

$$\vec{u} = \sum_{\{i,j,k\}} u^{ijk} \vec{w}_{ijk}, \tag{19}$$

where $u^{i,j,k}$ is the flux of $\vec{u}$ through facet {i,j,k}.

Finally, it is important to note that the relationship between the edge elements and facet elements is such that

$$\nabla \times \left(W^1\right) \subset W^2, \tag{20}$$

where W^1, W^2 are the vector spaces generated by edge elements and facet elements, respectively.

4.2 Whitney 1-Form (Edge Elements) & Helmholtz Decomposition

Within each element, the electric field can be expressed as

$$\vec{E} = \sum_{ij} e^{ij} \left(\lambda_i \nabla \lambda_j - \lambda_j \nabla \lambda_i\right) \tag{21}$$

To find the corresponding $\mathcal{S}$, the set of scalar functions whose gradient form the irrotational components, for the edge elements, we shall first evaluate $\nabla \bullet \vec{E}$. The result is

$$\begin{aligned} \nabla \bullet \vec{E}\,|_K &= 0 \\ \nabla \bullet \vec{E} &= \delta \quad \text{on } \partial K \end{aligned} \tag{22}$$

The notation $\nabla \bullet \vec{E} = \delta$ on ∂K means that there could be *point* charges exist on element boundaries resulted from the fact that the normal component of $\vec{E}$ could be discontinuous across element boundaries for edge elements. From Eq. 22, it can be shown that

$$\mathcal{S} = \left\{ s \mid s \in \mathcal{P}_1(\Omega^h) \cap \mathcal{H}^1(\Omega^h) \right\}. \tag{23}$$

Furthermore, by noting that

$$\nabla \mathcal{S} = \left\{ \vec{v} \mid \vec{v} \in \left(\mathcal{P}_0(\Omega^h)\right)^3 \cap \mathcal{H}(curl, \Omega^h), \nabla \times \vec{v} = 0,\ \vec{v} \text{ is tangentially continuous over } \Omega^h \right\}, \tag{24}$$

is a subset of $\mathcal{V}^h$, i.e. $\nabla \mathcal{S} \subset \mathcal{V}^h$. Therefore, we have

$$r^h(\nabla \mathcal{S}) = \nabla \mathcal{S} \tag{25}$$

for edge elements. Moreover, $\forall \vec{E}^h \in \mathcal{V}^h$, and by applying the Helmholtz theorem, we have

$$\vec{E}^h = \nabla s + \vec{w} \tag{26}$$

where $\vec{w}$ is a solenoidal field. Applying the projection operator to both sides of the equation, we have

$$r^h(\vec{E}^h) = r^h(\nabla s) + r^h(\vec{w}) \tag{27}$$

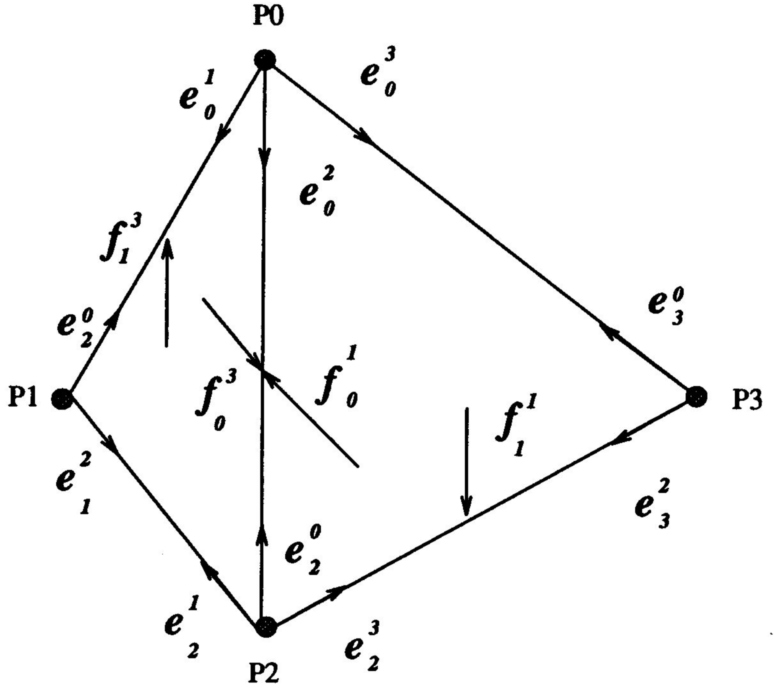


Figure 6: $\mathcal{H}_1(curl)$ TVFEM.

From Eq. 25 and the fact that $r^h(\vec{E}^h) = \vec{E}^h$, we conclude

$$\vec{w}^h = r^h(\vec{w}) = \vec{w}. \tag{28}$$

This implies the following decomposition for the edge elements

$$\mathcal{V}^h = (\nabla \mathcal{S}^h) \oplus (\nabla \times \mathcal{F}^h). \tag{29}$$

5 HIGHER-ORDER TVFEMs

Despite its beauty, the Whitney 1-forms (edge elements) have one serious drawback. In using edge elements, the interpolation errors in both $\vec{E}$ and $\vec{H}$ fields are only first order. Subsequently, it requires many unknowns to model a typical scattering problem with acceptable accuracy. In this section, we shall discuss two higher order TVFEMs, one is the $\mathcal{H}_1(curl)$ TVFEM (by Nedelec in 1980 [12]), and the other is the second-order TVFEM (by Nedelec in 1986 [13]).

5.1 $\mathcal{H}_1(curl)$ TVEFM

As early as 1980, Nedelec introduced a family of mixed finite elements in R^3 that is unisolvent as well as conforming in $\mathcal{H}(curl)$. It is interesting to notice that the Whitney 1-forms (edge elements) are also the lowest order realization of the mixed finite elements that Nedelec described in his 1980 contribution. The next higher order scheme which is incomplete to second-order for the vector field

$\vec{E}$, but is complete to first-order in the range of the *curl* operator, i.e. the magnetic field $\vec{H}$. In this case, the vector fields are interpolated/approximated by components in the vector function space $\mathcal{H}_1(curl,\Omega^h)$. Consequently, we shall refer to this finite element as $\mathcal{H}_1(curl)$ TVFEM.

The unknowns in the three-dimensional $\mathcal{H}_1(curl)$ TVFEM are assigned as shown in Fig. 6. In each tetrahedron there are two unknowns on each edge, and two unknowns associated with each triangular face. Therefore, a tetrahedral element has total twenty degrees of freedom to describe the vector field. The vector basis functions for the $\mathcal{H}_1(curl)$ TVFEM is subsequently divided into two groups, the *edge basis functions* and the *face basis functions*. Moreover, let us write, $\forall \vec{E}^h \in \mathcal{H}_1(curl,\Omega^h)$

$$\vec{E}^h = \vec{E}^h_{edge} + \vec{E}^h_{face}, \tag{30}$$

where $\vec{E}^h_{edge}$ and $\vec{E}^h_{face}$ are the vectors spanned by *edge* and *face* vector bases, respectively.

Edge Vector Basis Functions

The two vector basis functions for the two unknown coefficients, for example, e_0^1 and e_1^0 are $\lambda_0\nabla\lambda_1$ and $\lambda_1\nabla\lambda_0$, respectively. Subsequently,

$$\vec{E}^h_{edge} = \sum_i \sum_j e_i^j \lambda_i \nabla \lambda_j, \qquad i \neq j. \tag{31}$$

The physical meaning of the unknown e_i^j can be seen simply by noting that

$$\vec{E}^h_{edge} \bullet \vec{t}_i^j \,|_{P_i} = e_i^j. \tag{32}$$

Face Vector Basis Functions

The two vector basis functions associated with unknowns, say, f_0^3 and f_1^3, are

$$\begin{aligned} \vec{W}_0^3 &= 4\lambda_0\left(\lambda_1\nabla\lambda_2 - \lambda_2\nabla\lambda_1\right) \\ \vec{W}_1^3 &= 4\lambda_1\left(\lambda_2\nabla\lambda_0 - \lambda_0\nabla\lambda_2\right), \end{aligned} \tag{33}$$

respectively. The other six vector basis functions can be obtained simply by index rotations. The vector $\vec{E}^h_{face}$ can now be written as

$$\vec{E}^h_{face} = \sum_{i=0}^{3} \sum_{j=0}^{1} f_j^i \vec{W}_j^i. \tag{34}$$

Finally, the physical meanings of the unknown coefficients are

$$\begin{aligned} \vec{E}^h \bullet \vec{t}_k^l \,|_{\lambda_i=\lambda_k=0,\lambda_j=\lambda_l=0.5} &= f_0^i + 0.5e_l^j \\ \vec{E}^h \bullet \vec{t}_l^j \,|_{\lambda_i=\lambda_l=0,\lambda_j=\lambda_k=0.5} &= f_1^i + 0.5e_j^k \end{aligned} \tag{35}$$

where i, j, k, l form cyclic indices. The existence of a discrete Helmholtz decomposition for the $\mathcal{H}_1(curl)$ elements along with other finite elements are discussed in a recent article by Monk [11].

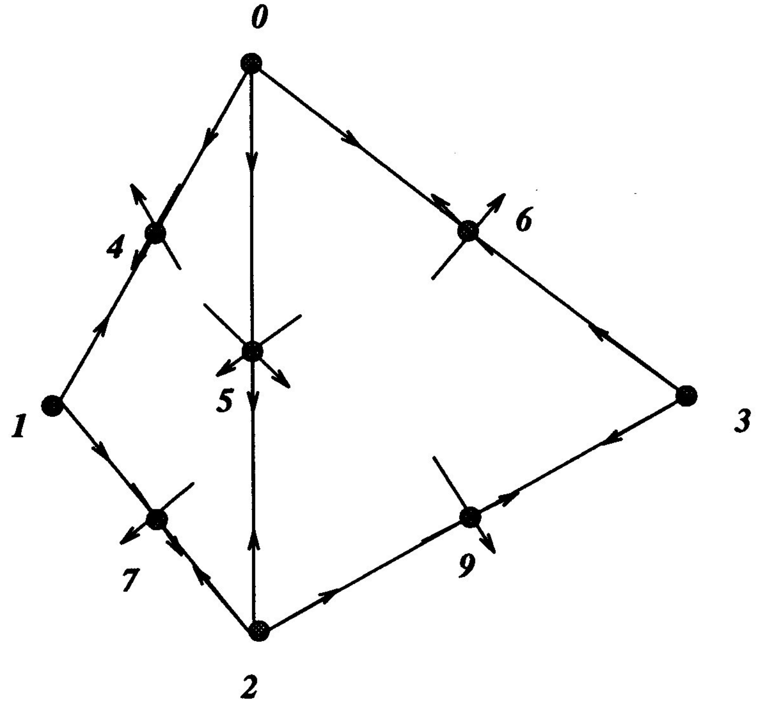


Figure 7: Second-Order TVFEM.

5.2 Second-Order TVFEM

Shown in Fig. 7 is the unknown configuration of the second-order TVFEM. Note the similarity in this FEM with the conventional nodal FEM. Namely, for each node there are three unknowns associated with it. Therefore, within each element, we start by writing the vector field $\vec{E}$ as it would be in the nodal FEM case, i.e.

$$\vec{E}^h = \sum_{i=0}^{9} \vec{E}_i W_i, \tag{36}$$

where $\vec{E}_i$ is the field value at node i and W_i is the usual second-order nodal finite element basis function for node i. However, instead of using the E_x, E_y, E_z components as the unknown coefficients, in the second-order TVFEMs the unknown coefficients are the field projections along edges or faces. For example, at node 0, we have

$$\begin{aligned} \vec{E}_0 \bullet \hat{t}_0^1 &= e_0^0 \\ \vec{E}_0 \bullet \hat{t}_0^2 &= e_1^0 \\ \vec{E}_0 \bullet \hat{t}_0^3 &= e_2^0. \end{aligned} \tag{37}$$

By solving $\vec{E}_0$ in terms of these three projections, we have

$$\begin{aligned} \vec{E}_0 &= e_0^0 \frac{\hat{t}_0^2 \times \hat{t}_0^3}{\hat{t}_0^1 \bullet \left(\hat{t}_0^2 \times \hat{t}_0^3\right)} \\ &+ e_1^0 \frac{\hat{t}_0^3 \times \hat{t}_0^1}{\hat{t}_0^2 \bullet \left(\hat{t}_0^3 \times \hat{t}_0^1\right)} \end{aligned}$$

$$+ \quad e_2^0 \frac{\vec{t}_0^1 \times \vec{t}_0^2}{\vec{t}_0^3 \bullet \left(\vec{t}_0^1 \times \vec{t}_0^2\right)}. \tag{38}$$

The other nodal vector values can be derived in a similar way.

Second-Order TVFEM and Helmholtz Decomposition

Once again, let $\mathcal{V}^h$ represent the trial and test vector function spaces for the second-order TVFEM. By taking the divergence of $\mathcal{V}^h$ as suggested by Fig. 6, we have

$$\begin{aligned} \nabla \bullet \mathcal{V}^h \,|_K &= \mathcal{P}_1(\Omega^h) \\ \nabla \bullet \mathcal{V}^h &= \delta \quad \text{on } \partial K. \end{aligned} \tag{39}$$

The corresponding scalar function space $\mathcal{S}$ in Fig. 6 is therefore determined to be

$$\mathcal{S} = \left\{ s \mid s \in \mathcal{P}_3(\Omega^h) \cap \mathcal{H}^1(\Omega^h) \right\}, \tag{40}$$

the set of continuous, piece-wise cubic polynomial functions over Ω^h. Furthermore, the gradient operator maps $\mathcal{S}$ into

$$\nabla \mathcal{S} = \left\{ \vec{v} \mid \vec{v} \in \left(\mathcal{P}_2(\Omega^h)\right)^3 \cap \mathcal{H}(curl, \Omega^h), \nabla \times \vec{v} = 0, \vec{v} \text{ is tangentially continuous over } \Omega^h \right\}. \tag{41}$$

From Eq. 41, we see that $\nabla \mathcal{S} \subset \mathcal{V}^h$ and $r^h(\nabla \mathcal{S}) = \nabla \mathcal{S}$. Therefore, similar to edge elements, we conclude a discrete Helmholtz decomposition exists for the second-order TVFEM as

$$\mathcal{V}^h = (\nabla \mathcal{S}^h) \oplus (\nabla \times \mathcal{F}^h) \tag{42}$$

6 PERFECTLY MATCHED ABSORBER

Traditionally, the truncation of finite element solution domains has been accomplished through the application of local or global boundary operators to the outer surface of the finite element mesh [6, 10]. There is a tradeoff involved between the accuracy of global operators (boundary integral solutions) and the efficiency of local operators (ABC's). Alternative methods of truncation based on placing a layer of absorbing material at the outer boundary of the solution domain have been widely investigated in the past [8]. These absorbers posses the same desirable property as local boundary operators: they preserve the sparse structure of the system matrix generated by the finite element method. Unfortunately, their accuracy is also similar to that of local boundary operators.

Recently, J.P. Berenger [1] introduced a high performance absorbing layer for FDTD simulations based on a non-physical generalization of Maxwell's equations. By splitting Cartesian field components into two subcomponents (i.e. $H_z = H_{zx} + H_{zy}$), this "Perfectly Matched Layer" (PML) approach yields a reflectionless interface between free space and the absorbing material. Berenger and others [5] have demonstrated that PML provides a much more accurate truncation scheme for

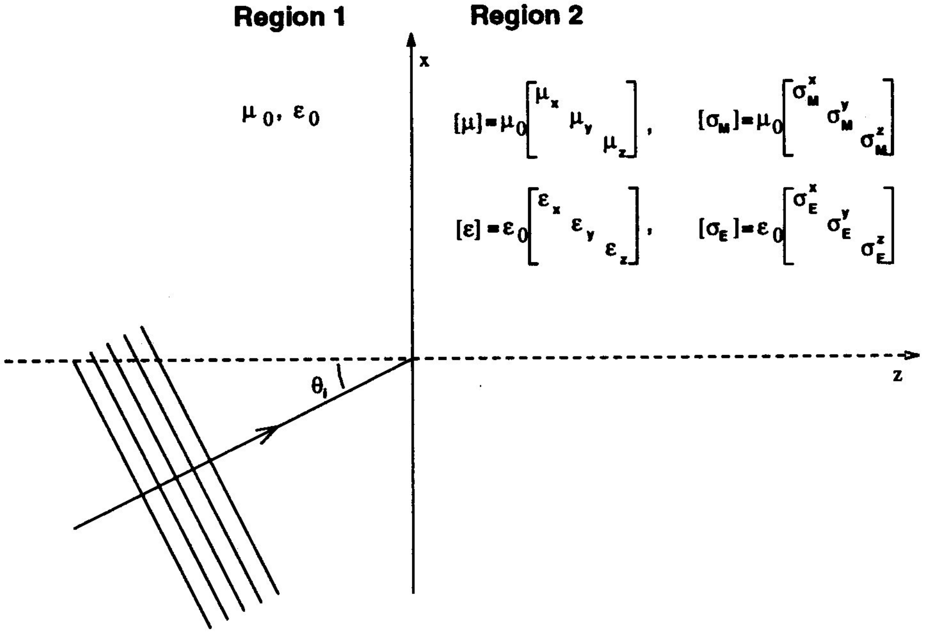


Figure 8: Reflection of a plane wave between free space and a "diagonal anisotropic" medium.

FDTD grids. A reflectionless interface between free space and a lossy material absorber can also be achieved when the bulk properties of the material, ϵ and μ, are anisotropic [15]. Specifically, if ϵ and μ are appropriately chosen complex diagonal tensors, the impedance of the medium will be independent of the frequency, polarization, and incident angle of the wave at the interface. A similar approach can also be found in Ref. [14].

6.1 Waves in Diagonally Anisotropic Media

Referring to Fig. 8, the time-harmonic form of Maxwell's equations can be written as

$$\begin{aligned} \vec{\nabla}\cdot[\overline{\epsilon}]\vec{E} &= 0 \\ \vec{\nabla}\cdot[\overline{\mu}]\vec{H} &= 0 \\ \vec{\nabla}\times\vec{E} &= -j\omega[\mu]\vec{H}-[\sigma_M]\vec{H} \\ \vec{\nabla}\times\vec{H} &= j\omega[\epsilon]\vec{E}+[\sigma_E]\vec{E} \end{aligned} \tag{43}$$

where $[\overline{\mu}]$ and $[\overline{\epsilon}]$ are the effective permeability and permittivity of Region 2, respectively. In this paper, we concentrate on materials with $[\overline{\mu}]$ and $[\overline{\epsilon}]$ diagonal in the same coordinate system.

$$\begin{aligned} [\overline{\mu}] &= \mu_0\begin{pmatrix} \mu_x+\frac{\sigma_M^x}{j\omega} & 0 & 0 \\ 0 & \mu_y+\frac{\sigma_M^y}{j\omega} & 0 \\ 0 & 0 & \mu_z+\frac{\sigma_M^z}{j\omega} \end{pmatrix} \\ [\overline{\epsilon}] &= \epsilon_0\begin{pmatrix} \epsilon_x+\frac{\sigma_E^x}{j\omega} & 0 & 0 \\ 0 & \epsilon_y+\frac{\sigma_E^y}{j\omega} & 0 \\ 0 & 0 & \epsilon_z+\frac{\sigma_E^z}{j\omega} \end{pmatrix} \end{aligned} \tag{44}$$

Furthermore, we select $[\bar{\epsilon}]$ and $[\bar{\mu}]$ such that

$$\frac{[\bar{\epsilon}]}{\epsilon_0} = \frac{[\bar{\mu}]}{\mu_0} = [\Lambda] = \begin{pmatrix} a & 0 & 0 \\ 0 & b & 0 \\ 0 & 0 & c \end{pmatrix}. \tag{45}$$

Consequently, Eq. 43 reduces to

$$\begin{aligned} \vec{\nabla} \cdot [\Lambda]\vec{E} &= 0 \\ \vec{\nabla} \cdot [\Lambda]\vec{H} &= 0 \\ \vec{\nabla} \times \vec{E} &= -j\omega\mu_0[\Lambda]\vec{H} \\ \vec{\nabla} \times \vec{H} &= j\omega\epsilon_0[\Lambda]\vec{E}. \end{aligned} \tag{46}$$

To derive the dispersion relation (DR) for Eq. 46, we start by assuming a plane wave solution,

$$\begin{aligned} \vec{E}(\vec{r};t) &= \vec{\mathcal{E}} e^{-j(\vec{k}\cdot\vec{r}-\omega t)} \\ \vec{H}(\vec{r};t) &= \vec{\mathcal{H}} e^{-j(\vec{k}\cdot\vec{r}-\omega t)}, \end{aligned} \tag{47}$$

where $\vec{k} = k_x\hat{x} + k_y\hat{y} + k_z\hat{z}$, and $\vec{\mathcal{E}}$ and $\vec{\mathcal{H}}$ are constant vectors. Substituting Eq. 47 into Eq. 46 results in

$$\begin{aligned} \vec{k} \cdot [\Lambda]\vec{\mathcal{E}} &= \vec{k} \cdot [\Lambda]\vec{\mathcal{H}} = 0 \\ \vec{k} \times \vec{\mathcal{E}} &= \omega\mu_0[\Lambda]\vec{\mathcal{H}} \\ \vec{k} \times \vec{\mathcal{H}} &= -\omega\epsilon_0[\Lambda]\vec{\mathcal{E}}. \end{aligned} \tag{48}$$

An easy way to derive the DR and expression for the fields of wave solutions is to employ the following change of variables

$$\begin{aligned} \vec{\mathcal{E}}' &= [\Lambda]^{\frac{1}{2}}\vec{\mathcal{E}} \\ \vec{\mathcal{H}}' &= [\Lambda]^{\frac{1}{2}}\vec{\mathcal{H}} \\ \vec{k}' &= \frac{1}{\sqrt{abc}}[\Lambda]^{\frac{1}{2}}\vec{k}. \end{aligned} \tag{49}$$

Eq. 48 then becomes

$$\begin{aligned} \vec{k}' \cdot \vec{\mathcal{E}}' &= \vec{k}' \cdot \vec{\mathcal{H}}' = 0 \\ \vec{k}' \times \vec{\mathcal{E}}' &= \omega\mu_0\vec{\mathcal{H}}' \\ \vec{k}' \times \vec{\mathcal{H}}' &= -\omega\epsilon_0\vec{\mathcal{E}}'. \end{aligned} \tag{50}$$

Since $\vec{k}'$ is perpendicular to both $\vec{\mathcal{E}}'$ and $\vec{\mathcal{H}}'$, the DR is obtained as

$$\vec{k}' \cdot \vec{k}' = k_0^2 = \omega^2\mu_0\epsilon_0 \tag{51}$$

Finally, by combining Eqs. 49 and 51, the DR becomes

$$\frac{k_x^2}{bc} + \frac{k_y^2}{ac} + \frac{k_z^2}{ab} = k_0^2. \tag{52}$$

The solution of Eq. 52 describes an ellipsoid in k space.

6.2 TE and TM Modes in Region 2

In the xz plane, as shown in Fig. 8, the DR of Eq. 52 reduces to

$$\begin{aligned} k_x &= k_0\sqrt{bc}\sin\theta \\ k_y &= 0 \\ k_z &= k_0\sqrt{ab}\cos\theta. \end{aligned} \tag{53}$$

Furthermore, we can decompose any plane wave into a linear combination of TE$_y$ ($\vec{E}$ has only a y component) and TM$_y$ ($\vec{H}$ has only a y component) modes. The detailed derivation of these modes in Region 2 is presented in this section. We start by writing the $\vec{E}$ field as

$$\vec{E}(\vec{r}) = \mathcal{E}\hat{y}e^{-j(k_x x+k_z z)}. \tag{54}$$

From Eq. 48 we have

$$\begin{aligned} H_x &= \frac{-1}{\omega\mu_0 a}k_z\mathcal{E} \\ H_z &= \frac{1}{\omega\mu_0 c}k_x\mathcal{E}. \end{aligned} \tag{55}$$

$$\tag{56}$$

Therefore, for TE$_y$ modes in Region 2, the complete description for the fields can be written as

$$\begin{aligned} \vec{E}(\vec{r}) &= \mathcal{E}\hat{y}e^{-jk_0(\sqrt{bc}\sin\theta x+\sqrt{ab}\cos\theta z)} \\ \vec{H}(\vec{r}) &= \sqrt{\frac{\epsilon_0}{\mu_0}}\left(-\sqrt{\frac{b}{a}}\cos\theta\hat{x}+\sqrt{\frac{b}{c}}\sin\theta\hat{z}\right)e^{-jk_0(\sqrt{bc}\sin\theta x+\sqrt{ab}\cos\theta z)}. \end{aligned} \tag{57}$$

Similarly, the complete description of the fields for TM$_y$ modes is

$$\begin{aligned} \vec{E}(\vec{r}) &= \left(+\sqrt{\frac{b}{a}}\cos\theta\hat{x}-\sqrt{\frac{b}{c}}\sin\theta\hat{z}\right)\mathcal{E}e^{-jk_0(\sqrt{bc}\sin\theta x+\sqrt{ab}\cos\theta z)} \\ \vec{H}(\vec{r}) &= \sqrt{\frac{\epsilon_0}{\mu_0}}\mathcal{E}\hat{y}e^{-jk_0(\sqrt{bc}\sin\theta x+\sqrt{ab}\cos\theta z)}. \end{aligned} \tag{58}$$

6.3 Reflection Coefficient

In this section we will derive the reflection coefficient for both TE and TM polarizations. For TE modes, the electric fields are written as

$$\begin{aligned} \vec{E}_i(r) &= \mathcal{E}\hat{y}e^{-jk_0(\sin\theta_i x+\cos\theta_i z)} \\ \vec{E}_r(r) &= R^{TE}\mathcal{E}\hat{y}e^{-jk_0(\sin\theta_i x-\cos\theta_i z)} \\ \vec{E}_t(r) &= T^{TE}\mathcal{E}\hat{y}e^{-jk_0(\sqrt{bc}\sin\theta_t x+\sqrt{ab}\cos\theta_t z)} \end{aligned} \tag{59}$$

where R^{TE} and T^{TE} are the reflection and transmission coefficients for TE_y polarization. Continuity of the electric field across the interface requires

$$1 + R^{TE} = T^{TE}, \tag{60}$$

and phase matching,

$$\sqrt{bc}\sin\theta_t = \sin\theta_i. \tag{61}$$

Using the DR (Eq. 53), continuity of the x component of the magnetic field across the interface gives

$$\cos\theta_i - R^{TE}\cos\theta_i = T^{TE}\sqrt{\frac{b}{a}}\cos\theta_t. \tag{62}$$

Solving for R^{TE} using Eqs. 60 and 62 gives

$$R^{TE} = \frac{\cos\theta_i - \sqrt{\frac{b}{a}}\cos\theta_t}{\cos\theta_i + \sqrt{\frac{b}{a}}\cos\theta_t}. \tag{63}$$

A similar procedure may be followed for finding the reflection coefficient of the TM polarizations, R^{TM}.

$$R^{TM} = \frac{\sqrt{\frac{b}{a}}\cos\theta_t - \cos\theta_i}{\cos\theta_i + \sqrt{\frac{b}{a}}\cos\theta_t}. \tag{64}$$

In Eqs. 63 and 64, θ_t is not independent of θ_i as shown by Eq. 61 and the equivalent in the TM derivation.

For the phase matching condition Eq. 61, we choose $\sqrt{bc} = 1$ so that the reflection coefficient will not be function of the incident angle. It follows that $\theta_i = \theta_t$. Eqs. 63 and 64 imply that in order for zero reflection to occur $a = b$, which is expected by the geometry of the problem. This zero reflection condition is independent of incident angle, polarization, and frequency.

Furthermore, since the complex constants a,b, and c are not independent (as shown above), only one complex number is required to specify the material properties of each medium. For example, the tensor required to provide a reflectionless interface in the xy plane and damp in the z direction is given by:

$$[\mu_r] = [\epsilon_r] = \begin{pmatrix} \alpha - j\beta & 0 & 0 \\ 0 & \alpha - j\beta & 0 \\ 0 & 0 & \frac{\alpha + j\beta}{(\alpha^2+\beta^2)} \end{pmatrix} \tag{65}$$

The wavelength in this absorbing medium is determined by α and the rate of attenuation in this medium is determined by β.

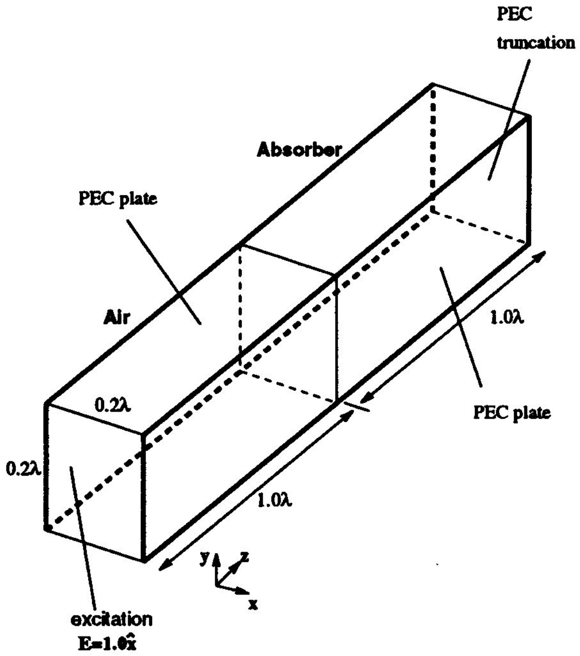


Figure 9: Geometry of the parallel plate TEM waveguide terminated with an anisotropic absorbing layer

6.4 Numerical Results

Numerical studies were conducted using one example problem. TEM wave propagation in a simple parallel plate waveguide was considered. The geometry of this example problem is shown in Fig. 9 below. The side walls of the structure are perfectly conducting. The structure is terminated by a metal backed absorbing layer. A TEM wave is excited at the opposite end. Two example results for this problem are shown in Fig. 10 and compared to the exact solutions.

The TEM waveguide problem revealed a drawback of using the anisotropic absorber for mesh truncation. Specifically, the matrix condition number grew significantly as the parameter β was increased. This led to unacceptable rate of convergence in the iterative matrix solver. Further investigation revealed that the matrix condition is sensitive to the value of α as well as β. For this example problem, the rate of convergence as a function of α is plotted for several values of β in Fig. 11.

Based on these observations, a near optimal choice of the parameter α is $\alpha = \beta$. Varying α along with β improved convergence rates considerably over using $\alpha = 1.0$, as shown in Fig. 12.

7 CONCLUSIONS AND LOOK-AHEAD

In this paper, several recent developments, based on the author's experiences, related to tangential vector finite element methods are presented. Although, in the past few years, we have witnessed many significant advancements in these areas, much still remains to be done. A robust/efficient automatic mesh generator and its relationship to the FEM solvers deserves much more attention.

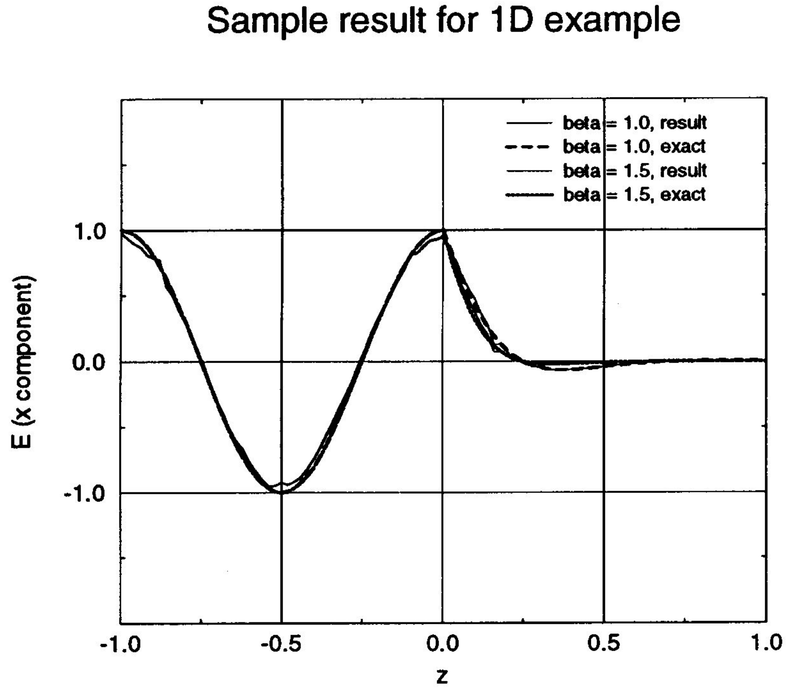


Figure 10: Result and exact solutions for $\beta = 1.0$ and $\beta = 1.5$

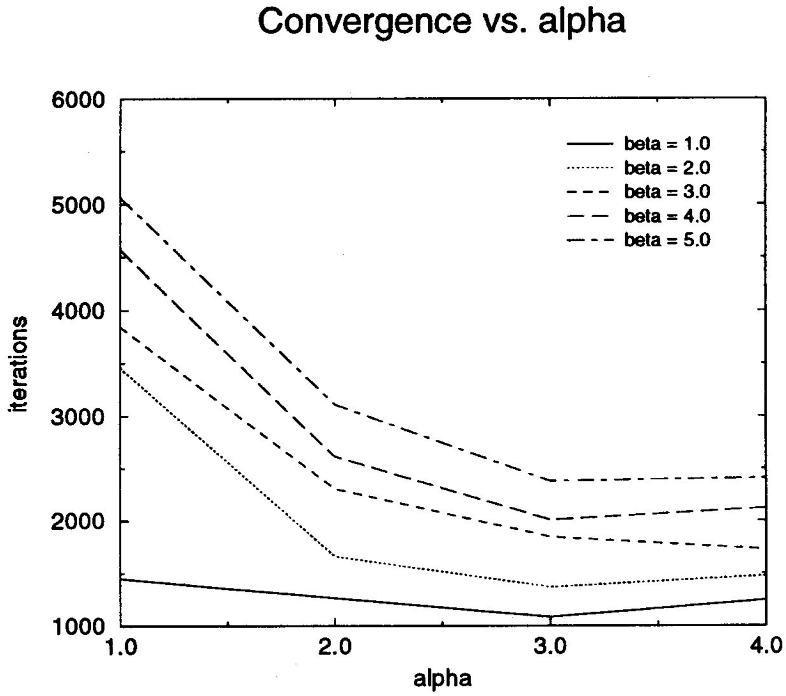


Figure 11: Number of iterations required for convergence of the matrix solution

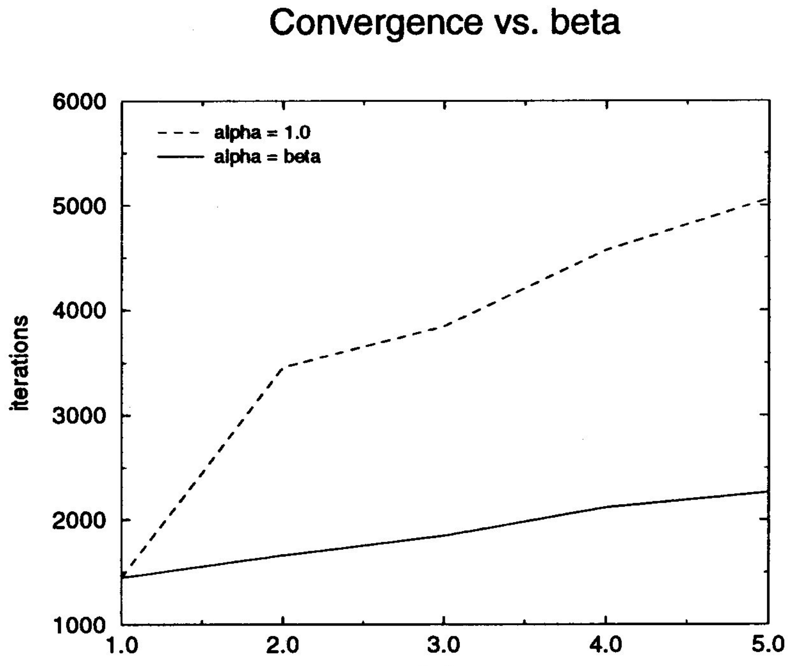


Figure 12: Number of iterations required for convergence of the matrix solution vs. β for $\alpha = \beta$ and $\alpha = 1.0$.

It is the author's experience (and others too) that *bad* FEM meshes usually result in *inaccurate* solutions and poor convergence in solving the matrix equation using conjugate gradient methods. Exactly how element shapes affect the matrix condition is not only theoretical challenging but practically important. Also, in generating the FEM meshes, should one pay attention to *average* mesh quality or to the *worst* case scenario? Linking together the mesher with the FEM solver in a feedback loop to perform adaptive mesh refinement is another subject of paramount significance. A good/accurate error analysis will be crucial in both the adaptive FEM process and the quality control of EM simulation software. Moreover, the continuing issue of *mesh truncation techniques* for open-region problems is still pressing. The PML/PMA technique is promising, but signs of problems are also appeared. The final *verdict* of this technique is yet to come.

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EDITORIAL

MOBILE ANTENNA DESIGN IN WIRELESS PERSONAL COMMUNICATION SYSTEMS

This is the second article in the series about the role of computational electromagnetics in the new era of wireless communications.

The market for mobile data communication services and end user equipment will more than quadruple from $1.7 billion in 1993 to $7.8 billion in 1999, a 28% compound annual growth rate. It is expected for this trend to continue into the 21st century. While the technological advancements involved in mobile wireless communication systems have dealt mostly with microelectronic design of RF/MW circuits, increasing attention is now being paid to "peripheral" areas of design such as the need for more efficient antennas. It is obvious from this last observation, that great opportunities exists for computational electromagnetics tools to be used as part of the design cycle of future wireless communications products.

The "boom" in wireless personal communication systems was the result of significant advances in digital communications over the last 10 years. Complete RF networks have now been put into a single chip (or small combination of chips). In the analog world it was very difficult to accomplish such microelectronic developments. For example, a whole phase lock loop (PLL) circuit can now be made completely digital and highly reduced in size. From simple pagers and cellular phones to data networks, application specific integrated circuits (ASIC) have dominated the development of RF communication systems. Presently, the telecommunication industry is emphasizing the need to reduce even further the number of components needed in personal communication systems with the objective of reducing size and increasing the reliability of such products. Lately, added attention has also been paid to make such systems more "efficient" which will reduce the battery size (e.g presently accounting for 50% of the size of a cellular phone), produce less heat dissipation, and less radiated power. Reducing the radiated power of such devices from several watts to less than 1 watt (200 mW to 600 mW foreseen) requires the design of better antennas.

The common "whip" antenna is still widely used wherever possible as it is in the case of cellular phones. The whip antenna has been used commonly in mobile radio both for vehicle installation and for handheld equipment. Antennas for handheld products are normally shortened by using loading inductance. Collinear antennas, like the vehicle antennas with their distinctive phasing coil, are used when there is a need for a greater antenna gain. Besides the simple dipole and monopole configurations, loop and patch antennas can also be used. Pagers make use of loop antennas comprising of etched copper traces around the perimeters of the circuit board. This approach permits the antenna to be located within the casing, a reasonable approach for a device commonly mounted on the waist. At the VHF frequencies, the loop is smaller than the full wavelength of a resonant loop, and matching is required through capacitive, linear or inductive loading. Patch antennas which are well known in radar and satellite applications are most useful above 2 GHz. The analysis and behavior of such antennas is well understood.

The role of computational electromagnetics in the design of wireless personal communication systems will probably be, most likely, in the development of "diversity" antennas. Diversity antennas will play a great role not only in the design of more efficient radiating system (i.e using less radiated power), but also in combating fading due to multipath. Furthermore, new requirements for such devices such as performing in severe electromagnetic environments, reduced size, and flat form factors will make the use of computational electromagnetics a necessity for antenna design. It may be even necessary for new antennas to cover more than one frequency. For example, a cellular phone using 900 MHz may need to communicate with a low orbit satellite operating at 2.5 GHz. Other products may use two or more of the unlicensed ISM bands in a single product as well. Very likely, there may be in some cases the need for using more that one antenna in a personal communication device, and such effects as mutual coupling and other interference problems will need to be addressed. Another factor that is also prompting the use of computational electromagnetics is the study of biological effects from electromagnetic radiation. The method of moments (with volume integral equation) and the finite difference time domain methods are presently being used to calculate the specific absorption rate (SAR) in the human body (head and neck primarily) from diverse types of personal communication systems. We will address this issue in more details in the next editorial.

The use of computational electromagnetics in antenna design has been around for over 20 years. However, most of this work was devoted primarily to "system" level needs. There are now new opportunities for research in a technology that is developing by leaps and bounds.

Reinaldo Perez
ACES Newsletter Chief Editor

BOOK REVIEW

MOBILE ANTENNA SYSTEM HANDBOOK

Editors: K.Fujimoto and J.R.James; Publisher: Artech House, 1994, 617 pages
Reviewed by R.Perez

Many of our readers are probably familiar with most of the antenna books presently in the market. The ACES membership contains some of the most skillful researches in antenna technology in the industry. Why do we want to review another antenna handbook ? Basically for two reasons: 1) antenna technology for mobile wireless communication systems is expected to evolve significantly within the next 10 years as the wireless personal communications revolution continues, and 2) this is not a book on antenna theory and methods for analysis and is not a book on computational electromagnetics for antenna analysis. The book is a timely account of the state of affairs of antenna techniques relating to communications, radar and navigation with emphasis on systems. This book is intended for those well versed in antenna theory/techniques who need to know a broad view of "what's going on" in the wireless telecommunication world.

The book covers the areas of interest in land, maritime, satellite, and aeronautical mobile systems. The chapters in the book are organized by classification-for-application. The main chapters separately address land, maritime, satellite, and aeronautical mobile systems. The final chapter, a glossary, gives a large classification and other details that have a strong coordinating role in the book. For each chapter attention is paid to design factors concerning propagation problems, operational requirements, and environmental conditions. The most important of the propagation problems, fading and the delay time effects caused by multipath propagation, are discussed in great detail. Discussion includes the relevance of various system parameters in antenna design such as communication zone, modulation schemes, frequency spectrum, interference, system signal-to-noise ratio, and bit error rate. The environmental conditions which affect mobile system performance directly are also discussed. Finally, proximity effects which are caused by the interaction between the antenna and the body of equipment, front-end circuits, and human operator are also treated since such are important factors that must be included in any antenna design.

The book is organized into eight chapters and one appendix. Chapter 1 titled "General View of Antennas in Mobile Systems" presents an overview of antenna systems, including some historical perspectives on mobile communications and related antenna technologies, trends, and antenna design concepts in modern mobile systems. Chapter 2 titled "Essential Techniques in Mobile Antenna System Design" discusses techniques applied specifically to mobile systems. The chapter discusses background material on technology, propagation, and antennas to support subsequent chapters. Problems related to propagation, radio transmission, choice of frequencies, communication zones, interference are treated. This is followed by the requirements for antenna systems, discussion of proximity effects, and the evaluation of antenna performance in a mobile environment.

Land mobile systems are divided into three chapters. Chapter 3 titled "Land Mobile Antenna System I" covers fundamental issues and techniques concerning land mobile antenna systems, such as propagation, the design and application of antennas for both base and mobile stations, and diversity system. Chapter 4 titled "Land Mobile Antenna Systems II" covers pagers and portable phone systems. The first part discusses the fundamentals and performance for the different antennas in paging receivers. Antenna design for different kinds of paging receivers, with shapes such as the conventional box, pencil, credit card are presented. In the second part of the chapter, antennas for portable phones are described. The last part of the chapter describes safety issues for portable mobile antenna systems. Of special interest to the computational electromagnetic community is the treatment, in chapters 3 and 4, of the method of moments and finite difference time domain approaches for analyzing and designing mobile antennas. The material presented is only application oriented, which means that no discussions are made on these techniques but instead the application of such techniques in designing these antennas are reviewed.

Chapter 5 titled: "Land Mobile Antenna Systems III" addresses antenna systems for different kinds of land mobile systems concerned with broadcast reception in a car, and communication in train and city bus systems. The design of a diversity antenna system for car broadcast reception needs the same technology that other mobile antenna systems. The challenge of receiving TV broadcasts from a moving vehicle is also addressed. In the chapter discussion are also made of how ferrite antennas can be used not only for receiving but also for transmitting . Chapter 6 titled:"Antennas for Mobile Satellite Systems" is devoted to mobile satellite systems embracing vehicle, shipborne, and broadcast applications. In the first half of the chapter antenna systems deployed in satellites such as INMARSAT are covered by introducing structure, performance and characteristics of such antennas. The material is of introductory nature only. In the second part of the chapter antenna systems for trains and cars to communicate with satellites are discussed. Finally, Chapter 7 titled: "Antenna Systems for Aeronautical Communications" is presented. At the introductory level the chapter describes a wide variety of airborne antenna systems for communication and navigation (slot, spiral, microstrip patch, helical, and dipole).

In this book chapters 2, 3 and 4 are highly recommended reading for those interested in this field. This book can be recommended as a reference in mobile antenna design.

LATSIS SYMPOSIUM 1995
on
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As an expert in the field of computational electromagnetics, you are invited to participate in the Latsis Symposiur 1995 19th-21st September 1995 at the Swiss Federal Institut of Technology in Zurich, Switzerland.

If you participate, you will have the opportunity to:

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- to see 15 invited lectures representing the state of the art in computational electromagnetics (see preliminary program below);
- to discuss the subject in workshops (the workshops include panel discussions, demonstrations and, if you like, a short presentation of your own work; see registration deadlines below):
- to obtain the Symposium's digest including both written papers of the invited lectures (up to 20 pages each) and abstracts of workshop contributions;
- to visit Switzerland and the delightful city of Zurich

Please reply by Fax, e-mail, phone, letter:

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- by 30 June 1995, if you want to get written information including hotel lists and travel information.
- Registration is possible at the Symposium.

TUESDAY SEPTEMBER 19

0730-0830	**REGISTRATION**	
0830-0840	**OPENING / WELCOME ADDRESS**	H. Baggenstos, ETH Zurich, Switzerland
0840-0920	"Error Estimate and Adaptive Meshing in Finite Element Solutions of Electric and Magnetic Problems", by G. Molinari, Univ. of Genova, Italy,	
0920-1000	"Recent Advances in the Electromagnetic Analysis of Integrated Microwave/Millimeter Wave and Optical Structures Using the Finite-Difference Time-Domain Method" by A.C. Cangellaris, Univ. of Arizona, USA	
1000-1020	**COFFEE BREAK**	
1020-1100	"Progress and Critical Issues in Time Domain Electromagnetic Modeling withTLM" by W.J.R. Hoefer, Univ. of Victoria, Canada	
1100-1140	"Computional Electromagnetics for Inverse Scattering" by K.J. Langenberg, Univ. Gesamthochscule Kassel, Germany	
1140-1220	"Circuit Oriented Electromagnetic Solutions in the Time and Frequency Domain" by A. Ruehli, IBM T.J. Watson, USA	
1220-1400	**LUNCH**	
1400-1800	**WORKSHOP**: NEARFIELD SIMULATIONS	

WEDNESDAY SEPTEMBER 20

0830-0910	"Numerical Computation and Measurement : Building an Experience Base for Code Validation", by C.W. Trueman and S. Mishra, Concordia Univ, Canada
0910-0950	"From MMP to Post-Modern Electrodynamics" by Ch. Hafner, ETH Zurich, Switzerland
0950-1010	**COFFEE BREAK**
1010-1050	"Quasi-Solution Conception in Wave Scattering Theory" by Y.A. Eremin, Moscow State Univ, Russia
1050-1130	"MMP - Dynamic Art, Static Stratagem or Common Technique?" by P. Leuchtmann, ETH Zurich, Switzerland
1130-1210	"The Methods of Auxiliary Sources in Applied Electrodynamics" by R. Zaridze, Tbilisi State Univ. Georgia
1210-1400	**LUNCH**
1400-1800	**WORKSHOP:** VISUALISATION
2000-2300	**SYMPOSIUM BANQUET**

THURSDAY SEPTEMBER 21

0830-0910	"Integral Equation Methods for Multilayer Structures" by F. Gardiol, ETH Switzerland
0910-0950	"Some Recent Developments in Integral Equation and PDE Methods for Electromagnetic Modeling of Large and Complex Structures" by R. Mittra, Univ. of Illinois, USA
0950-1010	**COFFEE BREAK**
1010-1050	"Field Analysis by an Integral Equation Method - New Features for SE Computation" by H. Singer, Techn. Univ. Hamburg-Harburg, Germany
1050-1130	"The Method of Lines for Modeling of Integrated Optics Structures", by R. Pregia, Fern Univ. at Hagen, Germany
1130-1210	"Scattering and Light Propagation in Three-Dimensional Anisotropic Media: A Numerical Green's Function Approach" by O.J.F. Martin, ETH Zurich, Switzerland
1210-1400	**LUNCH**
1400-1800	**WORKSHOP:** FIELD CALCULATION IN OPTICS

Organisation: Prof. H. Baggenstos, Prof. Dr. N. Kuster, PD Dr. Ch. Hafner, Dr. P. Leuchtmann, Dr. G. Klaus, and R. Ballisti

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CALL FOR PAPERS
1996 INTERNATIONAL SYMPOSIUM ON ANTENNAS AND PROPAGATION

ISAP '96

September 24-27, 1996, Chiba, JAPAN

The 1996 International Symposium on Antennas and Propagation (ISAP '96) will be held at the International Conference Hall of Makuhari Messe in Chiba, Japan, September 24 (Tuesday) through September 27 (Friday), 1996. This Symposium, the sixth ISAP, is sponsored and organized by the Institute of Electronics, Information and Communication Engineers (IEICE), and is held in cooperation with the International Union of Radio Science (URSI), the Professional Society on Antennas and Propagation of the Institute of Electrical and Electronics Engineers (IEEE/AP-S), and The Electronics Division of the Institution of Electrical Engineers (IEE).

OBJECTIVE

ISAP '96 is intended to provide an international forum for the exchange of information on the progress of research and development in antennas, propagation, electromagnetic wave theory, and related fields as shown in the SCOPE. It is also an important objective of this meeting to promote mutual interaction among participants.

SCOPE

This symposium will treat a wide range of subjects on antennas, propagation and electromagnetic wave theory as suggested below. Papers concerned with other aspects of these subjects will also be considered. In addition, special topics treating emerging technologies heralding a new era in radio communications and applications are invited for consideration.

Antennas and Related Topics

- Active Antennas
- Adaptive and Signal Processing Antennas
- Antenna Design, Analysis and Related Software
- Conformal Antennas
- Dual Polarization and Polarization Control Antennas
- Mobile Communication Antennas
- Reflector and Lens Antennas
- Small Antennas
- Antenna Feeds
- Array Antennas and Phased Arrays
- Broadband and Multifrequency Antennas
- Microstrip Antennas
- Digital Beam Forming
- Optical Technology in Antennas
- Satellite Communication Antennas
- Superconducting Antennas and Devices

Propagation and Related Topics

- Earth-space Propagation
- Millimeter-wave Propagation
- Radio Astronomy
- Remote Sensing and Polarimetry
- Noise and EM Radiation from Lines and Circuits
- Ionospheric Propagation
- Waves in Plasma
- Radio Meteorology
- Tropospheric and Terrestrial Propagation
- Propagation for Mobile Communications

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- Canonical Problems
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- Numerical Techniques
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- Visualization of EM Fields
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Special Topics

- Integrated and Millimeter-wave Antennas
- Microwave Power Transmission Technology
- Antennas and Propagation for Mobile Satellite Communication Systems
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- Recent Developments in Computational Electromagnetics
- Bioeffects and Biomedical Use
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Original papers are solicited that have not been presented previously and that describe new contributions in the area suggested in the SCOPE. Each author is requested to submit one 4-page English original and two duplicates, including all text, references, figures and photographs. The papers should be typed single spaced on white paper approximately 21.5cm X 28.5cm (8.5" X 11") in size. The title should be centered in capital letters 2.5cm (1") from the top of the first page. The author's name, complete organizational affiliation and mailing address should be two lines below. The title and the text should start three lines below this and be typed with 12-pitch characters (12 characters per inch). Left and right hand margins should be 2.5cm (1"). A 2.5cm (1") margin should be left at the top and bottom of all pages. Since the "Proceedings" will be produced directly from the author's originals with a reduction to 83% in linear dimension, letters and symbols in the paper should be sufficiently clear.

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The working language is English. Poster Sessions will be scheduled. A limited number of computer demonstration spaces will be available for poster session papers.

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Spaces for demonstration of softwares, books and products are also available with extra charge.

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Final call for papers	1 July 1995
Deadline for submission of papers	1 March 1996
Notification of accepted papers	1 May 1996
Deadline for advance registration	1 August 1996

VENUE

Chiba neighbors the Tokyo metropolitan region and is a staunch supporter of Japan's globalization. Narita Airport (New Tokyo International Airport) is in Chiba and the area called Makuhari New City, currently under further development, plays an important role in this internationalization. Narita Airport is Japan's major gateway and is used by 20 million people a year. Makuhari is located between Narita Airport and the Tokyo metropolitan region. It is a convenient access point as it takes 30 minutes to either location. Makuhari is making rapid progress as an international city of the future. It has Makuhari Messe (Nippon Convention Center) as its core, business, research, education, and recreation facilities, and residential complexes all of which will take it into the 21st century. Makuhari Messe, which boasts the largest convention facilities in the Asia region, opened in October, 1989. The convention complex comprises three main facilities. The "International Exhibition Hall", the "Makuhari Event Hall" and the "International Conference Hall", where the Symposium will be held. Makuhari Messe is visited by more than seven million people a year, attracting world attention as one of the most promising footholds for international marketing cooperation and information transmission.

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Young Scientist Awards will be presented for about ten young overseas speakers who present excellent papers. The applicants must be less than 35 years old on September 27 of the year of the ISAP '96. Accommodation expenses and free registration will be provided by the Symposium Organizing Committee. The deadline of the papers to be applied for YSA is February 1, 1996.

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INTENTION FORM

For further information, please return the intention form (E-mail preferred) to :

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Additional persons

Call for Papers

The Applied Computational Electromagnetics Society
Announces a Special Issue of the ACES Journal on:

Applied Mathematics: meeting the challenges presented by Computational Electromagnetics

The objectives of this special issue are **a)** to illuminate some of the current mathematical techniques in computational electromagnetics, by a series of review or survey articles, and **b)** to initiate and encourage interaction between the applied mathematics community on the one hand, and the electrical engineers and physicists on the other. Papers submitted must address mathematical problems arising in computational electromagnetics, and the conclusions must have, moreover, some practical value. Contact the Guest Editors.

Suggested Topics:

- ⋆ Integral equations and integrodifferential equations
- ⋆ Eigenfunction expansions, both interior and exterior
- ⋆ Selfadjoint, as well as non-selfadjoint, operator approximation
- ⋆ Singularity expansion method, scattering poles, natural modes
- ⋆ Diffraction and asymptotics, application of special functions

- ⋆ Variational principles, Galerkin and related methods
- ⋆ Finite element methods, finite difference methods
- ⋆ The radiation boundary problem

- ⋆ Solution of large scale linear systems
- ⋆ Eigenvalue estimation, especially for non-selfadjoint problems
- ⋆ Optimization, conjugate and bi-conjugate gradient methods, GMRES
- ⋆ Numerical evaluation of integrals with oscillatory or singular integrands

Wherever possible, attention should be given to error estimates. This is not just a difficult mathematical issue[1], it is absolutely vital for all engineering considerations and it is still largely unresolved in computational electromagnetics. Modern numerical analysis seems not to have lived up to its basic premise, because we do not yet possess useful error estimates.

The deadline for papers is June 30, 1995.
Mail one hard copy to each of the Guest Editors:

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[1] See, e.g., S.G. Mikhlin, *Error Analysis in Numerical Processes,* Wiley, 1991.

CALL FOR PAPERS

THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY ANNOUNCES A SPECIAL ISSUE OF THE ACES JOURNAL ON:

ADVANCES IN THE APPLICATION OF THE METHOD OF MOMENTS TO ELECTROMAGNETIC RADIATION AND SCATTERING PROBLEMS

The Applied Computational Electromagnetics Society is pleased to announce the publication of a 1995 Special Issue of the ACES Journal on the use of the Method of Moments in the evaluation of electromagnetic radiation and scattering problems. The objectives of this special issue are: (1) to provide the computational electromagnetics community with an assessment of the current capabilities and uses of the Method of Moments for electromagnetics problems from the low-frequency to the high-frequency regimes and (2) to provide information on recent advances that may extend range of applicability and usefulness of the Method of Moments. Prospective authors are encouraged to submit papers of archival value that address these objectives and other suggested topics listed below.

SUGGESTED TOPICS

- Modeling Guidelines for Complex Geometries
- Accuracy Assessment and Improvement
- Special Formulations: Low Frequency/High Frequency
- Hybrid Method of Moment Approaches
- New Integral Equation Formulations
- Parallelization of Moment Method Codes
- Novel Equivalence Principle Applications for the Method of Moments
- Fast Matrix Computation/Solution Techniques
- Large-Scale Problems

DEADLINE FOR PAPERS IS MARCH 31, 1995

Send papers and inquiries to:

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Special Guest Editors
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THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY

CONFERENCE ANNOUNCEMENT

The 11th Annual Review of Progress in Applied Computational Electromagnetics

March 20-25, 1995

Naval Postgraduate School, Monterey, CA

The Annual ACES Symposium is an ideal opportunity to participate in a large gathering of EM analysis enthusiasts. The purpose of the Symposium is to bring analysts together to share information and experience about the practical application of EM analysis using computational methods. The Symposium offerings include technical presentations, demonstrations, vendor booths and short courses. All aspects of electromagnetic computational analysis are represented. For information on the registration, agenda or short courses,see this newsletter.

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Papers will address general issues in applied computational electromagnetics, or focus on specific applications, techniques, codes, or computational issues of potential interest to the Applied Computational Electromagnetics Society membership. Areas and topics include:

- Code validation
- Code performance analysis
- Computational studies of basic physics
- Examples of practical code application
- New codes, algorithms, code enhancements, and code fixes
- Computer hardware issues
- Partial list of applications:
    - antennas
    - radar imaging
    - shielding
    - EMP, EMI/EMC
    - dielectric & magnetic materials
    - microwave components
    - fiberoptics
    - communications systems
    - eddy currents
    - wave propagation
    - radar cross section
    - bioelectromagnetics
    - visualization
    - inverse scattering
    - MIMIC technology
    - remote sensing & geophysics
    - propagation through plasmas
    - non-destructive evaluation
- Partial list of techniques:
    - frequency-domain & time-domain techniques
    - integral equation & differential equation techniques
    - finite differences & finite element techniques
    - diffraction theories
    - modal expansions
    - hybrid methods
    - physical optics
    - perturbation methods
    - moment methods

FINAL AGENDA

The Eleventh Annual Review of Progress in Applied Computational Electromagnetics

NAVAL POSTGRADUATE SCHOOL
20 - 25 MARCH, 1995

Raymond Luebbers, Technical Program Chairman

Richard Gordon, Proceedings Editor

Robert Lee, Short Course Chairman

Paul Goggans, Publicity Chairman

Richard Adler, Conference Facilitator

MONDAY 20 MARCH

0830-1630	**SHORT COURSE (FULL-DAY)** "Finite Elements for Electromagnetics"	**102 Glasgow** John Brauer, MacNeal-Schwendler Corporation
0830-1630	**SHORT COURSE (FULL-DAY)** "GEMACS from A-Z"	**122 Ingersoll** Buddy Coffey, Advanced EM
0830-1630	**SHORT COURSE (FULL-DAY)** "Physical Wavelets"	**101 A Spanagel** Gerald Kaiser, Univ. of Massachusetts at Lowell
1300-1630	**SHORT COURSE (HALF-DAY)** "The Multiple Multipole Program (MMP): Theory, Practical Use and Latest Features"	**265 Ingersoll** Pascal Leuchtmann, Swiss Federal Institute of Technology
1300-1630	**SHORT COURSE (HALF-DAY)** "Verification and Validation of Computational Software"	**323 Ingersoll** E. K. Miller, Ohio University
0800-2030	**CONFERENCE REGISTRATION**	**103 Glasgow Hall**

TUESDAY 21 MARCH

0700	**CONFERENCE REGISTRATION**		**103 Glasgow Hall**
0700-0800	**CONTINENTAL BREAKFAST**		
0800	**WELCOME**	Raymond Luebbers	**102 Glasgow Hall**

SESSION 1: SCATTERING (parallel with Sessions 2 and 3) — **122 Ingersoll Hall**
CHAIRS: V. CABLE, E. MILLER

0840	"A CGFFT Method Applied to the Scatttering from Finite Size Microstrip Antenna"	A. McCowen
0900	"Analysis of Scattering by Cluster of Nonspherical Particles Based on Complete Mathematic Models"	Y.A. Eremin, N.W. Orlov and V.I. Rozenberg
0920	"Analytic Solution for Calculating the Radar Cross-Section and Related Parameters of a Conducting Right Circular Cylinder Surrounded by Multiple Layers of Lossy Dielectrics"	G.W. Jarriel, Jr., M. E. Baginski, and Lloyd Riggs
0940	"RCS of High Permittivity Cubes Computed with the TLM Method"	C. Eswarappa and W.J.R. Hoefer
1000	**BREAK**	
1020	"Scattering Analysis of Antenna Installations/Panels on a Curved Surface Using Uniform Field Integration Method"	J.J. Kim and O.B. Kesler
1040	"Code Validation of Aircraft Scattering Parameters using IR Thermograms""	J. Norgard, R. Sega, M. Seifert, T. Blocher and A. Pesta

TUESDAY 21 MARCH

SESSION 1: SCATTERING (parallel with Sessions 2 and 3) (CONT)

122 Ingersoll Hall

1100	"A New Method for Solving Scattering Problems with Conducting Media in the Time Domain"	M. Schinke and K. Reiß
1120	"Experience and Experiments at Cray Research with JUNCTION-2"	J.A. Crow and Q.M. Sheikh
1140	"Quantitative Methods for Measuring and Improving the Performance of Electromagnetic Scattering Codes"	J.P. Meyers, A. J. Terzuoli, Jr., and G.C. Gerace
	LUNCH	

SESSION 2: LOW FREQUENCY (parallel with Sessions 1 and 3)

CHAIRS: K. KUNZ, H. SABBAGH

117 Spanagel Hall

0840	"Numerical Modelling of EMC in Underground Power Cable Systems with the Hybrid FE-BE Method"	J. Shen and A. Kost
0900	"New Contribution to the Study of Fault Currents Distribution in the Ground Systems"	H.O. Brodskyn, M.H. Giarolla, J.R. Cardoso, N.M. Abe and A. Passaro
0920	"On the Oscillatory Phenomena of Eddy Currents Along the A, V- Inferface"	Z. Cheng, Q. Hu, S. Gao, Z. Liu, M. Wu and C. Ye
0940	"A New MMP-Code for Static Field Computation"	M. Gnos and P. Leuchtmann
1000	**BREAK**	
1020	"Molten Aluminum Flow Induced by High Magnetic Fields"	W.P. Wheless, Jr. and C.S. Wheless
1040	"The Electrostatic Characterization of a N-Element Planar Array Using the Singularity Expansion Method"	J.E. Mooney and L. Riggs
1100	"A Volume-Integral Code for Electromagnetic Nondestructive Evaluation"	R.K. Murphy, H.A. Sabbagh, J.C. Treece and L. W. Woo
	LUNCH	

SESSION 3: RESEARCH AND ENGINEERING FRAMEWORK FOR CEM (parallel with Sessions 1 and 2)

102 Glasgow Hall

ORGANIZER: K. SIARKIEWICZ

0840	"Research and Engineering Framework (REF) for Computational Electromagnetics" (Invited)	B. Hantman, K. Siarkiewicz, J. Labelle and R. Jackson
0900	"Research & Engineering Framework (REF) Data Dictionary Specification for Computational Electromagnetics" (Invited)	J.A. Evans
0920	"DT_NURBS - A Geometry Engine for Integration of the MMACE Data" (Invited)	B. Ames and C. Whitcomb
0940	"Standardized Grid Generation for the Research and Engineering Framework" (Invited)	L.W. Woo, H. A. Sabbagh, J. LaBelle and B. Hantman
1000	**BREAK**	
1020	"Visualization and Standards" (Invited)	J. Cugini
1040	"A Visualization Toolkit for Computational Electromagnetics" (Invited)	B. Joseph
1100	"MMACE - Lessons for the Development of a CEM Computational Environment" (Invited)	R.G. Hicks and K.R. Siarkiewicz
	LUNCH	
1200	**BOARD OF DIRECTORS MEETING**	**Terrace Room, Herrmann Hall**

TUESDAY AFTERNOON 21 MARCH

1330-1730	**VENDOR BOOTHS AND WINE AND CHEESE BUFFET**	**Barbara McNitt Ballroom, Herrmann Hall**
1800	**HAPPY HOUR (NO HOST)**	**Barbara McNitt Ballroom, Herrmann Hall**
1900	**AWARDS BANQUET**	**Barbara McNitt Ballroom, Herrmann Hall**
1330-1530	**SHORT COURSE (PARTIAL DAY, NO FEE)** Bob Bevensee "Time Series Analyses of Equity Stock Prices and a Profitable Investment Strategy"	**102 Glasgow Hall**
1330-1530	**SESSION 4: INTERACTIVE TECHNICAL SESSION**	**Barbara McNitt Ballroom, Herrmann Hall**

SESSION 4A: EM THEORY I

Barbara McNitt Ballroom, Herrmann Hall

"Pulse Basis Function Implementation of the Radiation Condition Integral Equations"	P.C. Colby
"Finite Difference Solutions of Geometrical Optics and Some Related Nonlinear PDEs Approximating High Frequency Helmholtz Equation"	E. Fatemi, B. Engquist and S. Osher
"Conversion of Mechanical Energy to Electromagnetic Energy"	R.M. Bevensee
"Block-Toeplitz-Structure-Based Solution Strategies for CEM Problems"	V.I. Ivakhnenko and E.E. Tyrtyshnikov
"The Two-Dimensional Finite Integral Technique Combined with the Measured Equation of Invariance Applied to Transverse Electric Open Region Scattering Problems"	G.K. Gothard and S.M. Rao
"Artificial Transparent Boundaries in Computational Quasioptics"	A.V. Popov
"A Statistical Electromagnetics (STEM) Research Initiation Report"	W.P. Wheless, Jr., C.B. Wallace and W.D. Prather
"Optimization of Aperiodic Conducting Grids"	R.L. Haupt
"Accurate MOM Scattering Calculations Using Massively Parallel Computation"	L.D. Vann and J.S. Bagby
"A New Angle on a Low Cost Ground Screen for Model Testing in the Undergraduate Antennas Laboratory (Looking at Near Vertical Incidence Skywaves (NVIS) for a Coast Guard Patrol Boat)"	M.E. McKaughan, W.M. Randall and B. Nutter
"Efficient Extraction of the Near-Field from CGFFT Methods Applied to Scatterers in the Resonance Region"	A. McCowen

SESSION 4B: VISUALIZATION & INTERFACES

Barbara McNitt Ballroom, Herrmann Hall

"Computer Code for Field Calculation and Visualization in Quasioptics"	Y.V. Kopylov
"Dosimetry in a Voxel Model of the Head"	P.J. Dimbylow
"A Graphical User Interface for the NEC-BSC"	L.W. Henderson and R.J. Marhefka
"MF Communication and Broadcast Prediction System"	M.J. Packer and A.P. Tsitsopoulos
"A Finite Difference Time Domain Visualization Tool for Microsoft Windows™"	A. Z. Elsherbeni, C.D. Taylor, Jr. and C. E. Smith

SESSION 4C: VALIDATION

Barbara McNitt Ballroom, Herrmann Hall

"Transformable Scale Aircraft-Like Model for the Validation of Computational Electromagnetic Models and Algorithms: Initial Configuration and Results"	D.R. Pflug and D. Warren
"Measurement Study for Validation of Electromagnetic Scattering Codes on a Complex 3D Target"	T. Kienberger and D. Jurgens
"Validation Using a Moment Method Approach with Exact Object Representation"	J.A. Larsson, S. Ljung and B.Wahlgren
"IR Measurements for Validating EM Analysis Tools"	M. Seifert, T. Blocher and A. Pesta

TUESDAY AFTERNOON 21 MARCH

SESSION 4D: EMI/EMC/EMP — Barbara McNitt Ballroom, Herrmann Hall

"Analysis of Electromagnetic Interference at an Ocean Observation Post"	L. Bai and J.F. Dai
"Enforcing Correlation on Statistically Generated EM Cable Drivers"	R. Holland and R. St. John
"Analysis of Different Contributions to the Coupling Between Reflector Antennas on a Satellite"	C. Park and P. Ramanujam
"Simple Radiation Models in Lieu of EMC Radiated Emissions Testing"	R. Perez

WEDNESDAY MORNING 22 MARCH

0730	**CONTINENTAL BREAKFAST**		
0800	**ACES BUSINESS MEETING**	President Hal Sabbagh	**102 Glasgow Hall**

SESSION 5: OPTIMIZATION TECHNIQUES IN APPLIED ELECTROMAGNETICS (parallel with Sessions 6 and 7) 361 Ingersoll Hall
ORGANIZER: O.A. MOHAMMED

0840	"An Optimization Approach to Reduce the Discretization Error in Finite Element Explicit Solution Sceme" (Invited)	M. Feliziani, E. Latini, F. Maradei
0900	"Analysis and Design of a Reentrant Resonant Cavity Applicator for Radio Frequency Hyperthermia System" (Invited)	Y. Kanai, T. Tsukamoto, K. Toyama, T. Kashiwa, Y. Saitoh and M. Miyakawa
0920	"Analysis of Loaded Cavities Using the Constitutive Error Approach" (Invited)	R. Albanese, R. Fresa, R. Martone and G. Rubinacci
0940	"The Design of Electromagnetic Devices using Knowledge Based Systems and Sensitivity Information" (Invited)	D.A. Lowther, D. N. Dyck and R. Rong
1000	**BREAK**	
1020	"A Computer Program for the Design of Superconducting Accelerator Magnets" (Invited)	S. Russenschuck
1040	"Application of Optimization to the Design of Electromechanical Devices" (Invited)	J.K. Sykulski and Y.B. Cheng
1100	"Genetic Algorithms for the Optimal Design of Electromagnetic Devices" (Invited)	O.A.Mohammed, G.F. Üler
1140	"Linear Constraints - Gradient Technique for the Inverse Problem of Design Optimization" (Invited)	A.A. Arakadan and S. Subramaniam-Sivanesan
	LUNCH	

SESSION 6: COMPUTATIONAL ELECTROMAGNETICS APPLIED TO SHIP DESIGN (parallel with Sessions 5 and 7) 102 Glasgow Hall
ORGANIZERS: J. NEWCOMB AND J. LOGAN

0840	"The Naval Sea Systems Command Electromagnetic Engineering Program" (Invited)	D. Cebulski, N. Baron and J. Eadie
0900	"EM Engineering System Architecture" (Invited)	J. Winston
0920	"EM Engineering Ray Tracing and Casting Model RTC" (Invited)	L. Gray
0940	"Ship Transition-Frequency EM Environment Analysis Requirements" (Invited)	G. Piper
1000	**BREAK**	
1020	"Finite Volume Time Domain Analysis of Ship Topside EM Environment Features" (Invited)	B. Hall, A. Mohammadian, C. Rowell and V. Shankar
1040	"EM Engineering Ship End-To-End Application" (Invited)	L. R. Carlson, C. F. Juster, G. R. Allen

WEDNESDAY MORNING 22 MARCH

SESSION 6: (CONT) COMPUTATIONAL ELECTROMAGNETICS APPLIED TO SHIP DESIGN (parallel with Sessions 5 and 7) 102 Glasgow

1100	"EM Engineering Applied to Patrol Craft (PC-1)" (Invited)	D. Tam, J. McGee, C. Azu and M. Soyka
1120	"Shipboard Antenna Pattern Visualization and Analysis" (Invited)	L.C. Russell, J.C. Logan, J.W. Rockway and D.F. Schwartz
	LUNCH	

SESSION 7: FINITE DIFFERENCE TIME DOMAIN (parallel with Sessions 5 and 6) 122 Ingersoll Hall
ORGANIZER: J. BEGGS

0840	"Computational Analysis of Radiation from an Elliptical Shaped End Radiator" (Invited)	S. A. Blocher, E. A. Baca and J. H. Beggs
0900	"A Time Domain Harmonic Oscillator Model for an FDTD Treatment of Lossy Dielectrics" (Invited)	K. S. Kunz
0920	"FDTD Modeling of Electromagnetic Wave Interactions with Composite Random Sheets" (Invited)	J.G. Maloney and B.L. Shirley
0940	"An Improved Near to Far Field FDTD Algorithm" (Invited)	K. S. Kunz
1000	**BREAK**	
1020	"Unstructured Finite-Volume Modeling in Computational Electromagnetics" (Invited)	D.J. Riley and C.D. Turner
1040	"Scattering from Coated Targets Using a Frequency-Dependent, Surface Impedance Boundary Condition in FDTD"	C.W. Penney, R.J. Luebbers and J.W. Schuster
1100	"Hybrid Finite Difference Time Domain and Finite Volume Time Domain in Solving Maxwell's Equations" (Invited)	K.S. Yee and J.S. Chen
1120	"Reducing the Number of Time Steps Needed for FDTD Antenna and Microstrip Calculations" (Invited)	R. Luebbers and H.S. Langdon
1140	"Numerical Simulations of Light Bullets, Using the Full Vector, Time Dependent, Nonlinear Maxwell Equations"	P. Goorjian and Y. Silberberg
	LUNCH	

WEDNESDAY AFTERNOON 22 MARCH

SESSION 8: BERENGER'S BOUNDARY CONDITION (parallel with Sessions 10 and 11) 102 Glasgow Hall
ORGANIZER: J. FANG

1320	"Ultrawideband Termination of Waveguilding and Multilayer Structures for FD-TD Simulations in 2-D and 3-D" (Invited)	C.E. Reuter, R.M. Joseph, E.T. Thiele, D.S. Katz and A. Taflove
1340	"A 3-D Perfectly Matched Medium by Coordinate Stretching and Its Absorption of Static Fields" (Invited)	W.C. Chew, W.H. Weedon and A. Sezginer
1400	"Perfectly Matched Anisotropic Absorbers for Finite Element Applications in Electromagnetics"	D.M. Kingsland, Z.S. Sacks and J-F. Lee
1420	"Modification of Berenger's Perfect Matched Layer for the Absorption of Electromagnetic Waves in Layered Media"	M. Gribbons, S-K. Lee and A.C. Cangellaris
1440	"Performance of the Perfectly Matched Layer in Modeling Wave Propagation in Microwave and Digital Circuit Interconnects"	Z. Wu and J. Fang
1500	**BREAK**	

WEDNESDAY AFTERNOON 22 MARCH

SESSION 9: TIME DOMAIN/FDTD (parallel with Sessions10, 11 and 12) **102 Glasgow Hall**
CHAIRS: L. LONG, J. MALONEY

1520	"A FVTD Algorithm for Maxwell's Equations on Massively Parallel Machines"	V. Ahuja and L.N. Long
1540	"The Piecewise Linear Recursive Convolution Method for Incorporating Dispersive Media into FDTD"	D.F. Kelley and R. J. Luebbers
1600	"Combining Different Coordinate Systems in the Time Domain Finite Difference Method"	M. Mrozowski, M. Okoniewski, M.A. Stuchly and S.S. Stuchly
1620	"Time Domain Response of Simulated 2D Composite Scatterers"	A.Z. Elsherbeni and P. Goggans
1640	"An Object-Oriented Approach to Writing Computational Electromagnetics Codes"	M. Zimmerman and P. Mallasch

SESSION 10: FAST ALGORITHMS FOR COMPUTATIONAL ELECTROMAGNETICS (parallel with Sessions 8, 9, 11, and 12)
ORGANIZERS: E. MICHIELSSEN AND W. CHEW **122 Ingersoll Hall**

1320	"On the Use of Wavelet-Like Basis Functions in the Finite Element Analysis of Elliptic Problems" (Invited)	R.K. Gordon
1340	"Fast Wavelet Algorithm (FWA) for Moment Method Analysis of Electromagnetic Problems" (Invited)	K. Sabetfakhri and L.P.B. Katehi
1400	"Fast Far Field Approximation for Calculating the RCS of Large Objects" (Invited)	C.C. Lu and W.C. Chew
1420	"The Parameter Estimation Technique (PET): Speeding Up Dense Matrix Methods" (Invited)	C. Hafner and J. Fröhlich
1440	"A Novel Scheme for Massively Parallel Solution of Maxwell's Equations using FDTD" (Invited)	M.A. Jensen, Y. Rahmat-Samii and A. Fijany
1500	**BREAK**	
1520	"Reduction of the Filling Time of Method of Moments Matrices" (Invited)	G. Vecchi, P. Pirinoli, L. Matekovits and M. Orefice
1540	"The Fast Multipole Method for Large 2d Scatterers" (Invited)	L.R. Hamilton, J.J. Ottusch, M.A. Stalzer, R.S. Turley, J.L. Visher and S.M. Wandzura
1600	"A Multilevel Matrix Decomposition Algorithm for Analyzing Scattering from Large Structures" (Invited)	E. Michielssen and A. Boag
1620	"A 3D Fast Multipole Method for Electromagnetics with Multiple Levels" (Invited)	B. Dembart and E. Yip
1640	"Fast Multipole Method Solution of Combined Field Integral Equaltion"	J.M. Song and W. C. Chew

SESSION 11: MICROWAVE AND GUIDED WAVE (parallel with Sessions 8 and 10) **361 Ingersoll Hall**
CHAIRS: P. GOGGANS, A. TERZUOLI

1320	"Computer-Simulation of Isotropic, Two-Dimensional Guided-Wave Propagation"	R.A. Speciale
1340	"Analysis of Ultra-Short Pulse Propagation on Uniform and Tapered Printed Transmission Lines"	R.A.O. Veliz and J.R. Souza
1400	"Wave-Field Patterns on Electrically Large Networks"	R.A. Speciale
1420	"Scattering Characteristics of Dissimilar Waveguide Slot Couplers"	A. Singh and K.S. Christopher
1440	"An Alternative Formulation of the Tranverse Resonance Technique"	A.G. Neto, S. Ariguel, H. Aubert, D. Bajon and H. Baudrand
1500	**BREAK**	

WEDNESDAY AFTERNOON 22 MARCH

SESSION 12: MOM (parallel with Sessions 9 and 10) **361 Ingersoll Hall**
CHAIRS: A. PETERSON, R. ZIOLKOWSKI

1520	"Moment Method Analysis of Dielectric Covered Radiating Slots Using Alternative Green's Function Approach"	S. Christopher, V.V.S. Prakash, A.K. Singh and N. Balakrishnan
1540	"Computation of E-field Distribution of Low Gain Antenna on Conducting Body of Revolution"	J. Liu, J. Wang and Y. Gao
1600	"An Implementation of an Exact Scheme for Problem Decomposition Via the Use of Aperture Admittance"	D.L. Wilkes, C-C. Cha and T. Krauss
1620	"Parallelization of the Parametric Patch Moment Method Code"	X. Shen, G.E. Mortensen, C.C. Cha, G. Cheng and G. C. Fox
1640	"A Tool Box for Parallelization of Moments Method Codes"	E. Yip, B. Blakely, L. Johnson, D. Jurgens and R. Kochhar

THURSDAY MORNING 23 MARCH

0730 **CONTINENTAL BREAKFAST**

SESSION 13: RECENT DEVELOPMENTS IN FDTD ANALYSIS (parallel with Sessions 14 and 15) **102 Glasgow Hall**
ORGANIZERS: M. PIKET-MAY AND D. KATZ

0840	"Simulation of Microwave Circuits by FDTD Method" (Invited)	C.N. Kuo, B. Houshmand and T. Itoh
0900	"Adaptation of FDTD Techniques to Acoustic Modeling" (Invited)	J.G. Maloney and K.E. Cummings
0920	"FDTD Investigation of the Antenna-Tissue Interaction for Cellular and Satellite Systems" (Invited)	Y. Rahmat-Samii and M.A. Jensen
0940	"FDTD Modeling of Ground-Penetrating Radar Antennas"	B.J. Zook
1000	**BREAK**	
1020	"FDTD Modeling of Ultrashort Optical Pulse Interactions with Nonresonant and Resonant Materials and Structures" (Invited)	R.W. Ziolkowski
1040	"Time Domain Analysis of Electromagnetic Wave Propagation in Nonlinear Dielectric Slab"	G. Miano, C. Serpico, L. Verolino and F. Villone
1100	"An Efficient Sub-gridding Algorithm for FDTD."	D.T. Shimizu, M. Okoniewski and M.M. Stuchl
1120	"Using the Integral Forms of Maxwell's Equations to Modify and Improve the FDTD (2,4) Scheme"	M.F. Hadi and M. Piket-May
1140	"From the Berenger PML ABC to Micro-Lasers: Recent Advances in FD-TD Modeling Techniques" (Invited)	A. Taflove
	LUNCH	

SESSION 14: PROPAGATION (parallel with Sessions 13 and 15) **361 Ingersoll Hall**
ORGANIZER: K. CHAMBERLIN

0840	"Terrain and Refractivity Effects in a Coastal Environment: Results from the VOCAR Experiment"	A. Barrios
0900	"Capabilities and Limitations Associated With Using GTD to Model Propagation Path Loss in the Presence of Irregular Terrain"	K. Chamberlin
0920	"Comparison of Electromagnetic Wave Propagation Computer Programs"	S.A. Fast and T. H. Koschmieder
0940	"A Model for Estimating Electromagnetic Wave Attenuation in a Forest (EWAF) Environment"	C. Welch and C. Lemak
1000	**BREAK**	
1020	"Validation of the Radio Physical Optics Propagation Model"	R.A. Paulus

THURSDAY MORNING 23 MARCH

SESSION 14: PROPAGATION (parallel with Sessions 13 and 15) (CONT) — 361 Ingersoll Hall

1040	"VTRPE: A Variable Terrain Electromagnetic Parabolic Equation Model"	F.J. Ryan
1100	"Estimating Tropospheric Refractivity Fields Using a Nonlinear Gauss-Markov Procedure and the PE Model"	D. Boyer and F.J. Ryan
1120	"Modeling of Radio Wave Ducting Over Regular Boundary"	I.P. Zolotarev
	LUNCH	

SESSION 15: PARALLELIZATION OF EM CODES (parallel with Sessions 13 and 14) — 122 Ingersoll Hall
ORGANIZERS: J. VOLAKIS AND A. CHATTERJEE

0840	"Advances in Time-Domain CEM Using Massively Parallel Architectures" (Invited)	C. Rowell, V. Shankar, W.F. Hall and A. Mohammadian
0900	"Parallel Solutions of Maxwell's Equations on the Meiko CS-2" (Invited)	N. Madsen, B. Eme, D. Steich and G. Cook
0920	"Parallelization of the CARLOS-3D Method of Moments Code" (Invited)	J.M. Putnam, D.D. Car and J.D Kotulski
0940	"Parallel Computing for Electromagnetism at ONERA" (Invited)	A. de La Bourdonnaye, A. Cosnuau, X. Ferrières, P. Leca and F. X. Roux
1000	**BREAK**	

SESSION 15 PARALLELIZATION OF EM CODES (parallel with Sessions 13 and 14) (CONT) 122 Ingersoll Hall

1020	"The Performance of the Parallel Solution of the Quasi-Minimal Residual (QMR) Method on 2D Mesh Architectures" (Invited)	L. Hamandi, O. Ozguner and R. Lee
1040	"Advanced Parallel Solver Techniques" (Invited)	A.S. King
1100	"Parallelized FDTD for Antenna Radiation Pattern Calculations"	Z.M. Liu, A.S. Mohan, T. Aubrey and W.R. Belcher
1120	"Calculation of Electromagnetic Fields with the Multiple Multipole Method (MMP Method) on Parallel Computers"	C. Tudziers and H. Singer
1140	"Implementation of the Finite-difference Time-Domain Method on Parallel Computers"	R.S. David and L.T. Wille
	LUNCH	

THURSDAY AFTERNOON 23 MARCH

SESSION 16: EM THEORY II (parallel with Sessions 18 and 20) — 361 Ingersoll Hall
CHAIRS: K. YEE, R. GORDON

1320	"FDTD Investigation of the Ability to Increase Electromagnetic Fields Around Head Tumors"	D.B. Dunn, A.J. Terzuoli, Jr. G.C. Gerace and C.A. Rappaport
1340	"FDTD and PMM Based Design of a TEM Horn Antenna with Reduced Off-Boresight Fields"	D.J. Wolstenholme, A.J. Terzuoli, Jr. and G. C. Gerace
1400	"Determination of the Complex Aperture Distribution of a Planar Spiral Antenna from 3D Far-Field Radiation Pattern Data"	M. Kluskens, W. Lippincott and M. Kragalott
1420	"Analysis of Micro-Contamination of Silicon Wafers Based on Discrete Sources Method (DSM)"	Y.A. Eremin and N.W. Orlov
1440	"Analysis of Convergence Properties of Projection Methods for Solving CEM Applications"	V.I. Ivakhnenko, A.V. Kukk, E.E. Tyrtyshnikov, A.Y. Yeremin and N.L. Zamarashkin

THURSDAY AFTERNOON 23 MARCH

SESSION 17: ELECTROMAGNETIC MODELING TECHNIQUES FOR INTEGRATED OPTICS (parallel with Sessions 18, 19 and 20)

ORGANIZER: A. CANGELLARIS **361 Ingersoll Hall**

1520	"Analysis and Design of Guided-wave Optical Devices Using Finite-Difference Time-Domain Method" (Invited)	S.I. Chaudhuri and S.T. Chu
1540	"Vectorial Analysis of Optical Waveguides by the Method of Lines"(Invited)	R. Pregla and W. Pascher
1600	"Vector Finite Element Analysis of Lossless and Lossy Dielectric Waveguides" (Invited)	P. Cheung and A. Gopinath
1620	"NL-FDTD Modeling of Linear and Nonlinear Corrugated Waveguiding Systems for Integrated Optics Applications" (Invited)	R.W. Ziolkowski and J.B. Judkins
1640	"Analysis of Coupled Nonlinear Optical Waveguides by Matrix Method"	V. Tripathi, A. Weisshaar and H.S. Chang

SESSION 18: TOPICS IN FRACTAL AND WAVELET ELECTRODYNAMICS (parallel with Sessions 16, 17and 20) 102 Glasgow Hall

ORGANIZERS: D.H. WERNER AND P.L. WERNER

1320	"An Overview of Fractal Electrodynamics Research" (Invited)	D.H. Werner
1340	"Fractal Arrays and Fractal Radiation Patterns" (Invited)	P.L. Werner, D.H. Werner and A.J. Ferraro
1400	"Wavelet Transforms and Time/Time-scale Analysis" (Invited)	R.K. Young and T.G. Golsberry
1420	"Wavelet-based Processing to Efficiently Achieve Broadband Monostatic and/or Passive Cross-sensor Processing" (Invited)	R.K. Young and L.H. Sibul
1440	"The Intervallic Wavelets with Application in the Surface Integral Equations" (Invited)	G.W. Pan and J.Y. Du
1500	**BREAK**	
1520	"Radar Cross Section Data Reduction Using Wavelets"	A.S. Ali, S.E. Duval and R.L. Haupt

THURSDAY AFTERNOON 23 MARCH

SESSION 19: NEC APPLICATIONS (parallel with Session 17 and 20) 102 Glasgow Hall

ORGANIZER: J. BREAKALL

1540	"Computationally Efficient and Accurate Approximations for Impedance Matrix Elements of NEC-Type Method of Moments Formulations"	D.H. Werner, S.E. Metker and J.A. Huffman
1600	"Development of the Coupled-Resonator Antenna Principle A Computer Modeling Case History"	G. Breed
1620	"Antenna Design & Development Using NEC-WIN"	T. A. Erdley, J. J. Shapiro, J. S. Young and J.K. Breakall
1640	"The "Paint" System A UTD/NEC Hybrid Package for Simulating Antenna Patterns Over 3-Dimensional Irregular Terrain"	J.S. Young and J.K. Breakall

SESSION 20: FEM (parallel with Sessions 16, 17, 18, and 19) 122 Ingersoll Hall

CHAIRS: R. BURKHOLDER, J. KARTY

1320	"Numerically Characterizing Electromagnetic Fields Local to the Edge of a Conducting Strip Using a Matched Asymptotic Technique and the Finite Element Method"	A.S. Ali and C. L. Holloway
1340	"An Enhanced "A Postericri" Remeshing Algorithm for Adaptive Meshing of 2D Finite Element Problems"	P. Girdinio, A. Manella and G. Molinari
1400	"Finite Element Analysis of Waveguides Using Edge-Based Magnetic Vector Potential and Nodal-Based Electric Scalar Potential"	J. -F. Lee, G. Lizalek and J. Brauer
1420	"A Scattering Analysis of Laser Beam Wave by Groove Pits on Optical Memory Disk by Using FEM with BEM"	Y. Miyazaki and K. Tanaka
1440	"3D Nodal- and Mixed-Based Elements for Unbounded Microwave Problems"	A. Nicolas, L. Nicolas and J.L. Yao-bi
1500	**BREAK**	

THURSDAY AFTERNOON 23 MARCH

SESSION 20: FEM (parallel with Sessions 16, 17, 18, and 19) (CONT) **122 Ingersoll Hall**

1520	"A Rationale for the Use of Mixed-order Basis Functions Within Finite Element Solutions of the Vector Helmholtz Equation"	A.F. Peterson and D.R. Wilton
1540	"Finite Element Waveguide Simulator Techniques"	J.R. Sanford and N.M. Johansson
1600	"A Solution for Open Boundary Electromagnetic Field Problems by Mapped Infinite and Virtual Elements"	L.H.A. de Medeiros and A. Raizer

FRIDAY MORNING, MARCH 24

0730 **CONTINENTAL BREAKFAST**

SESSION 21: EM ANALYSIS TECHNIQUES FOR ELECTRICALLY LARGE CAVITIES (parallel with Sessions 22 and 23)
ORGANIZER: D. PFLUG **122 Ingersoll Hall**

0840	"Application of Modal and Plane Wave Expansions to Modeling Large Jet Engine Cavities" (Invited)	J. L. Karty and J.M. Roedder
0900	"Scattering from Dielectric Loaded Cavities Using Shooting and Bouncing Rays" (Invited)	M. Christensen, S. W. Lee D.J. Andersh
0920	"Xpatch Simulation of Large Inlet Structures" (Invited)	R. Bhalla and H. Ling
0940	"An Iterative Physical Optics Approach for the Em Analysis of Cavities and Other Multi-Bounce Geometries" (Invited)	R.J. Burkholder
1000	**BREAK**	
1020	"Improved Ray Basis in the Hybrid Analysis of EM Scattering by Large Open Cavities" (Invited)	R.J. Burkholder, P.H. Pathak, H.T. Chou, D. Andersh and J. Fath
1040	"Overlapping Modal and Geometric Symmetries for Computing Jet Engine Engine Inlet Scattering" (Invited)	D.C. Ross, J.L. Volakis, H. T. Anastassiu and D. Andersh
	LUNCH	

FRIDAY MORNING, MARCH 24

SESSION 22: ACCURACY ESTIMATION IN ELECTROMAGNETIC MODELING (parallel with Sessions 21 and 23) 109 Glasgow Hall
ORGANIZER: S.M. WANDZURA

0840	"Assessing the Influence of Coefficient Accuracy, Matrix Condition Number, Size and Type, and Computer Precision on Matrix-Solution Accuracy" (Invited)	E. K. Miller
0900	"Numerical Accuracy Issues in Finite Element Frequency Domain Solutions of Radar Scattering Problems" (Invited)	J. D'Angelo
0920	"Accuracy in Computation of Matrix Elements of Singular Kernels"	S.M. Wandzura
0940	"Accuracy Estimation and High Order Methods"	L.R. Hamilton, J.J. Ottusch, M.A. Stalzer, R.S. Turley, J.L. Visher and S. M. Wandzura
1000	**BREAK**	
1020	"Accuracy Issues in Time-Domain CEM Using Structured/Unstructured Formulations" (Invited)	V. Shankar, W. F. Hall and S. Palaniswamy
1040	"An Accuracy Study for the 3D Hybrid Finite Element Method of Moments SWITCH Code" (Invited)	G.E. Antilla and Y.C. Ma
1100	"Modeling Accuracy of 3D Method of Moments Techniques"	M.B. Gedera, L.N. Medgyesi-Mitschang, R.A. Pearlman, J.M. Putnam, D-S.Y. Wang
1120	"Requiring Quantitative Accuracy Statements in EM Data" (Invited)	E.K. Miller
	LUNCH	

FRIDAY MORNING, MARCH 24

SESSION 23: PDE METHODS IN ELECTROMAGNETICS (parallel with Sessions 21 and 22) 102 Glasgow Hall
ORGANIZERS: R. LEE AND J. -F. LEE

0840	"Optimization Issues in Finite Element Codes for Solving Open Domain 3D Electromagnetic Problems" (Invited)	A. Chatterjee and J.L. Volakis
0900	"A Characteristic-Based 3D Time Domain Maxwell Equation Solver" (Invited)	J.S. Shang and K.C. Hill
0920	"Finite Element Solution of Eddy Current Problems in Electromagnetics" (Invited)	O.A. Mohammed and G. F. Üler
0940	"Ten Years of Evolution of the FDTD-like Conformal Technique" (Invited)	K.S. Yee
1000	**BREAK**	
1020	"Whitney Elements Time Domain (WETD) Methods for Solving Three-Dimensional Waveguide Discontinuities" (Invited)	J. -F. Lee
1040	"An FDTD/FVTD 2D-algorithm to Solve Maxwell's Equations"	J.S. Chen, J.V. Prodan and K.S. Yee
1100	"Spectral Finite Methods for the Simulation of Electromagnetic Interactions with Electrically Long Structures" (Invited)	A.C. Cangellaris and D. Hart
	LUNCH	

SATURDAY, 25 MARCH SHORT COURSES

0830-1630 **SHORT COURSE (FULL-DAY)** "Using Mathematical Software for Computational Electromagnetics"	**101A Spanagel Hall** Jovan Lebaric, Naval Postgraduate School
0830-1630 **SHORT COURSE (FULL-DAY)** "Wire Antenna Modeling Using NEC"	**109 Glasgow Hall** Dick Adler, Naval Postgraduate School Jim Breakall, Penn State University Gerry Burke, Lawrence Livermore National Lab
0830-1630 **SHORT COURSE (FULL-DAY)** "FDTD, Generalized FDTD and FVTD Techniques in Solving Maxwell's Equations"	**102 Glasgow Hall** Kane Yee, Lockheed

SHORT COURSES AT THE 11TH ANNUAL REVIEW OF PROGRESS IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

The Applied Computational Electromagnetics Society (ACES) is pleased to announce eight short courses to be offered with its annual meeting of March 20-25, 1995. The short courses will be held on Monday and Saturday. Registration begins at 7:30 AM on Monday, 20 March 1995. [Note: Tues-Fri. will be the technical sessions, and vendor exhibits]. ACES has the right to cancel a course at any time with full refund. For further information contact Richard W. Adler, Symposium Administrator, Phone: 408-646-1111, Fax: (408) 649-0300, E-mail: 554-1304@mcimail.com

COURSE INFORMATION

"FINITE ELEMENTS FOR ELECTROMAGNETICS" by John Brauer, MacNeal-Schwendler Corp.

The course will develop and apply nodal-based and edge-based finite elements, including higher order isoparametric hexahedrons. Local and global mesh truncation techniques of various kinds will be examined. Applications will include antennas, microwave circuits, nonlinear magnetic apparatus, electronic packaging, and electromagnetic compatibility. (Full-day, Monday, 20 March)

"GEMACS FROM A-Z" by Buddy Coffey, Advanced EM.

The General Electromagnetic Model for the Analysis of Complex Systems (GEMACS) includes capabilities for method of moments, uniform theory of diffraction, finite differences, and numerically rigorous hybrids of any and all techniques. The code is supported by a rich command and geometry language consisting of over 100 commands. The Short Course will walk the user through the GEMACS command set and geometry elements as electromagnetic models are constructed for practical EM problems, such as antenna radiation, structure coupling, scattering, etc. Emphasis is on "how to" and participants are encouraged to bring portable computers to the class. A complimentary copy of the unlimited distribution version of the GEMACS software will be given to each participant. (Full-day, Monday 20 March)

"USING MATHEMATICAL SOFTWARE FOR COMPUTATIONAL ELECTROMAGNETICS" by Jovan Lebaric, Naval Postgraduate School.

The ability of MATHCAD to solve electrostatic (Superposition Integral Solution) and radiation/scattering (method of moments) problems is presented. MATLAB is used to obtain a finite difference solution of 2-D static problems where the open boundary is handled via Transparent Grid Termination (TGT). Also, MATLAB is used for 2D-FDTD wave simulations with extensions to 3-D. Open boundaries are handled with the Discrete Boundary Impulse Response (DBIR). All attendees will receive a copy of a MATLAB 2D electrostatic/magnetostatic FD program and a copy of the MATLAB 2D FDTD program. A PC for each attendee will be available for use with the class. (Full-day, Saturday 25 March)

"PHYSICAL WAVELETS" by Gerald Kaiser, University of Massachusetts at Lowell.

Wavelet analysis is a mathematical method allowing efficient representation of signals, usually without any connection to physics. We show that the PDE's governing EM and acoustics imply the existence of physical wavelets from which all other EM and acoustic waves can be built. These wavelets behave simply under propagation and scattering which should make them useful for radar and other imaging methods.
(Full-day, Monday 20 March)

WIRE ANTENNA MODELING USING NEC" by Dick Adler, Naval Postgraduate School, Jim Breakall, Penn State University, and Gerry Burke, Lawrence Livermore National Lab.

Historical background in wire antenna modeling is reviewed, tracing the development and capabilities of NEC-MoM codes 1, 2, 3 and 4. Modeling guidelines, code limitations, and lessons learned during two decades of NEC use are explained. Recent advances in user interfaces and optimizer applications are detailed. Several visualization programs are demonstrated. (Full-day, Saturday 25 March)

"FDTD, GENERALIZED FDTD AND FVTD TECHNIQUES IN SOLVING MAXWELL'S EQUATIONS" by Kane Yee, Lockheed.

The workshop will provide a coherent account of the development of the finite difference time domain (FDTD) and its generalization in solving Maxwell's equations. The generalized FDTD, which is based on the surface-curve integral form of the Maxwell's equations, will be emphasized in the derivation of the numerical algorithms. The finite volume time domain (FVTD), which is based on the volume-surface integral forms of the Maxwell's equations, can be very convenient when unstructured grids are employed. Boundary condition simulation will be emphasized. (Full-day, Saturday 25 March)

"VERIFICATION AND VALIDATION OF COMPUTATIONAL SOFTWARE" by E.K. Miller, Ohio University.

One of the most time-consuming activities associated with developing and applying EM computer models is that of verifying code (software) performance and validating the model results. Few available computational packages offer the user any built-in assistance in resolving these important issues. This lecture will discuss the kinds of errors that most commonly occur in modeling, and present numerous examples of validation checks that can be considered. Also discussed are the kinds of information that can be realistically expected from a computer model and how and why the computed results might differ from physical reality. (Half-day, Monday 20 March)

"THE MULTIPLE MULTIPOLE PROGRAM (MMP): THEORY, PRACTICAL USE AND LATEST FEATURES" by Pascal Leuchtmann.

A brief summary of theoretical background, in particular MMP as opposed to moment methods, is presented. This is followed by a discussion of basic modeling ideas and their application to scattering problems, dosimetry, near field optics, antennas, waveguides, etc. We also examine the 'art of MMP' and their automatization. Practical demonstrations (field movies etc.) are shown with a notebook workstation.
(Half-day, Monday 20 March)

THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY
11TH ANNUAL REVIEW OF PROGRESS
IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

March 20 - 25, 1995
Naval Postgraduate School
Monterey, CA

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"FINITE ELEMENTS for ELECTROMAGNETICS" by John Brauer Full-day, Monday	☐ $140	☐ $150	☐ $160
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"FDTD, GENERALIZED FDTD and FVTD TECHNIQUES in SOLVING MAXWELL'S EQUATIONS" by Kane Yee, Full-day, Saturday	☐ $140	☐ $150	☐ $160
"VERIFICATION and VALIDATION of COMPUTATIONAL SOFTWARE: by E.K. Miller Half-day, Monday	☐ $ 90	☐ $100	☐ $110
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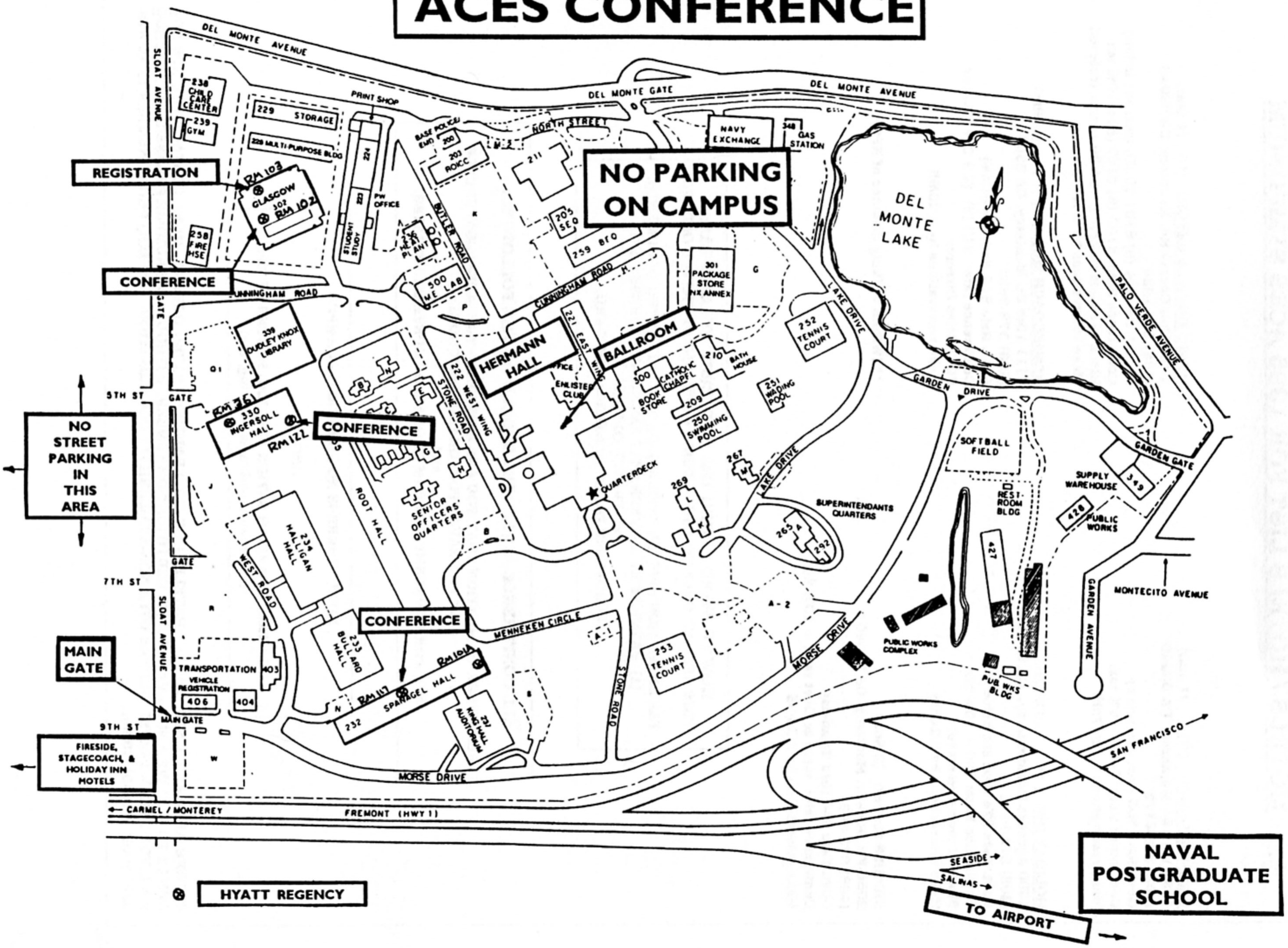

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