APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

Vol. 11 No. 2 July 1996

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NEWSLETTER ARTICLES AND VOLUNTEERS WELCOME

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

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

OFFICER'S REPORTS

PRESIDENT'S STATEMENT

I am pleased to announce that Ed Miller has accepted responsibility for producing our Software Sourcebook, and Atef Elsherbeni has accepted the position of Chairman of the Software Exchange Committee. Ed, of course, is a founding member of ACES, and has served in a number of capacities. This is Atef's first committee chairmanship; he stopped me in the hall after the honors banquet at Monterey in March, and offered to help me in any way. I told him that we very much needed somebody to chair the Software Exchange Committee, and he immediately accepted. The Software Exchange Committee and the Software Sourcebook are two of ACES most important endeavors. This "can-do" attitude of our volunteers will allow ACES to thrive in the years ahead and make an impact upon our profession.

Keith Whites has accepted the responsibility of Vendors Chairman, a subcommittee of the Conference Committee. In this position, he will work with Bob Bevensee, who is the chairman of the Conference Committee, in locating vendors who will display their products at the Annual Review. This is the one aspect of our Review that has not been as aggressively pushed as it should be.

In the meantime, stay busy. Remember, "Idle hands are the devil's workshop." On the other hand, "All play and no work makes Jack a dull boy." There are other aphorisms that are appropriate, and we will print them in the future, as the need arises. Of course, you can always choose the one that suits your personality best.

Have a good summer.

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SECRETARY'S REPORT

ACES BOARD OF DIRECTORS MEETING

ACES President Hal Sabbagh opened the Annual Business Meeting of Members at 0731 on Tuesday, 19 March 1996, in the Glasgow Auditorium on the campus of the Naval Postgraduate School, Monterey, California. The Financial Report, which appeared on page 6 of the March ACES Newsletter (vol. 11, no.1), was approved. Results of the most recent Board of Directors election were announced - Perry Wheless (125 votes), Hal Sabbagh (120) votes, and John Brauer (102 votes) were elected to office for the three-year term 1996-1999. It was announced that ACES now has 466 active members. The meeting concluded at 0740.

A regular annual meeting of the ACES Board of Directors was held later (at 1230) that same day at the Naval Postgraduate School. ACES President Hal Sabbagh presided. Directors present included Hal Sabbagh, Perry Wheless, John Brauer, Duncan Baker, Ed Miller, Andy Peterson, Pat Foster, and Todd Hubing. Director Adalbert Konrad was unable to attend.

The financial reserves of ACES increased by approximately $41k during the past year, largely due to continued success of the Annual Review Symposium. The original ACES long-range financial plan called for accumulation of sufficient cash reserves to support two years of operation. This goal has now been achieved. The success of the conference in recent years has allowed ACES to freeze membership dues at 1994 levels, and additional future success may allow dues to be rolled back.

The Ways and Means Committee is tasked with the challenge of identifying emerging opportunities for ACES revenue growth. Pat Foster discussed several preliminary concepts, to be refined by the Committee in the coming months. Also, Pat Foster presented an ACES U.K. report on behalf of Tony Brown. ACES U.K. enjoyed a year featuring well-attended short course and paper presentation activities.

A workshop-format ACES meeting has been proposed to take place in September of 1997 at Penn State. Jim Breakall will present a more detailed financial plan to the Board of Directors later this summer. The meeting would feature workshops and short courses, with a structure intended to be non-competitive with the annual March symposium in Monterey. The main conference activity of ACES will remain the Monterey Annual Review. A motion was passed to the effect that the Conference Committee is the ACES umbrella committee with oversight responsibility for all meetings, conferences, workshops, and short courses. As such, for example, the Conference Committee will oversee the 1997 PSU meeting.

The recent trend in conference papers away from practical problems in Applied Computational Electromagnetics was discussed. An ad hoc committee was appointed by Hal Sabbagh to consider the future needs which the Annual Review conference should address in its technical paper programs. Also, a policy regarding multiple paper submissions to the conference was debated, and the following was adopted by poll vote (on 20 March 1996):

i. The recommended conference paper length is six (6) pages, with eight (8) pages as a maximum.
ii. Each conference registration entitles the registrant to no more than sixteen (16) pages, total, in the conference Proceedings.
iii. The mandatory excess page charge for pages in excess of (a) eight (8) for a single paper, or (b) sixteen (16) total pages is $15/page.

The Chair of the Conference Committee is Robert Bevensee, and constructive suggestions for continued improvement of the Annual Review are welcome at all times.

Ed Miller is working on the Software Sourcebook project, begun earlier by Frank Walker. Ed is currently revising old material and seeking out additional entries.
A motion was passed that ACES should begin distribution of NECVU (a DOS-based viewer) at $35/copy and that beta copies of NECSHELL will be distributed without charges while that software continues with de-bugging.

Atef Elsherbeni was later appointed (20 March 1996) new Chair of the Software Exchange Committee. Atef's e-mail address is atef@sphinx.ee.olemiss.edu.

Submitted to the ACES Newsletter by
W. Perry Wheless, Jr.
ACES Secretary

PERMANENT STANDING COMMITTEES OF ACES INC.

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COMMITTEE REPORTS

ACES PUBLICATIONS

The annual Editors Dinner at ACES'96 in Monterey was held on Sunday night at Chef Lee's Mandarin House. The pre-conference atmosphere was relaxed, and we enjoyed an outstanding meal and social time together. The preliminary conference agenda for 1997 suggests that this annual Publications event will end up on Sunday evening once more. By earlier publicity, we will encourage more Editors to travel on Saturday and be in Monterey on Sunday next year.

An informal lunch meeting was held at ACES'96 to discuss ACES Publications issues. Attendees included Pat Foster, Todd Hubing, Ray Perez, Duncan Baker, Perry Wheless, David Davidson, Andy Peterson, and Don Pflug. Considerable discussion involved (1) the ACES WWW site, maintained by Todd Hubing at The University of Missouri-Rolla, (2) electronic submission and publishing, and (3) future Special Issues of the ACES Journal.

Todd Hubing plans to add an "Applied CEM" link on the ACES WWW site. Also, it was agreed that Don Pflug will work with Todd to put future Canonical Problems, along with data listings from some benchmark experimental measurement programs, on the Web site. Don has three new canonical problems on hand, with perhaps a fourth on the way at this point. It was agreed at the Board of Directors meeting on 19 March 1996 that these Canonical Problems should be refined into camera-ready copy one by one and published in successive issues of the ACES Newsletter, beginning with 1996 issue no. 3. Don will work with Todd to see that these problems are made available on the ACES Web site concurrently with their publication in the Newsletter. Ray Perez would like to see more electronic submissions to the Newsletter and, especially, would like to encourage the various ACES Standing Committee Chairs to submit their Newsletter reports electronically in the future. Because the circulation of ACES Publications is relatively small, it is difficult to see favorable economies associated with possible moves to CD and/or Internet electronic distribution of publication materials. It was agreed that these vehicles will become practical and important for ACES in the future, but that they are not yet feasible for our particular society size, structure, and member profile.

The ACES Journal Special Issues have been very effective in recent years for the dissemination of technical information on specialized topics in CEM. Because these projects require substantial advance planning, you are urged to convey your ideas for topics and potential Guest Editors (including yourself!) to Perry Wheless or Duncan Baker at your earliest convenience. Some openings are now on the horizon, and your input now would be especially timely and helpful for planning purposes.

An "ACES Member Satisfaction and Feedback Survey" was recently completed, and we thank all participants for their time and constructive feedback. A lot of thoughtful and intelligent comments were received, and we will endeavor to implement progressive ideas into ACES Publications. The five ACES Journal issues, between vol. 7 no. 2 and vol. 11 no. 1, receiving highest "interest and/or usefulness" marks in the survey were:

1. Journal vol. 8, no. 2 ("TEAM Benchmark Problem Solutions) Notes: ranked by only 7 respondents, but with high marks by all.
2. Journal vol. 10, no. 3 (Advances in the Moment Method) Notes: ranked by 15 respondents.
3. Journal vol. 11, no. 1 (Applied Math., Meeting the Challenge . . .) Notes: ranked by 10 respondents.
4. Journal vol. 9, no. 2 (Low-Frequency EM Fields) Notes: ranked by 8 respondents.
5. Journal vol. 7, no. 2 (Bioelectromagnetic Computations) Notes: ranked by 9 respondents.

Five prospective future Special Issue Topics received essentially equivalent overall rankings. They were:

1. EM Modeling for Microelectronic Packaging (6 respondents)
2. Optimization and Inverse Problems in EM Products and Systems (5 respondents)
3. Vectorization and Parallel Computation Techniques (8 respondents)
4. Error Analysis and Validation (7 respondents)
5. Hybrid Numerical/Asymptotic Methods for Scattering (8 respondents)

The remaining topics finished, in ranked order, as follows:

6. Progress in Low Frequency Techniques (5 respondents)
7. Computer-Based Design Optimization (6 respondents)
8. Dense Matrix Solution Techniques (6 respondents)
9. Selected Papers from Regional CEM Conferences (2 respondents)

A few other topic suggestions were made and noted, such as Expert Systems, Neural Nets, AI and Fuzzy Set Theory in CEM. Two other suggestions, Applications of NEC-4 Features and CEM Perspectives from Senior Practitioners, are more appropriately in the purview of the ACES Newsletter, and have been referred there.

The "discussion" responses to questionnaire items 3-5 were extensive and space precludes their inclusion here, but those remarks are all appreciated and they are receiving full consideration.

There is always a difficulty with the accurate and reliable interpretation of small samples, but we believe these results reasonably reflect ACES member interests and priorities at this point in time. If you wish to register additional or dissenting opinions, please contact me by e-mail or telephone at 205-348-1757. Again, ACES Publications thanks you for your interest and participation.

Submitted by
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ACES Publications Chairman and Editor-in-Chief
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AWARDS COMMITTEE

At the 1996 12th Annual Review of Progress in Applied Computational Electromagnetics, an Awards Banquet was held to recognize ACES memers who have made special contributions to the Society. This year four service awards were presented, along with awards to the two authors of the outstanding paper of the 1995 issues of the ACES Journal.

President Hal Sabbagh presented the following awards at the banquet:

The 1996 Exemplary Service Award was presented to Gerald J. Burke for his many outstanding contributions to the society newsletter.

The 1996 Mainstay Award was presented to Andrew F. Peterson for his dedicated service as Treasurer and Chair of the Finance Committee.

The 1996 Founders Award was presented to Edmund K. Miller for demonstrating exceptional leadership in the establishment of short courses and tutorials.

The 1996 Valued Service Award was presented to Ray J. Luebbers for his dedicated leadership as Chairman of the 11th Annual Review of Progress.

The 1996 Outstanding Paper Award was presented to Ulrich Jakobus and to Friedrich M. Landstorfer for the paper "Current-based Hybrid Moment Method Analysis of Electromagnetic Radiation and Scattering Problems" published in the 1995 ACES Journal.

Please join us in thanking these winners for their outstanding service. The opinions of all members are solicited in selecting all award winners, so feel free to send in your nominations for 1997.

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CONFERENCE COMMITTEE

ACES CONFERENCE COMMITTEE ISSUES

SHORT COURSE/WORKSHOP COMMITTEE

Rob Lee has stepped down as Chairman of the Short Course Committee. Keith Whites, co-chair, of ACES "97 will work with Eric Michielssen, '97 Annual Review Chairman, to handle short courses for ACES '97.

SHORT COURSE NOTES

Recommendation: Each short course instructor should be required to submit a copy of his notes (to be distributed to students) no later than two weeks before the first day of the course. The above mentioned committee would recommend a format for the notes. If instructor does not allow sufficient time for necessary modifications of the notes, or does not have notes, his fee would be reduced accordingly. (This would require developing a sliding scale of fees).

SPECIFICATIONS FOR REVIEW PAPERS

We believe there is a need for authors to address the issue of accuracy in their computed results. An attempt should be started to have as many refereed papers as possible. Maybe a format such as (1) Overview, including objectives, (2) Background, (3) Topics, with derivations of results (including estimates of numerical errors), (4) Conclusions-not just rehash of procedures followed, (5) Appendices, (6) References.

VENDOR CHAIRMAN

Keith Whites, ACES '97 co-chair, has accepted this assignment. We as members should be alert to possible vendors and pass their names to Keith at whites@engr.uky.edu. He can inform them of the fees and arrangements. (This committee has always been hard to staff and we appreciate Keith's acceptance of this task).

BEST-PAPER PRIZE FOR THE ANNUAL REVIEW

Sad to say, this project was nixed by the Board of Directors in March. Reason: no money has been allocated into the '97 budget for this project. The "drawing power" of a sizeable prize, for example, $500 or $1000 is considerable, so it is suggested that we all be on the lookout for company/corporate sponsors. If you talk to a company representative who appears interested, for at least $500, promise him the publicity *but don't promise him anything more, such as participation in choosing the winner*. Just say the Conference Committee will contact him for further negotiations! That way many heads can decide on the sponsor's role.

The details of selection of review committee (maybe 3 persons), reviews of the paid papers after final acceptance, criteria for choice, etc. can be resolved. Think about this! We can also avoid conflict of interest between ACES' officers and prize winners. If you envision any thorny problems, please convey them to me.

PARTICIPATION WITH APS/URSI, JUNE '98, ATLANTA

ACES members have shown no interest in this event.

FUTURE SPECIAL ACTIVITY - PSU (PENN STATE UNIV.) '97 COMMITTEE

(FALL '97 WORKSHOPS, SHORT COURSES AND VENDOR DISPLAYS)

The following information is taken from "Penn State Conferences and Institutes" information forms, sent by Jim Breakall, at Penn State. "To ensure that every Penn State conference, seminar, or meeting exceeds the University's standard of excellence, program planners from Continuing and Distance Education's Conferences and Institutes stand ready to assist you with comprehensive management, from pre-conference planning and assumption of financial management to coordination of marketing, logistics, registration, and evaluation. This complete planning and management service allows you to concentrate on the reasons for the conference, while remaining confident that the details will be handled with the utmost care". It is ACES' understanding that all arrangements will be handled by them: announcements; registration fees, etc., with minimal or no financial risk on the part of ACES. This activity will be discussed with each of the Board of Directors during the summer meeting of the Board.

PAT FOSTER'S "SOME THOUGHTS FOR THE FUTURE"

Pat gave us a document last March at the Review which contains several good ideas pertaining to the Conference Committee. (1) We could solicit funds from companies to sponsor the Review Cheese and Wine Party, (2) We could urge the Review Committee to suggest that the vendors could sponsor training sessions (for a fee to the students), (3) We could offer the vendors free advertisements in Symposium Proceedings.

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NOMINATIONS COMMITTEE

In the coming months, ACES members will be asked to vote for three board members. For uniformity, each candidate will be asked to provide a short statement that addresses:

(1) GENERAL BACKGROUND (e.g., professional experience, degrees, employment, etc).

(2) PAST SERVICE TO ACES (e.g., service on ACES committees, or other contributions).

(3) CANDIDATES' STATEMENTS (e.g., short statement of the candidates views of major issues relevant to ACES). Candidates' statements will be no more than 500 words, unless otherwise directed by the board.

(4) OTHER UNIQUE QUALIFICATIONS (An additional but optional statement).

It is hoped that these areas will provide data on each candidate that might otherwise be obscured in a general, unstructured statement. When the time comes, please take a few minutes to study the candidates' statements and vote. (see page number 3).

Directors-at-Large

Duncan C. Baker	1997	Pat Foster	1998	John Brauer	1999
Edmund K. Miller	1997	Todd Hubing	1998	Harold Sabbagh	1999
Andrew F. Peterson	1997	Adalbert Konrad	1998	Perry Wheless, Jr.	1999

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SOFTWARE EXCHANGE COMMITTEE

NECVU for DOS now available via the ACES Software Exchange Committee.

NECVU provides a convenient method for viewing and printing a NEC-MOM wire structure input file. It does not support surface patches. The unique feature of NECVU, developed by John P. Morgan of State College, PA is the ability to rotate, translate and zoom the screen image of the wire structure. Sliding the mouse in conjunction with the two buttons permits very rapid user control over the view of the structure. The no-button action rotates the structure about the centroids axis origin or about the NEC data card origin. The right button pans the image and the left button zooms in and out. The ability to select colors to distinguish junctions, open ends, groundplane connections and continunous wires provides a very powerful diagnostic tool to the NEC dataset developer. Segment ends can be displayed as a dot on the screen and as an asterisk in the printed image.

The user can choose screen colors via a setup file called NECVU.CFG. This also controls the printed image. Printer commands are for PCL5 printers, such as the LASERJET III, IV and V. One color printer that meets this requirement is the HP 1200C Deskjet. There is also support for Postscript printers. For other printers, the user may choose the DOS GRAPHICS screen dumpers which have limited gray scale color mapping. PCL3 support for black and white printers can also be obtained via EGALASER.COM, a freeware screen dumper included on the NECVU disk. Loss of color in the printed output is partially overcome via line width control for the same types of wires as mentioned above.

NECVU will also create an output file for off-line printing. If you have a printer or plotter that uses HPGL files, NECVU can produce that type of output file via commands in the NECVU.CFG file. Several sample .NEC files are contained on the disk. The DD963.NEC file (2,731 segments) shows the power of NECVU for DOS in handling large files, swiftly. NECVU supports free format NEC input files; those using a character such as "," or a space as a field delimiter. It terminates reading a line of data once it encounters its "comment" flag. For many versions of NEC3, this is two successive blanks. For NEC4 it is "!".

The following images are samples of the PCL5 output for the DD963 and for a FM broadcast antenna, showing segment width flags. NECVU for DOS is available from the ACES Software Exchange Committee for $35, postpaid.

For the ACES Software Exchange Committee,

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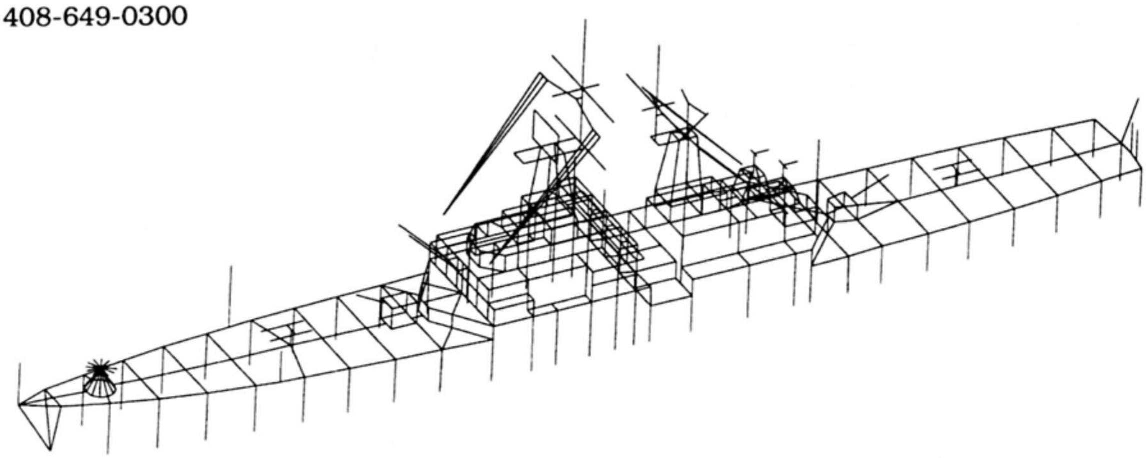
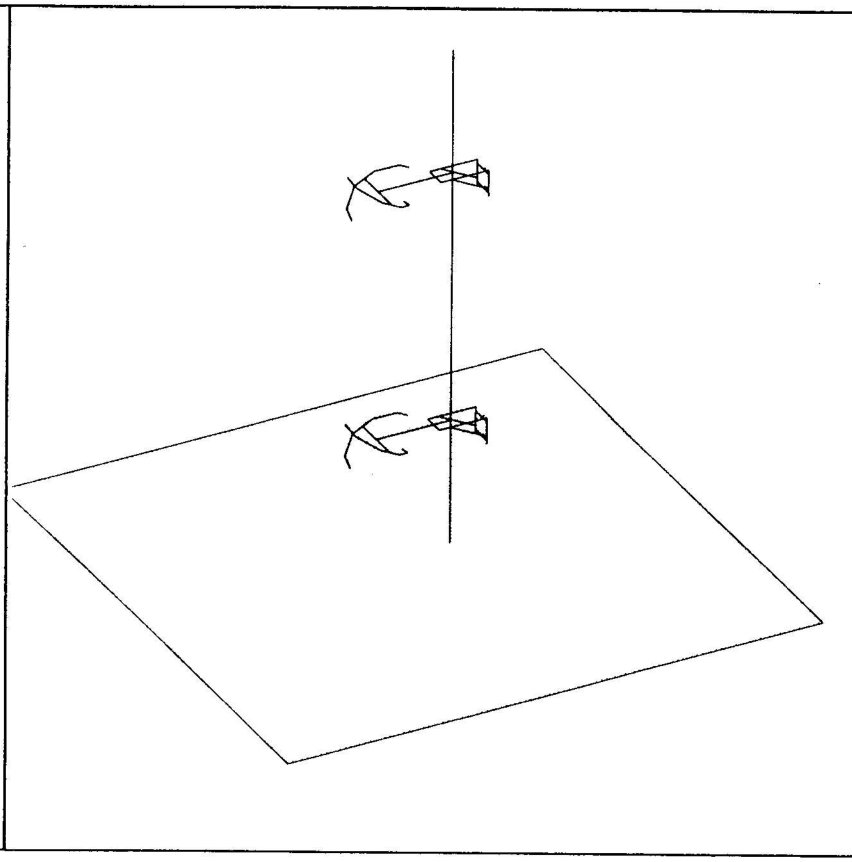


FM BROADCAST ARRAY, SHOWING GROUND PLANE. PCL5 PRINTER IMAGE

PHI = 62 (deg)
THETA = 59 (deg)

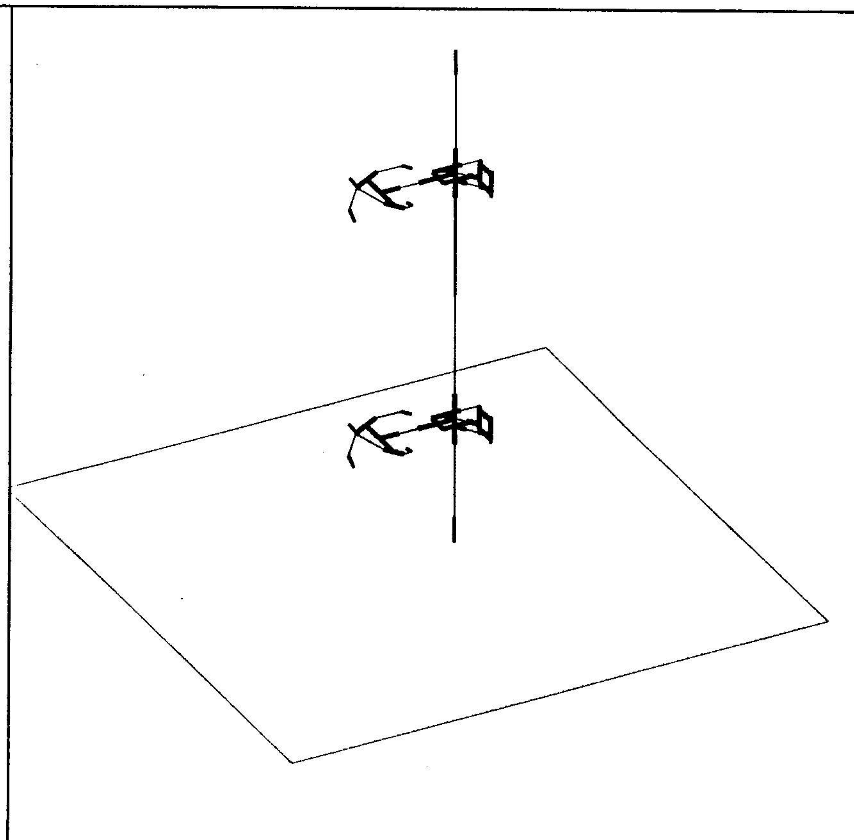
NEC SEGMENTS = 132
NEC JUNCTIONS = 30
NECVU LINES = 182



FM BROADCAST ARRAY, SHOWING GROUND PLANE. PCL5 PRINTER IMAGE W/THICKNESS.

PHI = 62 (deg)
THETA = 59 (deg)

NEC SEGMENTS = 132
NEC JUNCTIONS = 30
NECVU LINES = 182



CEM NEWS FROM EUROPE

Coordinated by Pat Foster, MAAS, UK[1]

INTRODUCTION

Lucas J.v. Ewijk has written the contribution for this issue which comes from TNO. TNO Physics and Electronics Laboratory (TNO-FEL) is one of the laboratories of the Netherlands organisation for applied scientific research and the main laboratory for radar research in the Netherlands. One of the major fields of research is radar and the activities include experimental and fundamental research into radar-signatures of targets and background and radar signal propagation. The computation of target scattering properties at radar frequencies is part of this research. In this paper the activities in this field at TNO-FEL will be explained. A future paper will deal with the other electromagnetic computational efforts that are done at TNO.

Electromagnetic Scattering Computations

The backscattering properties of targets strongly influence the performance of the detection and tracking process of a modern radar. The radar cross section of targets, therefore, is one of the essential parameters for radar system design, mission planning and determination of the survivability of platforms.

For these reasons TNO-FEL has been doing research on RCS for more than 35 years, the Netherlands ministry of defence being the largest contractor. The computational effort in this field has become more and more important during the last 8 years as modelling and simulation is less expensive than measurements and it has proven to be a valuable asset in system design in cooperation with measurements.

The mathematical modelling of electromagnetic scattering is done using various methods elaborated in the following sections.

Physical Optics and Ray-tracing

Perhaps the most commonly used method to compute the scattering of electromagnetic fields by arbitrary objects is Geometrical Optics (GO). It is also known as ray tracing and can be used to compute the scattered fields by curved surfaces. A more general method, applicable to flat surfaces as well, is Physical Optics (PO) which makes use of the induced surface currents at the scattering object. In itself PO doesn't incorporate multiple reflections, so a combination of ray tracing and PO is used for this purpose, [1, 2, 3, 5, 6]. The program using this method is called RAPPORT (Radar cross section and Prediction by Physical Optics and Ray Tracing). RAPPORT can compute the RCS of arbitrarily complex objects up to as many reflections as one wants. The accuracy of the results, within the accuracy of the inherent approximations of the method of course, can be adjusted by the user. The object is subdivided into a number of flat facets. Shadowing and multiple reflections are determined using the centre points of these facets. With RAPPORT the RCS of complex objects like complete aircraft and ships has been computed. The program is validated with measurement data obtained from simple targets [4] and a scale model of a ship.

Computation of Edge Diffraction

The need to compute diffracted fields from sharp edges arises directly from the application of PO for the computation of the RCS of objects. PO doesn't account for these contributions. Especially when computing the RCS of stealthy objects, or of objects that simply have a low RCS, the PO computations fail to give the correct answers. If one still wants to make use of approximating techniques for those objects, it is necessary to invoke for instance diffraction computation.

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A lot of techniques have been developed to perform such computations, like for instance Geometrical Theory of Diffraction (GTD), Uniform Theory of Diffraction (UTD), Incremental Length Diffraction Coefficients (ILDC) and Method of Equivalent Currents (MEC) to mention a few. We have adopted the MEC, first derived by Michaeli [7, 8], for this method has a wider application base than the ray-optical methods like GTD and UTD. The ILDC, first derived by Mitzner, could be used just the same because, although derived separately, both methods are similar in background and results, [10].

Our implementation of the MEC is such that only the diffracted fields from sharp edges are computed, omitting the terms that accounts for the reflection by the flat surfaces on both sides of the edge. The reason for this is that we are now able to obtain separate results for reflection and diffraction and that we can apply the diffraction program only in those cases necessary [9]. In all other cases we use RAPPORT stand alone.

Multiple diffraction is the effect when diffracted fields from one edge are incident upon another edge. At near grazing incidence angles the secondary diffracted field can cause large scattering peaks in the direction of the original incident field. This phenomenon is known as a travelling wave. For the interesting angles of incidence the second edge is in the transition region of the first edge which prohibits the direct application of the diffraction theory at the second edge. The diffracted fields are, therefore, decomposed into plane waves first [11], after which the secondary diffraction can be computed. This methodology has been used in combination with MEC and it is applicable to parallel edges.

Finite Difference Time Domain Method

In the first sections we discussed some high frequency scattering programs, useful when the high frequency approximations are valid. When the objects are smaller, these methods fail and more exact computations are necessary. For this purpose the Finite Difference Time Domain (FDTD) method has been adopted. This well known method has been implemented in a 2D and a 3D program that can be used for a wide variety of electromagnetic scattering computations, ranging from objects of pure scientific interest to some (small) real life problems. This method basically gives a solution to the Maxwell equations for a given configuration, so it is suitable for more than just RCS computations. One of the other areas the code has been used is the computation of field intensity in microwave ovens, in order to optimise the location of the antennas in these ovens, [12, 13].

Computing Forward Scattering from Obstacles

The computation of forward scattering by objects is a technique that is used at TNO to determine the effects of shadowing of radar radiation by large obstacles.

The forward scattered field undergoes a phase shift of 180 degrees with respect to the incident field. The total field is obtained, therefore, by subtracting this field from the original field. This creates the shadow behind an obstacle, [1, 2].

Such a shadow can become prohibitive in cases where the performance of radar systems is crucial in directions where large obstacles are erected. Separate software is developed for the computation of such shadows. From this research it appeared that obstacles like, for instance, church towers and large wind turbines can cast a shadow that causes a serious degradation of radar performance.

Lucas J.v. Ewijk can be reached on ewykl@fel.tno.nl.

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Gerald J. Burke

We do not have a contribution for Modeler's Notes for this issue, but there are a couple of NEC-4 bugs to report. Once again Roy Lewallen has found a problem in the ground modeling. This one involves the situation when a GD command is used to set or change the parameters of the "second ground medium" beyond the ground set by the GN command. When the GD command is read after the currents have already been computed the subroutine SETGND does not get called as needed for the new parameters to take effect. This problem can be fixed by adding one line to the main program after the call to RSETGD at about line 205 of main, as shown below.

```
ELSE IF (AIN.EQ.'GD) THEN
     CALL RSETGD(ITMP1, TMP1, TMP2, TMP3, TMP4, IFLOW)
      IF(IGO.GT.2)CALL SETGND(FMHZ)                    !NEW
     GO TO 14
```

Another problem in NEC-4 was encountered by Bobby Cox in the midst of a crash effort to get results to present at a conference. This involves the out-of-core operation of the NGF solution when the matrix for the new unknowns does not fit into the program's array and must be factored on disk. For out-of-core solution the matrix is split into blocks sized so that two blocks will fit into the array. The last block may be smaller than the rest, but the I/O routines read and write full-sized blocks even for the last one. However, the NGF routine FACGF wrote the last block of actual size, so that when the factoring routine tried to read a full sized block it ran out of data. The problem can be fixed by changing NPC to NPBL in line 51 of subroutine FACGF as shown below:

Wrong:

```
IF (ICASX.GT.1) CALL RECOT(D,14,1,N2C*NPC,IC,' WRITE D IN FACGF')
```

Corrected:

```
IF (ICASX.GT.1) CALL RECOT(D,14,1,N2C* NPBL,IC,' WRITE D IN FACGF')
```

The line can be found by searching for "WRITE D"

Probably the reason that this error did not get caught earlier is that I seldom use the out-of-core solution. Most computers these days have a lot of RAM, and while disks may start out with lots of space, they rapidly get filled up with garbage. It is always best to dimension the program's matrix array as large as possible to minimize or eliminate the need for disk storage of the matrix, since the solution will run faster without disk I/O. In NEC-4 and the newer versions of NEC-2 and 3 that we have sent out, the size of the matrix array is set by the parameter MAXMAT in an INCLUDE file. The array is dimensioned to MAXMAT**2 complex numbers. Hence MAXMAT should be greater than or equal to the number of unknowns in the model, which is the number of wire segments plus two times the number of patches. In older versions of NEC-2 and 3 the array dimension was hard wired into the array CM in COMMON block /CMB/, and there is also a variable IRESRV that must be set equal to that dimension.

The array storage situation gets more complicated when the NGF solution is used, since part of the in-core array is then reserved for use when new segments or patches are added to the NGF model. The total array size is still IRESRV = MAXMAT**2 complex numbers, but a part of this array, set by the value IRNGF, is reserved for future use if new segments or patches are added to the NGF model. Hence the array size available for the solution initiated by the WG command is IRESRV - IRNGF. We have the codes set up to set

IRNGF = IRESRV/2, to reserve half of the total array space for additions to the NGF model. If you use the NGF only to save solutions for re-use without adding new structures, or with only small additions, you may want to change the setting of IRNGF to a smaller value, such as IRESRV/10 or even zero to keep the code from going into out-of-core mode unnecessarily. If you later want to add to the NGF file you can recompile with a larger MAXMAT (or IRESRV) if there is enough RAM available. IRNGF is set at about line 506 of the main program in NEC-2 and at line 249 of main in NEC-4.

This will be a short Modeler's Notes, since we do not have any external contribution. There is some interesting coming out, but I have not had a chance to review it yet. Several months ago Absoft announced a new release of their Fortran compiler for the Mac and also a beta version of a Fortran 90 compiler. I have ordered the F77 compiler, but will wait a while before investing in the Fortran 90. There seem to be enough bugs in the UNIX F90 compilers at this point. Absoft also has a F77 compiler for Windows that is source-compatible with their Mac compiler. It would be interesting to hear how it compares with compilers such as Microsoft and Lahey, but I have not heard of anyone using it to compile NEC.

There is a lot of interest here in C++ for developing complex modeling codes. I am attempting to learn C++ with the CodeWarior compiler on the Mac. CodeWarior includes an editor with colored syntax coding and a beta-version class browser which is nice, but sometimes crashes the system. A new release, version 9, is now out and should arrive soon as one of the "two free upgrades" that they offer with any purchase. This Mac compiler, and similar PC/Windows compilers certainly seem to be better for learning C++ than the UNIX environment. Personally I hope that Fortran 2000 will develop to give us the object-oriented capabilities of C++ in a form that is easier to read and understand, but it looks like the academic push is to C/C++.

Another interesting release to wait for is Mathematica 3.0, which looks like it should be available around July. It sounds like there will be some big improvements, especially in the front end.

As usual, if anyone can contribute material on modeling, NEC or otherwise, they are encouraged to submit it to our editor Ray Perez or to:

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Numerical Methods for Nonlinear Optical Wave Propagation

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ABSTRACT

The numerical solution of nonlinear partial differential equations (PDE's) is at the center of the study of electromagnetic wave propagation in nonlinear media. A wide variety of numerical methods are available to solve the equations that describe propagation in nonlinear media.

Finite difference time domain methods, in which the Maxwell's time dependent curl equations are solved directly are seeing increased use, especially in the study of ultrashort pulse propagation in optical fibers. Time domain techniques offer model accuracy, but require vast amounts of computation.

Finite difference and spectral methods applied to the nonlinear Schrödinger equation and similar propagation models are superior to time domain methods in terms of required computation, and accurately model pulse envelope propagation in weakly guiding structures, such as optical fibers.

The use of wavelets as a basis for a spectral method analogous to Fourier transform methods has been proposed. Further research is needed to fully evaluate the potential of wavelet transform methods.

I. INTRODUCTION

The study of nonlinear systems has a long history, but many problems of interest can only be explored experimentally or numerically. Hence, the broad spectrum of behaviors of nonlinear systems was not revealed until the advent of computers with the capacity to solve problems within reasonable time frames [1, 2].

Some problems, such as predicting the weather, have long been of intense practical interest. Other applications have grown up hand-in-hand with the technology that provides the means to study the relevant nonlinear phenomena. For example, the growing demand for higher speed, higher capacity communications has fueled the development of optical communications systems that rely on the properties of nonlinear single mode optical fibers to achieve extremely high transmission rates (10's of gigabits per second). Digital optical computer systems have been devised and demonstrated, and devices with which to construct all optical switching systems are nonlinear in nature and are a topic of current research.

Solution of nonlinear partial differential equations (PDE's) is at the center of studies of nonlinear systems. Several PDE's appear frequently enough in the study of propagation in nonlinear optics to warrant special attention, including the Korteweg-de Vries (KdV) equation (which models shallow water waves, in which solitons were first observed by Scott Russell in 1834 [3]) and the Klein-Gordon equations. Of particular interest is the nonlinear Schrödinger (NLS) equation, which in its pure form is [4]

$$i\frac{\partial q}{\partial Z}+\frac{\alpha}{2}\frac{\partial^2 q}{\partial T^2}+|q|^2 q=0. \qquad (1)$$

where q is the soliton envelope, and Z and T are respectively the normalized space and time. The NLS equation was used to model propagation in optical fibers in 1973 [5, 6], where solitons in optical fibers were first predicted; the first experimental observation of solitons in optical fibers was reported in 1980 [7]. In its generalized form, the NLS equation, has broad applicability in the study of wave propagation in many nonlinear media, including plasmas and deep water waves [2, 8, 9]. For this reason, this paper will concentrate on numerical methods useful for the nonlinear Schrödinger equation; the techniques discussed here are also applicable to many similar equations.

Derivation of the NLS equation, in the context of propagation in nonlinear optical fibers, begins with Maxwell's equations. Nonlinearity is introduced through the electric polarization vector, specifically the third order contribution to the nonlinear susceptibility (χ_3), which results in a nonlinear (intensity dependent) refractive index modeled as [4]

$$\hat{n}=n_0+\hat{n}_2|q|^2. \qquad (2)$$

The assumption of an isotropic material and that the difference between the refractive index of the fiber core and cladding is much less than one ("weakly guiding" approximation) allows the vector nature of the field to be ignored, resulting in a scalar expression. The further approximation of ignoring the second derivative of the field with respect to the direction of propagation ("slowly varying envelope" approximation), yields a wave equation describing the propagation of the wave envelope. Finally, to achieve Eqn. **1**, a coordinate transformation is applied that results in a frame of reference moving at the group velocity, and the entire expression is normalized to remove dependence on physical dimensions of the fiber.

Solitons, of great interest in high speed data transmission, are the result of balancing linear dispersion with the self-focusing effect of the nonlinear refractive index to permit propagation over great distances without pulse broadening. The pure NLS equation, Eqn. **1**, models first order linear dispersion (the second term) and the intensity dependent refractive index (Kerr nonlinearity, third term) of a nonlinear optical waveguide, a system in which solitons can propagate. Higher order effects, such as higher order linear dispersion, stimulated Raman scattering, and other forms of the intensity dependent refractive index, may be modeled with a generalized form of the NLS equation that includes terms for each effect [4, 10, 11, 12].

Few practical problems in nonlinear optics can be readily solved using analytical techniques, although inverse scattering techniques have been used to derive soliton solutions to the NLS equation, the KdV equation, and others [3]. These solutions accurately model propagation given the exact initial conditions. However, the problem of arbitrary initial conditions has not been handled analytically, and it remains necessary to compute numerical solutions to the majority of real problems.

II. FINITE DIFFERENCE TECHNIQUES

Finite difference methods are useful in the solution of many equations of interest in nonlinear optics. These well known techniques rely on representing the equation to be solved at closely spaced discrete points (a grid), replacing partial derivatives with approximations obtained from truncated Taylor series expansions [13].

$$i\frac{q_n^{m+1} - q_n^{m-1}}{2\Delta t} = \frac{\alpha}{2}\frac{q_{n+1}^m - 2q_n^m + q_{n-1}^m}{\Delta x} - 2(q)_n^m q_n^m, \quad (3)$$

is the explicit finite difference approximation for Eqn. 1. The Δx and Δt are the distances between grid points in the x and t directions, respectively.

Finite difference schemes fall into two fundamental categories; explicit, and implicit. Explicit schemes are so called because each point in the solution at any time step is computed explicitly in terms of the solution at previous time steps. In an implicit scheme each point in the solution for the current time step depends not only upon the solution at previous time steps but also on points in the current time step. This results in a system of equations that must be solved simultaneously at each solution step.

The choice of finite difference formulation has a significant effect on the stability of the method, achievable accuracy, and amount of computation required [14].

For most finite difference methods, the computational grid is uniform (i.e. points are evenly spaced). Nonuniform, or irregular, grids are possible, and have been proposed for the solution of propagation problems (for example [15]). However, consistency[1] of the finite difference formulation for a given partial derivative cannot in general be guaranteed with an irregular grid [16]. The value of nonuniform grid spacing comes from the savings in computation that results from concentrating points in the area of interest (for the NLS equation, this is usually near the center of the grid, where wave shape changes are expected).

[1] Consistency, a fundamental constraint on a finite difference formulation, requires that in the limit as grid spacing approaches zero the actual derivative must be recovered [16]. Equivalently, a consistent finite difference formulation will have solutions that converge to the solution of the differential equation as the grid spacing approaches zero [13].

III. PSEUDOSPECTRAL METHODS: SPLIT STEP FOURIER TRANSFORM METHOD

Although the nonlinear Schrödinger equation can be solved using finite difference techniques, pseudospectral methods have been shown to be an order of magnitude faster for the same accuracy in most cases[14]. The split-step Fourier transform (SSFT) method, also known as the beam propagation method in continuous wave optical applications, is the method of choice for many problems involving the NLS equation.

Spectral methods involve the expansion of a solution in terms of an infinite set of basis functions as in [3]

$$q(T,Z) = \sum_{p=1}^{\infty} \langle q, \varphi_p \rangle \varphi_p, \quad (4)$$

and the subsequent approximation of the solution by a truncated series as in

$$q(T,Z) \approx \sum_{p=1}^{m} \langle q, \varphi_p \rangle \varphi_p. \quad (5)$$

Here, $\langle . \rangle$ is inner product and φ_p are orthogonal basis of functions. A method is called pseudospectral rather than spectral if numerical integration is used to evaluate the φ_p rather than spectral analysis. A convenient basis is the trigonometric functions.

To develop the SSFT method, consider the NLS equation (Eqn. 1) in the form

$$iq_Z = (L + N)q, \quad (6)$$

where L is a linear operator and N is a nonlinear operator that is dependent on q. Formally integrating Eqn. 7, we get the operator expression

$$q(T,Z) = \exp(-i(L\Delta Z + \int_0^{\Delta Z} N(q)dZ'))\, q(T,0). \quad (7)$$

Assuming that over small distances ΔZ the linear and nonlinear components of the operator act

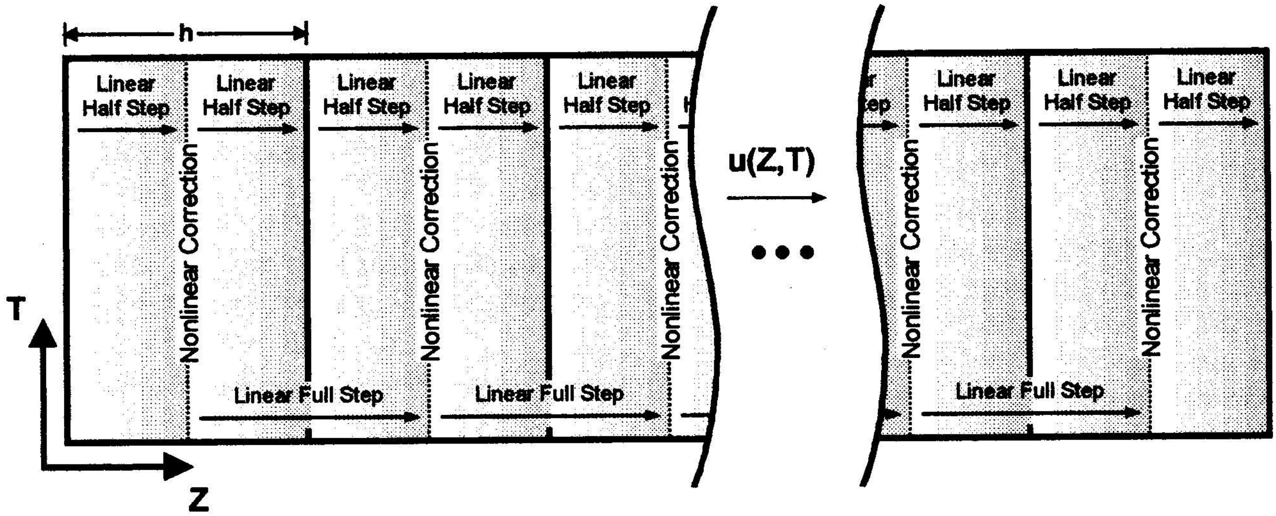

Figure 1: The split step Fourier transform method.

independently, we can split the operator in Eqn. 7 yeilding the approximation [10, 17]

$$q(T,Z) \approx \exp(-iL\Delta Z)\exp\left(\int_0^{\Delta Z} N(q)dZ'\right) q(T,0) . (8)$$

We can approximate propagation over a small distance using Eqn. **8**; each step in the propagation is a combination of a nonlinear propagation and a linear propagation over the step length $h = \Delta Z$. The resulting split step Fourier transform method exhibits truncation error proportional to h^2.

The linear step may be implemented by transforming $q(Z,T)$ into the frequency domain, multiplying by a phase term, and retransforming. The fast Fourier transform (FFT), for which many efficient implementations have been developed [18, 19], makes this computation quite fast.

By approximating the exponential operator in Eqn. **8** with a split operator of the form [10, 17]

$$e^{-i(A+B)} \approx e^{-i\frac{A}{2}} e^{-iB} e^{-i\frac{A}{2}}, \qquad (9)$$

wherein A corresponds to the linear component and B corresponds to the nonlinear component, the truncation error of the split step Fourier transform method can be made proportional to h^3. The method then becomes a linear propagation over a half step, a full step nonlinear propagation applied to the result of the linear half step (a "nonlinear correction"), and finally another linear half step. The algorithm is illustrated in Figure 1.

Although it may seem that the increase in accuracy that stems from the use of the split operator in Eqn. **9** comes at the cost of doubling the effort required to compute the linear component of the propagation, this is not so. The number of linear propagations can be reduced by half (except at the initial and final steps) by combining the initial linear half step of a solution step with the final linear half step of the previous solution step (see Figure 1).

As previously stated, the split step Fourier transform method is the method of choice for many problems involving the NLS equation. The method is easily extended to generalized forms of the NLS equation, providing a fast, memory efficient method for solving nonlinear propagation problems. However, the method suffers from the need to ensure that the grid in the normalized time (T) direction is wide enough to avoid interactions at the grid boundary, due to the periodic boundary conditions imposed by the discrete Fourier transform used in the method (see the following section).

IV. BOUNDARY CONDITIONS

The NLS equation is used to model the propagation of a pulse envelope through a medium that is effectively infinite in the normalized time (T) dimension (see Figure 1). In the finite difference and pseudospectral schemes described above, solutions are determined over a grid of typically evenly spaced points. Since computation over an infinite grid is impractical, boundary conditions must be specified at the limits of the grid. Some basic boundary conditions, for a computation where T ranges over $0 \rightarrow T_f$, include [9]:

$$\begin{aligned} q(T_f) &= q(0) \\ q(T_f) &= q(0) = 0 \\ q(T_f) &= q(T_f - \delta T) \end{aligned} \tag{10}$$

In Eqns. **10**, the boundary conditions listed correspond to periodic, zero field, and zero slope boundary conditions, respectively.

In many computations modeling electromagnetic propagation, absorbing boundary conditions are used to reduce a large grid to a manageable size. The goal of any absorbing boundary condition (ABC) is to allow radiation to "pass through" the computational boundary, eliminating reflections that would otherwise invalidate a numerical solution. A large body of literature exists describing the development and properties of ABC's (see, for example, [20]).

In practice, for the solution of the NLS equation using the split step Fourier transform method, the grid is made large enough that little or no interaction with the computational boundary is encountered. This is practical since the NLS equation models a frame of reference moving at a specific "group velocity;" the pulse envelopes being studied travel at or near the velocity of the reference frame, and hence generally remain near the center of the grid for the duration of the computation. Energy that does reach a boundary of the grid, because of the periodic boundary condition imposed by the Fourier transform, "wraps around" and reenters at the other boundary rather than disappearing from the computation. Such behavior can introduce errors and instability in the computation.

For those cases when significant energy is expected to reach the grid boundary, finite difference techniques with appropriate absorbing boundary conditions may permit a valid solution to be computed, at the cost of an order of magnitude in run time over the split step Fourier transform approach. Alternatively, it may be possible to apply a windowing function between linear steps if the split step Fourier transform method is to be used. In either case, the computation does not conserve energy and there is no simple method of relating energy to propagation distance; this has consequences for monitoring the accuracy of a computation.

V. MONITORING ACCURACY

Numerical solutions of PDE's by their nature rely on approximations to the actual PDE's, and as such require considerable care from the practitioner to ensure that the solutions obtained are useful. Common problems include aliasing in spectral methods, instabilities due to large step sizes or interaction with the boundaries of a computation, and magnification of accumulated errors. The latter problem is of particular concern in nonlinear problems, since small errors can be magnified dramatically due to the nature of the nonlinear system being modeled. For example, the phenomenon of modulational instability [21] results in strong sensitivity to small variations in optical intensity, with the result that even very small errors can rapidly invalidate a computation.

As a computation proceeds, it is important to monitor whatever measures of accuracy are available. Adaptive techniques that adjust step sizes may be employed, or computations may be halted when errors exceed preset limits. Adaptive techniques, while attractive since they promise to avoid computing an entire solution with a small step size, are complex to implement in practice since it may be desirable to backtrack several steps (from the point where the error limit is exceeded) to preserve the desired accuracy.

Measurement of conserved quantities as solutions are computed is essential to detecting problems with any numerical solution. The pure NLS equation, for example, has an infinite number of conserved quantities [9], the first two of which are "energy,"

$$I_0 = \int |q^2| dT, \qquad (11)$$

and "momentum,"

$$I_1 = \int (q^* q_T - q q_T^*) dT. \qquad (12)$$

When losses are included in the model, through the addition of a linear loss term in a generalized NLS equation, the above quantities are not conserved. In this case, the equation of motion of the energy can be used to predict the energy loss per step, permitting the total pulse energy at any step to be used as a measure of the performance of the numerical method.

VI. WAVELET METHODS

Wavelets and wavelet transforms have become a topic of great interest in recent years. Conceptually similar to the Fourier transform, in the wavelet transform [22]

$$q(T,Z) = \sum_{p=1}^{n} \langle q, \varphi_p \rangle \widetilde{\varphi}_p \qquad (13)$$

where $\widetilde{\varphi}_p$ is called the dual of φ_p and $n > m$.

$$q(T,Z) = \frac{2}{A+B} \sum_{m,n} \langle q, \psi_{mn} \rangle \psi_{mn}(T) \qquad (14)$$

where ψ_{mn} is called "baby wavelet" related to "mother wavelet" ψ through

$$\psi_{mn}(t) = a_0^{-m/2} \psi(a_0^{-m} t - n\tau_0). \qquad (15)$$

Here, A and B are constants such that $A \neq B$ but $A \approx B$, a_0 and τ_0 are constants relating respectively to the width and center of the windowing function that is incorporated in the wavelet transform. The computation in wavelet split-step Fourier transform method follows the SSFT method very closely; the nonlinearity is treated the same way as in SSFT method where as the dispersion is treated differently; Fourier transform operation is carried out on the wavelet, followed by multiplication of a phase term to account for dispersion. The pulse is then reconstructed in time domain using inverse Fourier transform followed by the evaluation of wavelet transform given in Eqn. **14**. Because of the flexible windowing function that is incorporated in the wavelet transform, multi-resolution is possible. The advantage of the wavelet transform is the high resolution of both time and frequency which is not possible in the other methods.

VII. TIME DOMAIN METHODS

Models of electromagnetic propagation derive from Maxwell's equations, with material properties accounted for in the constitutive relations and boundary and initial conditions defining the problem geometry. The obvious method of attacking propagation is direct solution of Maxwell's time dependent curl equations [23].

Time domain solutions to Maxwell's equations, using finite difference formulations, offer accurate models at the expense of requiring extensive computation. Incorporating nonlinear effects, which by their nature are time delayed, introduces considerable complexity over the linear case, but time domain techniques are useful in the study of propagation in nonlinear optical materials, especially for pulses of short duration [23].

The NLS equation models the propagation of pulse envelopes, eliminating the optical carrier through the use of the "slowly varying envelope" approximation. The NLS equation is accurate for "long" pulses with duration much greater than the optical carrier period, and offers considerable computational efficiency, but imposes significant limitations. These limitations include ignoring backward propagating waves (including reflected waves) and the vector nature of electromagnetic fields (hence polarization effects are not accounted for in the NLS equation) [10].

Approaches based on time domain solutions of Maxwell's equations achieve greater accuracy by modeling all optical properties. Since the optical carrier is modeled explicitly, the spacing of grid points must be less than the optical carrier wavelength. In addition, the time step must be a fraction of the optical carrier period. These constraints result in huge grids and large numbers of time steps for even short propagation problems. With the constant advances in computer technology that result in supercomputer capability on the practitioners desktop, time domain techniques are becoming more practical, and may offer the best solution for ultrashort pulses of only a few cycles of the optical carrier.

VIII. CONCLUSIONS

A rich variety of techniques are already available to solve models commonly encountered in nonlinear optics, and new techniques are presented regularly. Each practitioner should be familiar with several numerical approaches, as each family of numerical methods offers advantages for specific situations but suffers in another.

It is by no means clear that wavelet methods will offer clear advantages over other spectral methods, but the emerging application of wavelets to computation bears watching.

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THE INTELLIGENT COMPUTATIONAL ELECTROMAGNETICS EXPERT SYSTEMS (ICEMES)

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Key Words: Computational Electromagnetics (CEM), Artificial Intelligence (AI), Expert Systems, Computer-Aided Simulation, Modeling Methodology Validation, General Electromagnetic Model for the Analysis of Complex Systems (GEMACS)

ABSTRACT

This paper reviews the results of research and development to establish an Artificial Intelligence/Expert System (AI/ES) pre-processor for Computational Electromagnetics (CEM) codes. The AI/ES-enhanced pre-processor, called the Intelligent Computational Electromagnetics Expert System (ICEMES), makes use of a commercially-available expert system and an existing government-developed CEM code. The present version was designed using Gensym's G2 Real Time Expert System and the US Air Force's General Electromagnetic Model for the Analysis of Complex Systems (GEMACS) program.

Rationale for considering AI/ES technologies in the CEM pre-processor concept design include the ability to successfully merge various CEM software codes, physics/solution methods and processing algorithms, as well as establishing a common simulation environment which exploits code/data reuse and concurrent engineering methodologies. This environment employs rule-based and procedural techniques for knowledge incorporation, for establishing relationships among Knowledge Base (KB) components (objects), and for defining inherited properties for attributes sharing among various objects of the KB.

The results of the ICEMES development and demonstration discussed in this paper are based on Phase I research performed by the authors under US Air Force Contract No. F30602-95-C-0198, sponsored under the DoD Small Business Innovation Research Program, Topic AF-055 entitled, "AI/ES Pre-processor for CEM".

BACKGROUND

CEM modeling, simulation, and analyses are necessitated by the need to assure life-cycle performance, desired operability, and long-term survivability of systems in electromagnetically-rich environments, both intentional as well as unintentional. Whereas CEM computer codes are used as one means of assessing such performance early on in the life-cycle of systems, such codes may present certain usage difficulties to the novice or non-CEM analyst, and may require a significant degree of user proficiency or knowledge of CEM assessment methodologies. These factors can make CEM modeling, simulation, and analysis daunting tasks.

The ICEMES capability is intended to alleviate many of the potential drawbacks and difficulties associated with using individual CEM codes for complex system electromagnetics modeling, simulation, and analyses [1-6]. It combines advanced knowledge/rule-base modeling and simulation technologies "wrapped around" conventional CEM engineering wisdom and experience, proven assessment methodologies, and certain code-specific constraints that collectively represent core CEM knowledge. The environment for capturing this collective knowledge is the expert system's Knowledge Base (KB).

The incorporation of CEM modeling rules-of-thumb based on proven experience as well as theory, along with the integration of CEM code-specific constraints within a KB environment establishes a new, powerful, intelligence-driven pre-processor capability. The intelligent pre-processor concept is aimed at: (a) enhancing the analyst's efficiency in rapidly developing complex system geometry models where burdensome modeling tasks are assigned to the intelligent engine; (b) facilitating the automatic selection of the most appropriate physics formalisms and solution techniques within the constraints of select CEM tools, methods, and algorithms applied to electromagnetics problem-solving (i.e., CEM modeling optimization and validation); and (c) assisting the analyst in implementing effective CEM assessment methodologies for the rapid development of valid simulation models.

During ICEMES' evolution, a wealth of knowledge related to various CEM codes, formalisms, and modeling tasks will be embodied within the KB structure. Although GEMACS modeling rules are presently emphasized and automated within ICEMES' KB, its architecture and rule-base structure are being expanded to include other CEM knowledge, formalisms, code constraints, and software support functions. Support functions include but, are not limited to I/O data managers, network communications, and visualization tools.

In addition to GEMACS, other CEM codes under consideration include the Numerical Electromagnetic Codes for Method of Moments (NEC-MOM) and the Basic Scattering Code (NEC-BSC), CARLOS-3D, Apatch, Xpatch as well as several others [7].

The CEM formalisms of interest include but, are not limited to: Method of Moments (MoM), Geometrical Theory of Diffraction (GTD), Uniform Theory of Diffraction (UTD), Shooting and Bouncing Rays/Physical Theory of Diffraction/Physical Optics (SBR/PTD/PO), Finite Element Analysis/Modeling (FEA/M), and hybrids thereof. The modeling methodology and step-by-step tasks within ICEMES' knowledge/rule base are driven by: (a) general knowledge, usually associated with CEM theory, experience, and assessment practice; and (b) specific knowledge, that pertains to the modeling restrictions, constraints and guidelines associated with individual codes and their inherent physics formalisms.

Inherent in the overall ICEMES concept and modeling approach is its demonstrated ability to read and convert available Computer-Aided Design (CAD) data for the automatic generation of corresponding CEM geometry models. In particular, the AI/ES-enhanced pre-processor generates CEM structure models within the restriction and modeling constraints of the GEMACS code, for example, and then creates relevant command stream inputs in accordance with the code's required syntaxes and formats. The CAD data types of interest include facet and IGES. Such are provided in CAD and CEM analysis programs as ACAD, AutoCAD, ProEngineer, BRL-CAD, CADRA, SDRC I-DEAS, and Apatch. Considerations are also given to mathematical library functions for B-splines, NURBS, interpolations, smoothing, etc. available from a number of sources including Netlib, IMSL, and DT_NURBS.

Demonstrations of ICEMES' capabilities have focused on generating a complete complex system structure model (e.g., an aircraft comprised of hybrid, canonical geometry elements consisting of GTD cylinders and plates, and MoM mesh structures), and on CEM-to-CEM conversions (e.g., MoM-to-GTD or vice versa) for select portions of the surface geometry. CEM model generation and conversions of these types are driven by several prioritized and interlinked factors. These include: frequency, physical dimensions, relative location of electromagnetic sources with respect to the structure geometry, desired accuracy, available computing resources, etc.

Further, in order to facilitate access to the embedded knowledge necessary for automatically generating complex system CEM structure models in view of the above factors, ICEMES must incorporate or provide the following: (a) Graphical User Interfaces (GUIs) that include a Modeling Assistant and Help Functions; (b) a 3-D Interactive Geometry Modeler (IGM) or visualization capability which allows the operator to display the models, institute modifications, and dynamically translate any such changes to the expert system; and (c) links to external data files including CAD and CEM model libraries, CEM Data Dictionaries, Relational Database Management System (RDBMS), and flat/text files.

On a broader level, the ICEMES capability could be considered a potential component of other, more general computational environments and simulators that support Concurrent Engineering and Integrated Product Team thrusts. This aspect is further discussed below.

The availability of a mature ICEMES capability is expected to effectively address the government's needs with regard to assuring desired electromagnetic properties (i.e., compatible performance, operation, and functionality) of advanced system procurements and existing assets. It is also expected to similarly benefit the commercial/private sector and a variety of civilian applications which include but, are not limited to: commercial aircraft and satellite designs, consumer electronics, wireless telecommunications systems, Intelligent Transportation System (ITS) communications items, medical equipment, power utility systems, and automobile design/manufacturing [8].

Pre-processor Design for GEMACS

The technical objectives of the Phase I effort focused on defining the general software design of an AI/ES pre-processor, developing a preliminary rule base, and demonstrating its functionality for GEMACS. This involved:

- Adapting a commercial AI/ES tool for the CEM-based pre-processor.
- Developing a flexible, modular architecture to encompass various government and university CEM formalisms/codes.
- Implementing knowledge to automatically generate optimized (valid) CEM structure models (and associated command streams) from system architectural files, consistent with the CEM tool modeling constraints, input syntaxes and formats.
- Establishing and demonstrating a capability to validate user-generated CEM models.
- Automatically having the expert system determine the most appropriate physics/solution technique(s) and define the most accurate/efficient simulation approach, for a user-defined analysis scenario.
- Providing an interactive front-end to aid novice as well as CEM experts.

The Phase I prototype system was successfully demonstrated to meet each of the above technical objectives directed at the development of an intelligent pre-processor to support the GEMACS structure modeling task. The next stage in ICEMES' development will focus on expanding its architecture to encompass additional CEM formalisms, codes and associated data formats, and algorithms. Several candidate codes and formalisms are mentioned in this paper. Other ancillary features and capabilities will also be adapted to ICEMES' architecture and functionality. These will include: database management systems, CEM model libraries, data dictionaries to provide required CEM model parameters and defaults, interactive geometry modeling and visualization tools, and tailored graphical user interfaces (GUIs).

Concurrent Engineering and Integrated Product Team Thrust

ICEMES' architectural design and development emphasizes a stand-alone capability which is only "loosely coupled" to the individual CEM tools, input databases, and other software support functions (e.g., visualization tools, databases, file system, etc.). However, its applicability is not necessarily restricted to CEM. Because of its inherent modularity, it can function as an optional "layer" in conjunction with other codes, applications, and system architectures while communicating with these entities through tailored software interfaces. In this manner, ICEMES has the potential to be integrated with other simulation system architectures such as: the Air Force's Integrated Computational Environment/Research and Engineering Framework (ICE/REF) which stresses Concurrent Engineering applications using common data and a "global" modeling/simulation environment; the Air Force's Electromagnetic Modeling and Simulation Environment for Systems (EMSES), a subset of ICE; and the Joint-Service Microwave and Millimeter-Wave Advanced Computational Environment (MMACE) [9-13].

The Concurrent Engineering approach, in turn, supports Integrated Product Team thrusts whereby the mutual impacts of multi-disciplinary engineering designs and joint recommendations can be assessed. Furthermore, the ICEMES concept generally supports and is in conformance with related architectural design and functional features of ICE/REF, EMSES, and MMACE. These include "code wrappers", Applications Program Interface (API) routines, CAD file data extraction, library structures generated via database managers, and the CEM Data Dictionary. With regard to the Data Dictionary, the present ICEMES architecture shows a possible link to this data repository as an indication of the potential for integrating ICEMES in the future with the aforementioned simulation environments.

Exploiting Current and Future Research, Development and Advanced Technologies

To assure an economical capability for private sector and government applications, the ICEMES design approach attempts to exploit existing government and university CEM tool suites as well as relatively-low-cost commercial software products. In order to support the ICEMES functionality and operation as it continues to mature, it is also advantageous to adapt upcoming software technologies, computer engineering hardware advancements, and effective implementation strategies. These include: government/university code reuse; data reuse (e.g., finite-element data used for thermal, structural, and electromagnetic engineering purposes); exploiting mature 3-D visualization tools; and research into CEM code parallelization schemes and Web-based interactive and distributed high performance CEM methods. The latter exploits advancements in High-Performance Computing (HPC) together with parallelized code architectures to realize enhanced speed and performance for highly-complex CEM model development tasks.

WHY ADAPT AI/ES TECHNOLOGIES?

There are clearly several important reasons for selecting AI/ES technologies for the CEM pre-processor concept. To begin, the fusion of software is facilitated with the use of an expert system. Depending upon the expert system, a "common" simulation environment can be provided that readily permits the integration of various CEM codes, physics/solution methods, and processing algorithms. This environment employs rule-based and procedural techniques for knowledge incorporation, for establishing relationships among components or "objects" of the KB, and for defining inherited properties which can be used for attribute sharing among various objects of the KB environment. Information and data associated with objects and any of their "clones" (implying a parent-child relationship) are characterized as attributes consisting of: parameters, variables, constants, formulas, boundary constraints, and other descriptors. In this way, similar characteristics of various codes, algorithms, or solution methods can be identified and "linked" to provide a vehicle for item-to-item or object-to-object communications and data sharing.

For certain expert systems, programming and entity description, modification, and manipulation are based on an object-oriented structure and approach. This helps to facilitate problem definition and rapid prototyping of the KB, which in turn, expedites the development of a mature simulation capability. G2 is an example of this type of expert system.

G2 also performs automated rule-based logic inferencing and deductive reasoning using a combination of backward chaining, forward chaining, and dynamic code/KB/rule modification or reconfiguration. In essence, the system has the ability to "learn" based on what it "observes", and to optimize certain aspects of the rule base and its functionality. This becomes important when establishing the design of a system that can be used by a novice, a non-CEM analyst, or a CEM expert. For example, the expert system can learn about its user(s) and develop corresponding user profiles.

Expert systems such as G2 make use of procedures which like subroutines in FORTRAN or PASCAL, contain and execute a series of rules for a specific purpose. Special functions can also be developed using tailored procedures in conjunction with external control rules.

Another very important aspect of most expert systems is their ability to accommodate or contain both general and specific knowledge for a given domain application. In this way generic, common, or universal aspects of a problem can be assigned to all objects and items of the KB, as appropriate; also, specific rules or knowledge including tailored attributes and code-related constraints can be selectively defined for certain objects or items. For CEM, general knowledge expressed as rules, procedures, and object attributes may refer to CEM theory, practical experience, or conventional practice. Specific knowledge, on the other hand, expressed similarly, may refer to certain aspects of codes and their unique formalisms.

Expert systems, therefore, provide an environment to perform automated inferencing, reasoning, and decision-making; in this case, to assist the analyst in implementing effective CEM simulation/assessment methodologies, and step-by-step modeling procedures for generating "optimized" CEM models using the most appropriate physics/solution methods.

While this concept has been demonstrated to be advantageous for CEM pre-processing applications, its utility can be extended to establish an effective means of performing intelligent post-processing of computed CEM results. This will be the subject of future papers as the technology and developments progress for the present application.

Key Definitions

The following keywords and definitions are applicable to AI/ES/KB technologies and applications. These are provided to assist the reader in understanding certain key AI/ES/KB concepts and how these apply to the present discussion.

- Artificial Intelligence (AI) - Captured "human" knowledge or intelligence manifested as computer hardware or software systems that perform reasoning/inferencing and decision making.
- Expert System (ES) - A computer program application of AI that emulates the behavior of a human expert in a well-bounded domain of knowledge (a vehicle for captured knowledge consisting of dialog structure, inference engine, and knowledge/rule base).
- Knowledge Engineering - Development of a (concept-oriented) rule-based ES for a domain task.
- Knowledge Base (KB) - A set of facts (captured knowledge) and rules-of-thumb (heuristics) on the domain task.
- Knowledge Encoding - Implementing domain knowledge using an ES applications development/modeling environment or "shell".
- Knowledge Representation - Hierarchical rules (IF-THEN-ELSE), procedures (collections of rules), functions, relations, and object-classes with associated attributes (parameters, variables, constants, etc.).
- Domain Knowledge/Domain Expert - Knowledge derived from a general "source" and/or from human expertise/experience, respectively.

Additional information on AI/ES/KB-related terms and definitions, and their application to electromagnetics problem-solving can be found in recent technical literature [1-7].

ICEMES ARCHITECTURE

The ICEMES architecture is sufficiently-flexible and modular to accommodate the inclusion of new features and functions as the system evolves. At the heart of this architecture is the expert system or the inferencing/reasoning engine. The expert system together with the Main Controller also store and route commands and data to each of its linked components.

In general, the ICEMES design configuration can be viewed as a collection of interlinked KBs, with a main or master KB performing certain overhead functions. Separate KBs are used to incorporate the CEM knowledge and interface links required for each specific formalism or process, and respective software package. Since each of these KBs share the same basic structure, they can easily be duplicated and updated to accommodate new analysis capabilities, including individual CEM formalisms and unique CEM code modeling constraints. Using this approach, the end-user is not required to have available all of the modules or analysis programs in order to operate selected parts of the system. The knowledge is incorporated into the KBs via objects, rules, procedures, and relations.

The layered elements of the architecture consist of:

- GUI plug-in (User Control Panel)
- Expert System Module (Intelligent Core)
- Main Controller Module
- AI/ES modeling environment
- N-Partitioned KB sets for individual CEM formalisms
- Data translation and storage environment
- Intermodule communications interfaces
- CAD Engine Interface
- System and storage files for CEM models
- Geometry Modeler
- CEM Data Dictionary interface
- External CEM codes, display programs and data files.

The role and inter-relationship of the various layered elements of the architecture are further illustrated in the block diagram of Figure 1.

In the original, prototype concept design the expert system functioned as a Data Server in addition to a reasoning engine. In this capacity, the Expert System Data Server also stored and routed commands and data to each of its linked components. While the Data Server can be an entirely separate software program, its functionality and capabilities were originally incorporated as part of the expert system and implemented as a separate knowledge base. In the original configuration, a series of individual KBs were also established to facilitate the incorporation and storage of the CEM knowledge associated with each specific formalism or process, as well as the development of interfaces required for respective software packages (e.g., GEMACS, NEC, geometry modelers, etc.) linked in some form with the expert system.

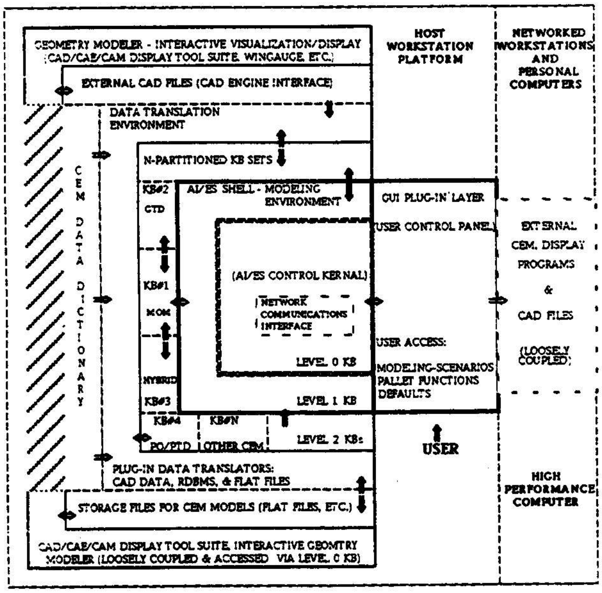

Figure 1. Pre-processor Layered Architecture

In order to overcome certain drawbacks and potential functional limitations associated with the Data Server configuration, a modified design was enabled where now the expert system would function as a separate component focusing only on the inferencing/reasoning activities associated with the generation of the CEM structure models. The Expert System Module configuration is illustrated in Figure 2.

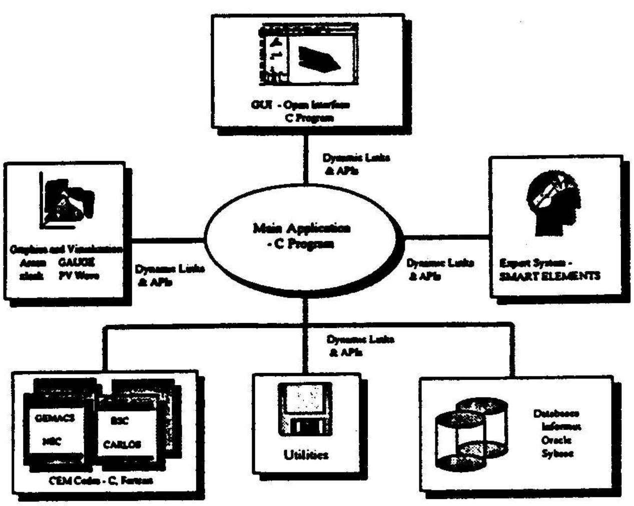

Figure 2. ICEMES Module Configuration

In addition to enhancing modularity and portability, and supporting maintenance and future expansion, the Module design offers several advantages over the former Server layout. In particular, it allows the many system functions that do not require the expert system to be performed by more traditional C or FORTRAN programs. These functions include: user interfaces, on-line help systems, object storage, data translation, and software interfacing. This permits the expert system to focus on tasks and functions that require inferencing or reasoning. This approach also limit the number of direct links between the expert system and external programs. These interfaces may, for some expert systems, cause system performance bottle necks.

Further, each module is a separate program, including the expert system. The ICEMES' primary application module serves as the Main Controller for the entire system. The main application is typically coded in C and C++. The flexibility and portability of C/C++ enables the main application to communicate with the GUIs, Expert System Module, the Graphics Module as well as virtually any other C, FORTRAN or PASCAL programs. The main program performs a number of house-keeping functions such as identifying authorized users, loading user profiles, storing data, and calling the various modules. This application also performs many of the normal simulation functions that do not require the expert system's reasoning/inferencing capability.

This modified approach allows the individual modules to be maintained and upgraded independently of each other. Additionally, the linking process does not fix the design to operate with a single version of any one of its components. The use of Application Program Interfaces (APIs) also simplifies the incorporation of additional tools as the system grows.

Knowledge Base Structure

An illustration of the ICEMES KB Structure Hierarchy is shown in Figure 3. This diagram provides information on the individual nature of the internal KB partitions and their purpose. The block diagram emphasizes the partitioning of knowledge, first as a function of the CEM formalism (i.e., "general" knowledge) then by individual CEM codes and their peculiar modeling constraints (i.e., "specific" knowledge). Figure 4 further emphasizes the role and application of general versus specific knowledge in the generation of the CEM structure models. This approach supports modularity, portability, and expansion to include other formalisms and code constraints.

SYSTEM OPERATION/FUNCTIONALITY

Usage Scenario

The Usage Scenario refers to the general procedures involved in a typical ICEMES model development session. The methodology, providing a "roadmap" with the GUI as its infrastructure, is illustrated in Figure 5. The methodology illustrated is based on the feasibility demonstration for GEMACS, however, the approach is generally applicable to other CEM formalisms and codes. A significant degree of user interaction is accommodated via a comprehensive, menu-driven query-response system. The degree of interaction depends on the analyst's CEM domain expertise.

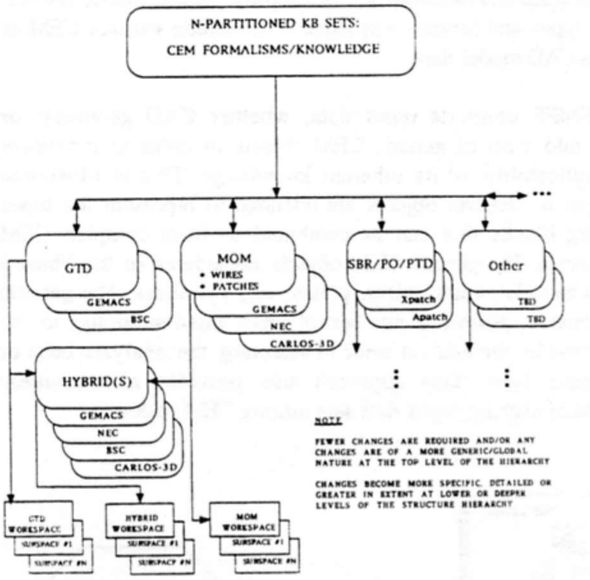

Figure 3. ICEMES Hierarchical KB Structure

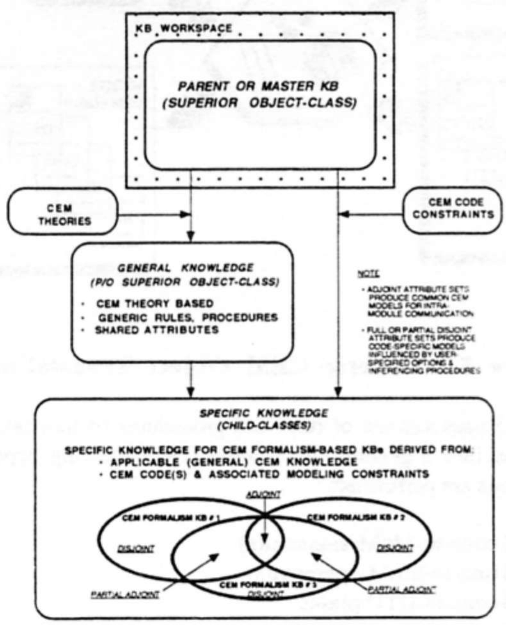

Figure 4. Generic Knowledge/Rule-Base

The analyst has the option of using a standard set of pull-down menus, tool bars, or an automated Assistant (Modeling Advisor) to navigate through the system during a session. The Assistant consists of a series of menus that lead the operator through each step of the modeling task, and provides recommendations (including defaults) regarding the use of various modeling parameters as specified by the user or as determined by ICEMES. The ICEMES Assistant feature is particularly advantageous to the CEM novice or the non-CEM analyst.

The menuing system also provides push-button features that allow the user to skip ahead or revert to a previous menu. The menus developed for this function are defined by the following headers: Use ICEMES Assistant, Open CAD File, Analysis Frequency, Observable Specification, E-Field/Parameters, User Interaction Level/CEM Model Generation, View CEM Model, Edit/Modify CEM Model, View CEM Model (second request), Run Analysis, View Output Data, and Save File. An example of a start-up menu showing several of these features is given in Figure 6.

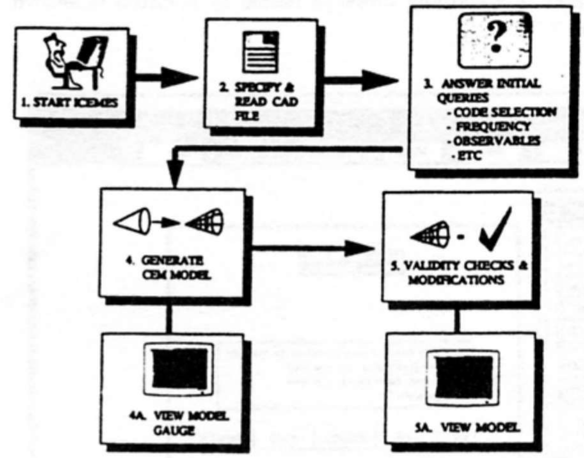

Figure 5. ICEMES Operational Flow

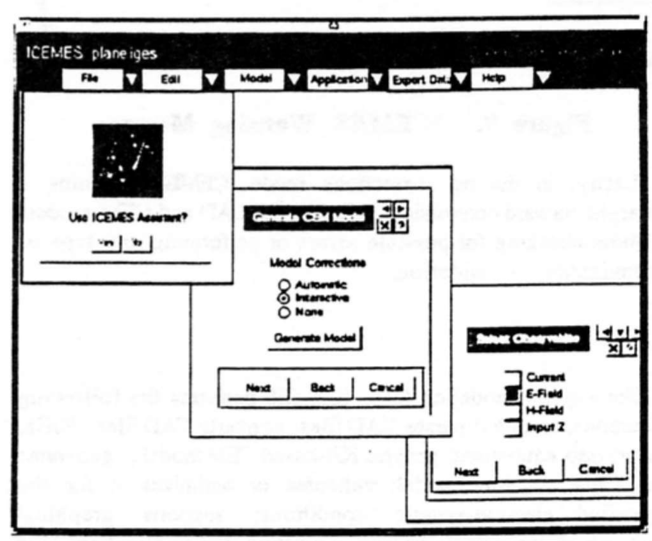

Figure 6. ICEMES Workspace Menu

Also, ICEMES exhibits three levels of user interaction capability for error detection and validation. These include automatic, interactive, and none (No Corrections mode).

In the automatic mode, ICEMES implements corrections and uses the methods that it logically determines to be the best for generating optimum CEM geometry models; in this mode, the CEM model is generated without querying the user to any significant degree. The user has the option of changing the CEM model once it is generated by ICEMES.

In the interactive mode, ICEMES identifies problem areas and recommends possible solutions during the process of model generation. The user has the option of ignoring the problem, fixing the problem, or exiting this validation mode. ICEMES also posts CEM model warning messages in a scroll bar such that the user can view all issued messages at once rather than having to continually respond to a series of system prompts. An example of a warning message issued by ICEMES is shown in Figure 7.

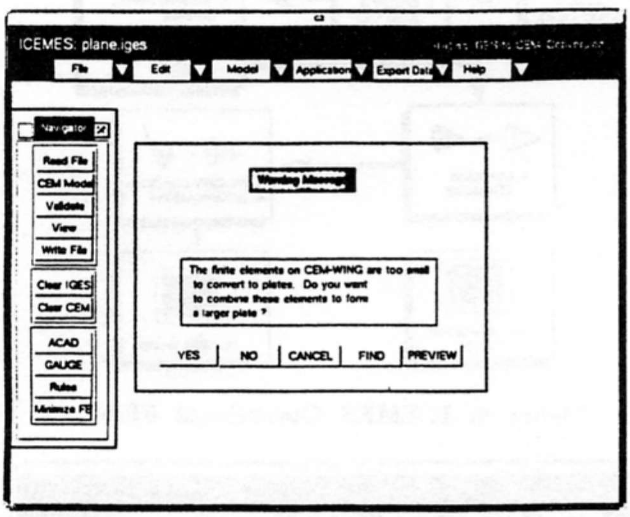

Figure 7. ICEMES Warning Message

Lastly, in the no corrections mode ICEMES performs a straight-forward conversion between the CAD and CEM models without checking for possible errors or performing any type of optimization or validation.

Functionality

For a given modeling task, ICEMES performs the following functions, in order: parses CAD files; converts CAD files (IGES, facet) into equivalent, generic KB-based CEM models; generates the CEM structure model; validates or optimizes it for the specified electromagnetic conditions; supports graphical viewing of the model for user inspection and verification; and outputs a final data set that is compatible with the CEM code for subsequent processing and analysis. These functions are accomplished via a series of rules, procedures, mathematical routines, and manipulation of object structures. The expert system core uses these elements to represent the associated CEM knowledge.

Regarding CAD file parsing, the present version of ICEMES accepts IGES and facet-based CAD inputs. In the future, the list of file types and formats will expand to include various CEM as well as CAD model data.

ICEMES converts input data, whether CAD geometry or CEM, into a set of generic CEM objects in order to maximize the applicability of its inherent knowledge. This is illustrated in Figure 8. Generic objects are intended to represent the basic building blocks that can be combined to form complex CEM geometries. The generic CEM objects considered in the Phase I design include points, wires, plates, and cylinders. The generic components permit a number of data manipulations to be performed by the analyst prior to selecting the analysis code or formalism type. This approach also provides a convenient method of sharing input data sets among CEM codes.

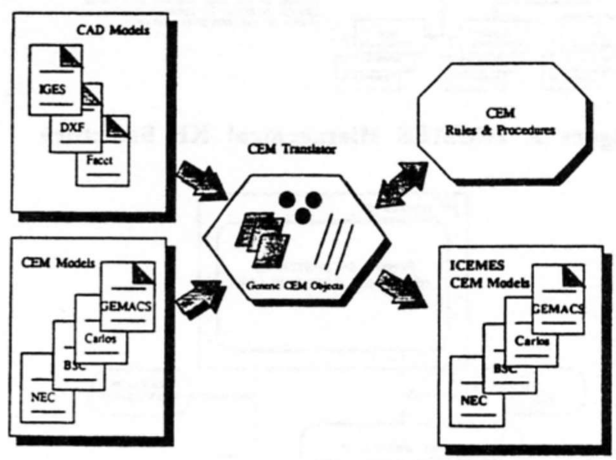

Figure 8. Generic CEM Object Translation

ICEMES uses a series of rules and procedures to translate the CAD model into a generic CEM model. The following types of conversions are performed:

- IGES cone-to-MoM segment(s)
- IGES line-to-MoM segment(s)
- IGES cone-to-GTD plates
- IGES cylinder-to-GTD cylinder
- IGES finite-elements-to-GTD plates
- IGES nodes-to-CEM points
- IGES group-to-CEM group
- ACAD facets-to-GTD plates.

The ICEMES model validation and correction measures exclusively act upon the generic CEM objects. Thus, any size adjustments, position changes, connectivity modifications, etc. are applied directly to the generic CEM model components. Ultimately, ICEMES will enable the operator to also incorporate the changes into the CAD geometry.

Other validations that are performed during the model generation and optimization process include: finite-element resizing (plate sizing), connectivity checking (MoM wire segments-to-GTD objects and GTD plates-to-GTD cylinder), incomplete definitions, and MoM element sizing and connection angles. Each of these validations is based upon assessing the relevant electromagnetic conditions and "physical" parameters defined for the given problem, such as: frequency, object dimensions, relative location of source(s) with respect to the system geometry, specified observables (e.g., field points, wire currents, patch current densities, etc.), and any specified accuracy constraints.

For the prototype system based around GEMACS, the CEM model is displayed using the WinGAUGE or X-GAUGE visualization tools. Both of these programs were exclusively developed to display and manipulate GEMACS input geometry models as well as display certain GEMACS computed outputs. ICEMES makes use of these codes by first writing a GEMACS-compatible data file from the generic CEM data model, then issuing a command to launch the display program(s). After viewing the CEM model, the user has the option of modifying it and re-assessing impacts or tradeoffs with ICEMES.

However, this approach using GAUGE does not permit the results of interactive manipulations to be translated back to ICEMES. To address this limitation, an Interactive Geometry Modeler (IGM) will be integrated to provide a method of creating, displaying and manipulating both CAD and CEM models. The IGM will be dynamically linked to the main application module such that changes in the geometry, either CAD or CEM, can be monitored by the knowledge base. ICEMES' recommendations for geometry changes, whether to identify (i.e., highlight) elements, move structures (e.g., groups or single components), or update the geometry will be displayed directly on the IGM. The IGM will also have the capability of displaying output results atop the geometry display. Both modelers will be linked via APIs to the main application to facilitate a high degree of user interaction.

Once the geometry complies with the basic CEM rules, it passes through a "filter" for the application code selected. This filter converts the generic parameters into a specific format required by the CEM code.

It is also noted that interface codes link ICEMES to popular databases such as Informix, Oracle, Sybase, and Ingres. The links, which are bridge codes for passing SQL queries, allow the ICEMES to read and write data to the databases. This data may include CAD models, CEM models, data translations, analysis parameters and results, or transaction data.

OTHER PROGRAM UTILITIES/FEATURES

Several specialized utility programs and user features are being researched for future incorporation into the ICEMES architecture. Several of these are briefly described next. Upcoming research and development will focus on specialized data conversion utilities, On-line Help, and expanded GUIs. Anticipated features and utilities, and their possible implementation will also be assessed as to their impact on configuration management requirements and procedures. The progress of research and development, and demonstrations associated with these will be reported upon in a future paper.

Utility Programs

Utility programs include file translators, mathematical and function libraries, and specialty programs to support CEM-to-CEM conversions. For example, Xpatch has a number of utility programs that convert IGES 128 (NURBS), IGES 4.0, BRL-CAD, and ACAD facet files (Versions 7, 8 and 9) into Xpatch-compatible data files. It may be advantageous to adapt similar conversion routines to ICEMES.

On-line Help is another program capability to be incorporated. Such a system could be written using an html format compatible with Mosaic and Netscape readers.

Graphical User Interfaces (GUI)

In order to facilitate efficient use of ICEMES particularly by the novice CEM operator, more detailed, expanded GUIs will be required. The GUIs for this application are typically stored as resource files that are linked, via APIs, to the particular application modules. GUIs with identical formats are to be developed for each application within the ICEMES suite in order to provide the user with a "common" look and feel. The GUIs can also allow the user to manipulate CEM files either graphically, via the Interactive Geometry Modeler, or with the use of a text editor. The former permits the user to add, modify, or delete any part of the geometry by dragging elements or objects with a mouse.

Additionally, the ICEMES GUIs are to be portable across operating systems and will exhibit a Motif, OpenWindows, or MS Windows appearance. These will contain features that include the standard set of pull-down menus providing file access, editing capabilities, viewing, analysis, application, and help utilities. The pull-down menus will be supplemented by a number of user-configurable tool bars that allow the operator to customize his/her own applications window. The tool bars will contain a series of icon buttons that allow the operator to quickly perform functions such as starting an application program or editing a file. As mentioned earlier, a hyper-text help system, complete with tutorials and demo programs, can be incorporated into the system. Drag and drop, keyboard short cuts, and mouse controls can also assist the user in navigating through ICEMES.

Applications Program Interfaces (API)

APIs are callable routines or entry points within a program that can be accessed by other modules within the application or from separate, external processes. ICEMES will make extensive use of API constructs both in linking to its supporting programs as well as providing a means of incorporating the system into broader computation and simulation environments (e.g., the ICE/REF) [9-13]. APIs permit the ICEMES suite of programs to share and pass parameters, arrays, and object structures. APIs also enable the ICEMES modules to interact with the host computer and network file system. This, in turn, enables ICEMES to make use of all standard shell commands, and operating system functions and utilities as well as its internal library of functions.

Code Wrappers

Code wrappers provide information which describe an application's function, including data types, valid ranges, etc. The wrappers simplify the long-term maintenance, modification, and reuse of code. The specific input/output information for each module is contained within the source code. Use of code wrappers is expected to play an important role in the development and standardization of the maturing ICEMES software capability.

DEMONSTRATIONS/LESSONS LEARNED

Several test cases were developed to demonstrate ICEMES' initial capabilities, particularly, its ability to: read in simplified CAD-based aircraft geometries; convert CAD data into a valid CEM model; detect anomalies and recommend modifications; automatically update the CEM model; and generate a GEMACS/GAUGE-compatible input data set.

A series of demonstrations was performed to show ICEMES' ability to detect and correct for anomalous conditions such as: ill-defined geometries based on disconnected or misaligned objects (as defined in the CAD data or by the user in the CEM model); and mounting MoM wire segments too close to a GTD object (i.e., cylinder or plate) edge and its diffraction center(s). It was also demonstrated with these test cases that depending upon the frequency and the location of the source, certain portions of the structure model are subject to CEM-to-CEM conversion (e.g., GTD-to-MoM or vice versa). Other test cases focused on demonstrating ICEMES' ability to detect non-planar conditions for faceted wing structures or plate entities, and to represent these accordingly in the GEMACS model. Related conversions involved the automatic creation of a single, large GTD plate sized to the frequency of interest, from a multi-faceted wing structure.

Each of the test cases successfully demonstrated ICEMES' ability to effectively address the above types of validations for GEMACS.

Test Case 1: Canonical Aircraft Model

The primary test case is based upon an IGES data set containing a series of constructive solid geometry elements, finite elements, and lines. The combined structure forms the simplified aircraft geometry illustrated in Figure 9.

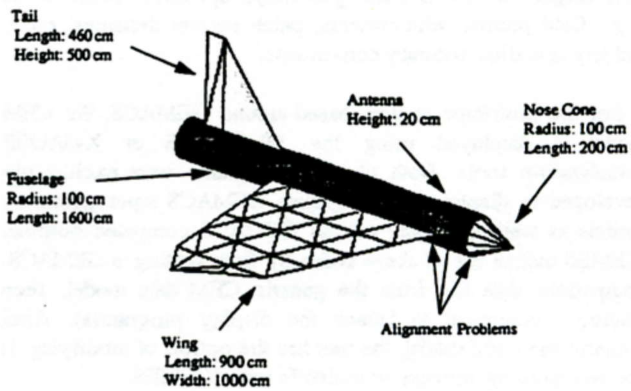

Figure 9. Test Case Geometry

In this model, the fuselage is represented by a right circular cylinder that is 1,600 cm long with a radius of 100 cm. The nose is represented by a right circular cone that is 200 cm in length with a base radius of 100 cm. The wing and tail section are formed by a series of triangular finite elements. A 20-cm length antenna, represented by a line, is located atop the fuselage.

As noted earlier, several error conditions were intentionally introduced into the CAD model data to determine whether ICEMES would correctly detect and evaluate the anomalies. One of the errors involved placing the antenna 5 cm above the cylinder to assure that it is not attached to the cylinder surface. Another error involved positioning the nose cone base 5 cm short of the forward cylinder section. A third error involved displacing the aircraft main wing 5 cm from the fuselage surface. The 5-cm distance used in each of these cases was arbitrarily selected, but was considered sufficient (as a function of frequency versus physical dimensions) to effectively result in disconnected or misaligned objects.

The aircraft model as defined not only challenged ICEMES' ability to detect and correct for errors, but also to convert CEM data (finite elements in this case) to another CEM format (e.g., GTD plates). The model was also dimensioned to allow ICEMES to convert the IGES nose cone to an MoM wire mesh or a series of contiguous GTD plates. The MoM antenna model was used to demonstrate ICEMES' ability to dynamically resize an MoM structure grid based on frequency and other related constraints, and to detect wire elements that are too close to a GTD edge or which are not properly attached to a surface.

Test Frequency: 125 MHz. The first test scenario emphasized the development of the aircraft structure model with the source antenna operating at 125 MHz. At this frequency, the nose cone and antenna appear short compared to a wavelength. In this case, ICEMES determines that an MoM model is the most appropriate representation, and generates a corresponding wire mesh and linear wire array for these CEM structures in accordance with the GEMACS MoM modeling rules.

At this same frequency, the cylinder is electrically large compared to the wavelength; further, a significant number of wire segments would be required to define a corresponding wire mesh. ICEMES therefore models the cylinder as a GTD object.

Also, ICEMES checks the size of the finite elements comprising the wing and tail sections. The minimum sizes of the finite elements for these objects are determined to be larger than a wavelength, therefore, ICEMES converts each of these elements into one or more GTD plates of total equivalent dimensions.

Once the IGES-to-CEM conversions are complete, ICEMES performs a series of validations to ensure that the structures are correctly sized, that no extraneous wires exist, and that connectivity is achieved where necessary.

First, ICEMES flags the intentional misalignments of the nose cone and cylinder, and queries the user as to whether or not to correct the problem. If the user specifies that an anomaly be corrected, then ICEMES determines what it considers to be the most appropriate fix. In this case, ICEMES suggests that additional wire segments should be added to extend the cone's base in order to attach it to the cylinder. If the user approves of this recommendation, then ICEMES automatically computes the attachment points and generates the new wires.

A view of the aircraft model produced by WinGAUGE 2.0 is shown in Figure 10. This figure illustrates the grid structure used to represent the cone. The grid is shaped such that it conforms to the MoM CEM rules for sizing and connectivity (i.e., avoidance of shallow angles and too-many junctioned wires at the cone tip). The radial segments near the face of the cylinder are generated by ICEMES to accommodate the "attachment" of the meshed cone to the cylinder. The connection points are located 0.1λ-0.25λ from the cylinder edge, which represents an acceptable range for the placement of connecting wires depending on the engineering accuracy desired.

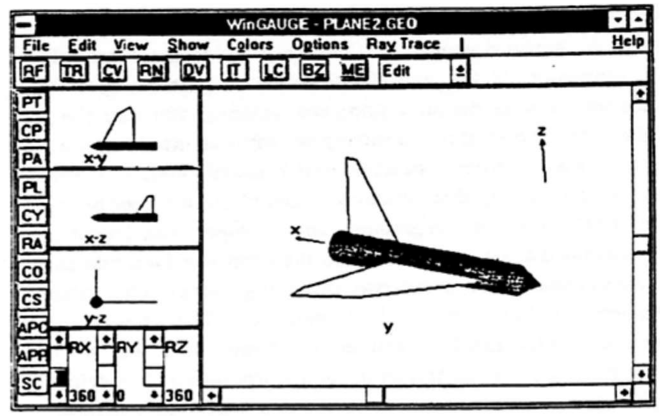

Figure 10. 125 MHz Test Case (GAUGE View)

Next, in the case of the antenna ICEMES notifies the operator that the entire antenna should be linearly translated to locate its base point effectively "on" the cylinder. If the user approves this translation, then ICEMES computes the "attachment" point and correspondingly translates the entire antenna structure.

Internal checks and conversions are also performed to properly represent the wing structures in final form as well as connecting the main wing to the fuselage. Figure 9 shows that the finite elements comprising the wing and tail sections are combined to form two separate GTD plates, one each for the main wing and tail stabilizer. The main wing is also translated such that its edge is in contact with the cylinder.

It is imperative to point out that certain restrictions exist regarding the attachment of wires to GTD surfaces in GEMACS. Wires (excluding junctions of wires) may be connected to patches, ground planes, or GTD plates; however, the joining of wires directly to cylinders or endcaps is discouraged. Such an attachment can result in an incomplete or invalid model definition which, in turn, could lead to numerical inaccuracies. An attachment of this type can be performed, nevertheless, without GAUGE or GEMACS fatal errors being issued. This is because the subset of the hybrid physics for this boundary condition and type of attachment, as well as the numerical methods for accurately computing corresponding electromagnetic interactions are not completely supported in GEMACS at the present time. Regardless, this scenario demonstrates the ability to connect objects using several different attachment methods. The ramifications of this type of attachment will be further discussed in a future paper. It will address degraded interactions and inaccuracies in computed induced currents and radiated fields as a consequence of locating an MoM antenna structure on a GTD cylinder surface.

For the purposes of the prototype capability demonstrations based on the canonical model, a simple antenna represented as a "roving" MoM source was defined and placed in the vicinity of a GTD cylinder. The antenna for all intents and purposes was effectively attached within a (small) acceptable delta distance from the cylinder's surface. While no true, valid attachment is made, the model demonstrates how such a placement can affect the generation of the total CEM model or parts thereof. The main idea was to define a primitive antenna structure (i.e., a linear array representing a monopole whip or dipole antenna), place it near the aircraft structure, test ICEMES' ability to detect and correct for any discontinuities, and allow the user to make the final selection regarding any desired attachment. If demonstrated to be successful, then the approach (and rule base) could be expanded to cover cases involving more exotic antenna platforms, dipole arrays, stiff sources, etc. The allowance for possible "attachments" between an MoM wire and a GTD cylinder is also in anticipation of incorporating the detailed, hybridized physics required to handle this modeling situation.

The proper way of flagging and handling this condition within the present restrictions of GEMACS and ICEMES' reasoning capability is to modify the rule base to ensure the detection of this "attachment" condition as it occurs, alert the user of this, and then provide options or recommendations to the operator. Options may include leaving the situation as is with the understanding that inaccuracies may arise, or instituting a restricted range of modifications to the model to help ensure accuracy and validity, where the former involves issuing an appropriate warning to the user. Indeed, this approach is currently implemented. However, if the user opts to "attach" the wire to the cylinder, ICEMES will caution the user, but will not necessarily indicate that inaccuracies may arise. A few additional rules need to be instituted to properly handle this condition.

It is also emphasized that the user always has the final choice as to whether or not to connect certain parts of the structure model. The only drawback to this is that more burden tends to be placed on the user in that he/she must be aware of the impacts of certain connection methods and associated restrictions which could call into question the accuracy of the resulting CEM model. A solution to this is the implementation of additional rules which would sufficiently warn the user of the impact that certain selections may have regarding connectivity depending upon the CEM formalism, code base, etc.

Test Frequency: 150 MHz. In the next stage of demonstration, the modeling frequency is changed to 150 MHz (a transition frequency which affects certain portions of the aircraft model resulting in the conversion of MoM objects to equivalent GTD elements). The frequency shift causes ICEMES to review the existing CEM model and re-determine its validity or accuracy.

At the 150 MHz transition frequency, the nose cone starts to appear electrically large (i.e., on the order of a wavelength). The cone is then converted by ICEMES from an MoM mesh into a series of contiguous GTD plates. The electrically-large nature of the nose cone becomes even more pronounced at frequencies significantly greater than 150 MHz.

Also recall that the minimum lengths of all the finite elements forming the wing and tail sections were large compared to the wavelength at 125 MHz; at that frequency, ICEMES generated a series of equivalent GTD plates for each wing structure (an intermediate step). At 150 MHz, the finite elements used to derive the GTD wing structures still appear electrically large so that these continue to be represented by a corresponding series of GTD plates sized in accordance with frequency. ICEMES then repeats validity checks to determine any new or residual inconsistencies due to the frequency shift and/or any user specifications that may have been applied. The CEM structure model at this point is shown in Figure 11. Not shown in Figure 11 is the conversion of the series of GTD plates comprising the wing structures into two large GTD plates.

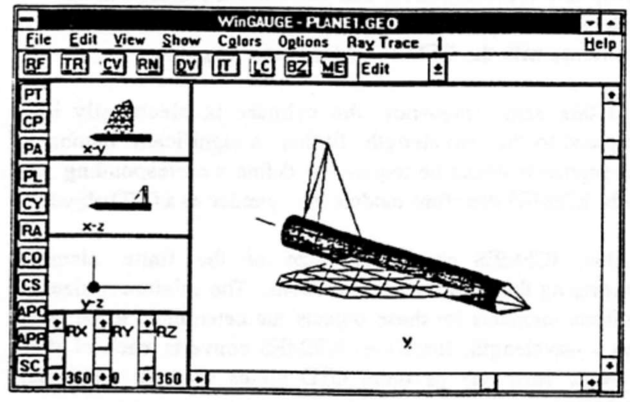

Figure 11. 150 MHz Test Case (GAUGE View)

Test Frequency: 500 MHz. Changing the modeling frequency to 500 MHz requires ICEMES to "resize" and redefine the entire structure model. This effectively results in the aircraft model (except for the source antenna) to be represented as a GTD structure, a trend that is generally expected with increasing frequency. Also, at this frequency the MoM segments associated with the antenna structure now exceed 0.1λ in length. The antenna is then resegmented and resized based on the GEMACS modeling guidelines to assure electrically-short segments.

Additional demonstrations were performed showing ICEMES' ability to detect conditions where MoM segments are mounted too close to an edge of a GTD object (i.e., cylinder or plate). This was primarily demonstrated for the cylinder (fuselage) where the antenna is moved towards the cylinder's forward edge. When an MoM object is located less than or within the violation distance from the GTD cylinder edge, ICEMES warns the operator of this anomaly and advises that the MoM structure be relocated.

It was also demonstrated with this test case that depending upon frequency and the location of the electromagnetic source, certain portions of the structure model (e.g., nose cone) are subject to CEM-to-CEM conversion (i.e., GTD-to-MoM or vice versa).

Test Case 2: Aircraft with Non-Planar Wings

A second version of the aircraft model was developed to demonstrate ICEMES' ability to discern multiple or non-planar surfaces. This problem scenario is similar to Test Case #1 at 150 MHz, except that the wing tip is tilted upwards as illustrated in Figure 12. In this case, ICEMES correctly discerns that the finite elements forming the wing reside in two different planes. It then generates separate GTD plates to represent the family of finite elements in each plane.

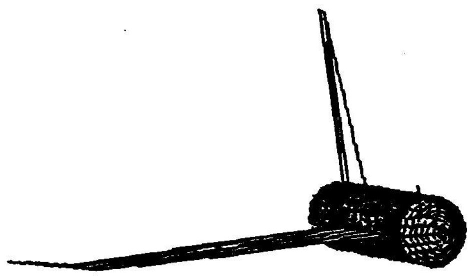

Figure 12. Non-Planar Wing Model

Test Case 3: Facet-to-GTD Wing Conversion

A third test case was generated using an ACAD facet file format. This geometry consisted of a wing essentially comprised of the finite-element parts of the canonical aircraft problems stored as facet files instead of IGES entities. The purpose of this test case was to demonstrate ICEMES' ability to read multiple CAD file formats while achieving comparable results regardless of CAD data type.

This test case for the wing conversion was performed at 150 MHz. ICEMES successfully converted the facets into a single, large GTD plate. The facet and GTD representations of the wing are shown in Figure 13. It is noted that a great deal of interest has been expressed recently in this conversion mode based on the Apatch and Xpatch programs, for example, which utilize or produce facet-compatible data files for PO/PTD/SBR simulations. The US Air Force Rome Laboratory has generated a number of problem geometries characterized as facet files which may be used as rigorous test cases for the ICEMES Phase II capability.

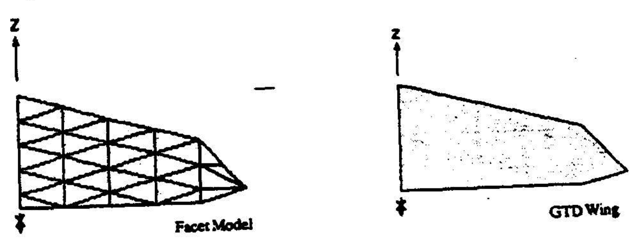

Figure 13. Facet-to-GTD Wing Translation

SUMMARY AND CONCLUSIONS

The ICEMES capability is considered an innovative, significant step forward in the successful adaptation and integration of next-generation software technologies with existing CEM codes. The prototype system developed in Phase I was successfully demonstrated to meet each of the technical objectives directed at the development of an intelligent pre-processor to support the GEMACS structure modeling task. The next stage in ICEMES' development will focus on expanding its architecture to encompass additional CEM formalisms, codes and associated data formats, and algorithms. Several candidate codes and formalisms were briefly mentioned in this paper. Other ancillary features and capabilities will also be adapted to ICEMES' architecture and functionality. These will include: database management systems, CEM model libraries, data dictionaries to provide required CEM model parameters and defaults, interactive geometry modeling and visualization tools, and tailored graphical user interfaces (GUIs).

Since ICEMES' architectural design emphasizes a stand-alone capability which is "loosely coupled" to the individual CEM tools, databases, and other software functions, its applicability is not necessarily restricted to CEM. Due to its inherent modularity and ability to communicate with other codes and applications, ICEMES has the potential to be integrated with other simulation architectures and computational environments, that include: the Joint-Service Microwave and Millimeter-Wave Advanced Computational Environment (MMACE) and the Air Force's Integrated Computational Environment/Research and Engineering Framework (ICE/REF) which stresses Concurrent Engineering applications, the use of common-type data, and a "global" modeling/simulation environment. The ICEMES concept design is generally in conformance with architectural and functional features of ICE/REF, EMSES, and MMACE that include "code wrappers", Applications Program Interface (API) routines, CAD file data extraction, library structures generated via database managers, and the CEM Data Dictionary.

Finally, to assure an economical, viable capability the ICEMES design approach attempts to exploit existing government and university tools as well as relatively-low-cost commercial products. It will also take advantage of upcoming software technology developments, as well as computer engineering advancements and effective hardware implementation strategies. These include: government and university code repackaging; data reuse; advanced 3-D visualization tools; CEM code parallelization research; and High-Performance Computers in conjunction with parallelized code architectures to realize enhanced speed and performance for highly-complex CEM model assessments.

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The authors wish to acknowledge Mr. Victor K. C. Choo for his technical contributions, assistance , and support of the ICEMES program particularly on behalf of the prototype capability development. Mr. Choo is currently on the staff of the Naval Undersea Warfare Center (NUWC) in Newport, RI. He is also providing part-time technical support to ANDRO Consulting Services on behalf of the ICEMES project.

BIOGRAPHIES

Andrew L. S. Drozd is Owner and Chief Senior Engineering Consultant for ANDRO Consulting Services. He has nearly 20 years of experience in the field of Electromagnetic Effects, Electromagnetic Compatibility and Computational Electromagnetics. He holds a B.S. in Physics and Mathematics (1977) and an M.S. in Electrical Engineering (1983), both from Syracuse University. He has also worked extensively in the area of applying AI and expert systems to CEM applications and has participated in training courses on Gensym's G2 Expert System.

Kenneth R. Siarkiewicz has over 30 years experience in the field of Computational Electromagnetics at the Rome Laboratory. He holds a B.S. and M.S. in Electrical Engineering, respectively, from the University of Detroit and the University of Michigan.

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The Practical CEMist

- practical topics in communications -

Perry Wheless, K4CWW

Many readers appreciated and commented on Part I of "The Twin Delta Loop Antenna: a Novel Approach to the Ultimate Multiband Antenna" by Rudy Anders, which appeared in the last ACES Newsletter. Fate precluded the completion of Part II in time for this publication deadline, but we expect to have that installment available for the next Newsletter.

The feature article for this issue is "HF Multi-Frequency Antennas Using Coupled Resonators" by Gary Breed, K9AY. This paper describes three practical antennas which operate in several of the HF amateur bands. The construction notes and electrical performance reported here are both interesting and useful. Gary's presentation of this paper at the ACES 12th Annual Review of Progress in Applied Computational Electromagnetics in March was received with considerable enthusiasm. The paper is reprinted here because the ACES Newsletter circulation is much larger than the distribution of conference Proceedings, and the Newsletter reaches a substantially different audience of practical communicators. Readers are encouraged to experiment with HF multi-band antennas using the coupled-resonator principle, and to report their findings and experiences with this class of antennas.

Gary Breed is in the process of relocating to Atlanta, GA. He may be contacted at his new work address:

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Gary, we all wish you tremendous success in your new publishing business!

The Amateur Radio Social and Session at the ACES '96 conference were both hailed as good ideas. Gene Tomer is investigating means of combining the two next year, so an innovation in conferencing may be in the works! Note well that the deadline for ACES '97 paper submissions already will be past when you receive your next Newsletter. Work on a paper submission over the summer months, and plan now to join us in Monterey next March! Several conference attendees were heard on one or more of the 2-meter repeaters in Monterey this year, and you are encouraged to bring a VHF radio next year.

Only three accounts of Richmond code use were received - one by e-mail and two verbally - in response to my solicitation on page 9 of the March Newsletter. Perhaps additional reports will come later.

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HF Multi-Frequency Antennas Using Coupled Resonators

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Crestone Engineering
Littleton, Colorado
and
Editor and Associate Publisher
RF Design magazine

Introduction

This paper is a continuation of material presented at the 1995 ACES Symposium [1], describing the author's work with multi-frequency antennas which use the technique of closely-spaced coupled resonators. Three practical antennas are described, which operate in several of the HF amateur radio bands.

The Coupled-Resonator Principle

The *coupled-resonator* (also called *multiple-open-sleeve*) principle is a useful technique for obtaining multi-frequency operation in dipole and monopole antenna elements. It is derived from previous work, the *coaxial sleeve antenna* and the *open-sleeve antenna*. The coaxial sleeve antenna places a cylindrical sleeve around a driven dipole (or monopole), resulting in a single structure which exhibits two resonances — that of the driven element, and of the sleeve. In the open-sleeve antenna, the sleeve is reduced to two parallel conductors which create a skeleton representation of a coaxial sleeve. Coaxial sleeve and open-sleeve techniques have been used extensively in two-frequency and broadband antennas.

Because the original work in this area involved coaxial or open-sleeve configurations, most developmental work assumed that the additional resonators were required to follow that type of construction. Relatively few antenna designers understood that only a single additional conductor is required to create a second resonance. This simpler topology allows individual conductors to be placed radially around the driven element, creating antennas with three, four, five, and more resonances. The upper limit to the number of frequencies that can be obtained in a single structure is determined by unwanted coupling among the many different conductors.

Using MININEC and NEC computer modeling, combined with several experimental antennas, the author has derived an equation that relates the conductor size, spacing, and the feed-point impedance. The equation is based on the basic relationship:

$$\frac{\log(d)}{\log(D/4)} = 0.54$$

where,

- D is the diameter of the conductors (assumed to be equal) in wavelengths at the resonant frequency of the coupled resonator.
- d is the spacing on centers between the conductors, also in wavelengths at the resonant frequency of the coupled resonator.
- The system impedance is that of a dipole in free space, or a monopole fed against perfect ground.

- The lengths of the conductors have been adjusted for a non-reactive impedance.
- A two-frequency antenna is assumed, although the equation is a reasonable approximation for each frequency in a larger system.

Correction factors have been derived for other impedances, and for the special case where the coupled resonator approaches the driven element resonant frequency. These are described in [1] and [2], and they are combined with the above expression into a single equation:
where,

$$d_{1n} = 10^{[0.54\log(D/4)]} \times \frac{Z_0 + 35.5}{109} \times \left[1 + e^{-[(((F_n/F_1)-1.1)\times 11.3)+0.1]}\right]$$

- Z_0 is the desired impedance (resistive, between 25 and 125 ohms)
- F_n is the frequency of the additional resonator
- F_1 is the frequency of the driven element
- d_{1n} is the spacing between the driven element and the desired *n*th resonator, in wavelengths at F_n
- D is the diameter of the conductors (assumed equal), in wavelengths at F_n

The above equation describes conditions for resistive impedances. The length of the elements can be adjusted to change the reactance. It is easily seen that this technique provides a wide range of control over the feedpoint impedance at a given frequency — by controlling the variables of conductor diameter, spacing and length. This flexibility in design is the principal advantage of the coupled resonator technique, and is the key to successful operation of the antenna described in Example 3 presented below.

Example 1: 10.1, 18.068, 24.89 MHz Wire Dipole

The first example is a three-frequency antenna built with #12 AWG wire conductors, operating on the 10.1, 18.068 and 24.89 MHz amateur bands. Antenna element dimensions are given in Figure 1. A free-space comparison of radiation patterns on the three bands (modeled in ELNEC) is shown in Figure 2. The radiation patterns at 10.1 and 18.1 MHz are indistinguishable from that of an ordinary dipole. At 24.9 MHz, the current in the driven element is significant, and when summed with the coupled-resonator current, results in a gain of 0.6 dB.

Feedpoint VSWR in a 50-ohm system is comparable to MININEC-calculated VSWR at the installed height of 50 feet above ground. The amateur bands covered by this antenna only

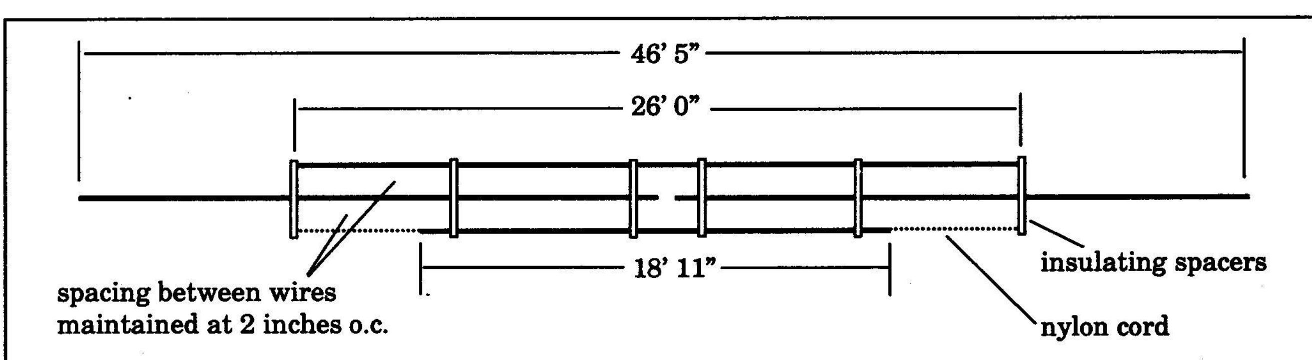

Figure 1. Dimensions of the 10.1, 18.068, and 24.89 MHz wire dipole of Example 1.

require 0.4 to 0.55 percent bandwidth, well within the bandwith provided by this antenna. The only unexpected behavior of this antenna is a greater sensitivity to height above ground than a simple dipole. This behavior had not been investigated through modeling, and it was confirmed later that modeling also predicts these impedance excursion.

On-air performance of this antenna is comparable to that expected for a dipole at each frequency.

Example 2: 14, 21, 28 MHz Aluminum Tubing Dipole

The second example antenna is also a three-frequency antenna, built for the 14, 21 and 28 MHz amateur bands, using aluminum tubing construction (dimensions in Figure 3). The 14 and 21 MHz elements taper from 1-1/4-inch diameter tubing to 5/8-inch diameter, and the 28 MHz element tapers from 1-1/8-inch diameter to 5/8-inch diameter. Spacing between the driven 14 MHz dipole and the coupled-resonator elements was fixed at 7 inches on centers.

VSWR bandwidth exceeds 4 percent at 14 MHz, and is greater than 2.5 percent at both 21 and 28 MHz. This is sufficient to cover the entire amateur band at 14 and 21 MHz, and covers the most actively-used portion of the 28 MHz band. Larger conductors were intentionally chosen for these wider amateur bands. Although operating on different frequencies than the previously-described wire antenna, a comparison shows that the larger-conductor antenna hss more than three times the percentage bandwidth for 2:1 VSWR.

The larger conductors mitigate the variations in impedance versus installed height that were first seen with the wire antenna. As with other test antennas, this version demonstrates that larger dimensions result in a less critical design, because of the inherently broader bandwidth of the larger diameter conduc-

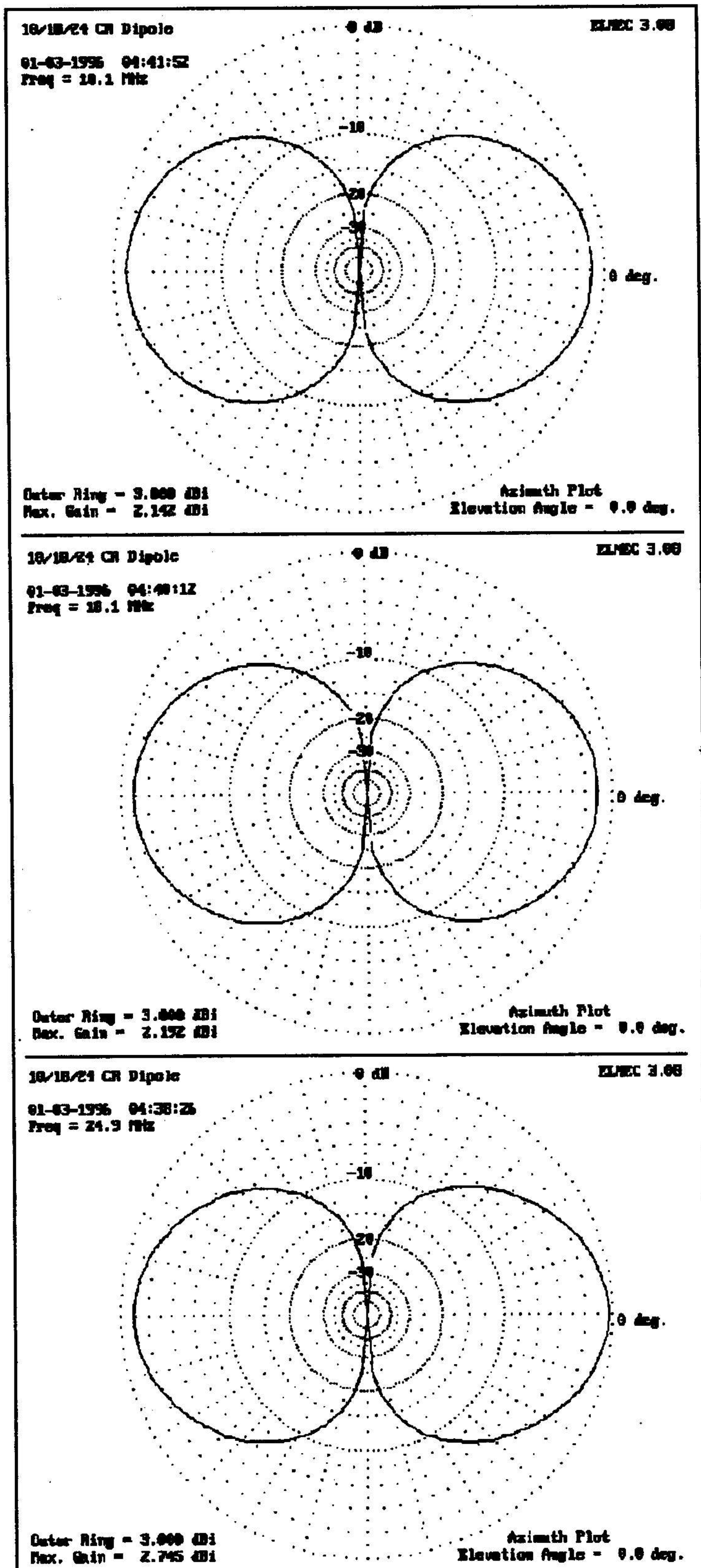

Figure 2. Radiation patterns for Example 1 — 10.1 MHz (top); 18.1 MHz (center); 24.9 MHz (bottom).

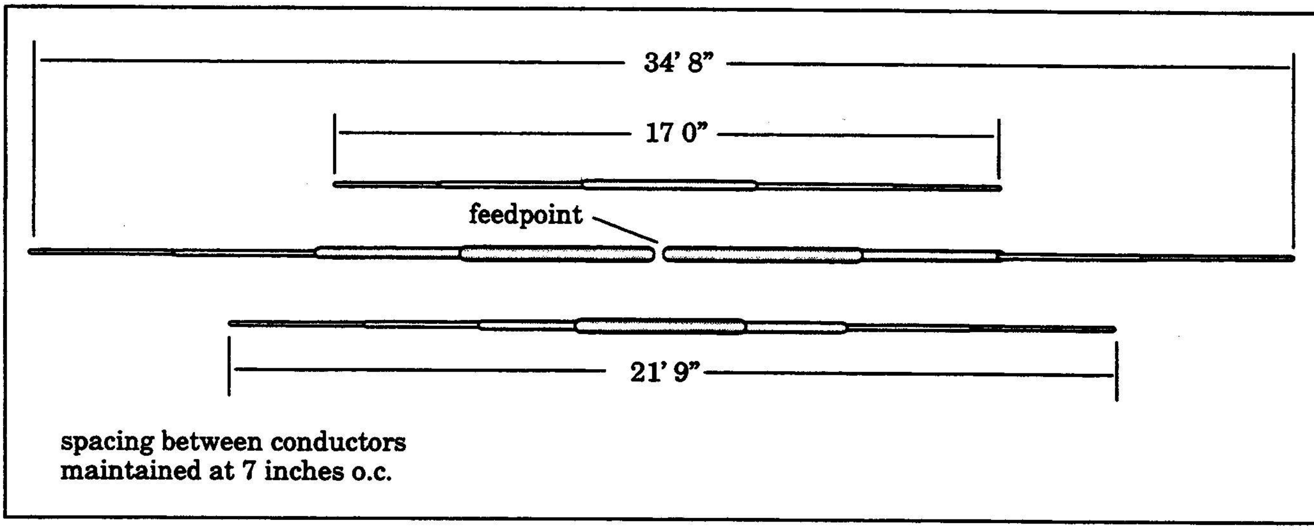

Figure 3. Dimensions of the three-frequency aluminum tubing dipole of Example 2.

tors, and the larger spacing distances for the desired feedpoint impedance. Based on modeling and experiments, the use of very small conductors (less than 0.0001 λ) is not recommended.

Example 3: A 14, 18, 21, 24, 28 MHz Vertical Dipole

The third example is a more complex antenna, a vertical dipole operating on five frequencies covering the 14, 18.068, 21, 24.89 and 28 MHz amateur bands. This antenna is illustrated in Figure 4. The driven element is a modified vertical dipole, with an inverted "T" for the lower half to reduce the overall height. The lowest conductor is installed at four feet above ground, and the vertical portion extends to 30 feet above ground. The feedpoint is eight feet above the horizontal portion, and the feedline is run inside this lower section of tubing. Above the feedpoint, the driven element tapers from 1-1/4-inch diameter to 5/8-inch diameter. Each of the additional resonators is 3/8-inch diameter tubing, mounted on fiberglass insulating spacers.

A vertical dipole installed close to ground has a feedpoint impedance in the range of 110 ohms. The inverted "T" configuration lowers this to about 90 ohms. But, operation in a 50-ohm system is desired, requiring some type of matching. A matching section of 75-ohm transmission line, 80 degrees electrical length at 14 MHz, was selected. To obtain a 50-ohm feedpoint impedance through this transmission line section, the antenna impedance should be:

14 MHz —	107.3 +j17.0 Ω
18.068 MHz —	108.2 –j15.9 Ω
21 MHz —	88.8 –j30.3 Ω
24.89 MHz —	66.6 –j27.6 Ω
28 MHz —	55.4 –j13.8 Ω

The selected line section achieves an acceptable match at 14 MHz. Using the flexibility of the coupled-resonator method, we can obtain the desired antenna impedances at the other frequencies by controlling the size, spacing and length of each resonator. This is a classic conjugate matching problem, but with the source and load reversed from the typical situation. The procedure starts by using the design equation to determine the required spacing for the resistive component of the impedance. The length of the resonator is then iteratively changed to create the inductive or capacitive reactance. Further iteration may be needed to optimize the spacing,

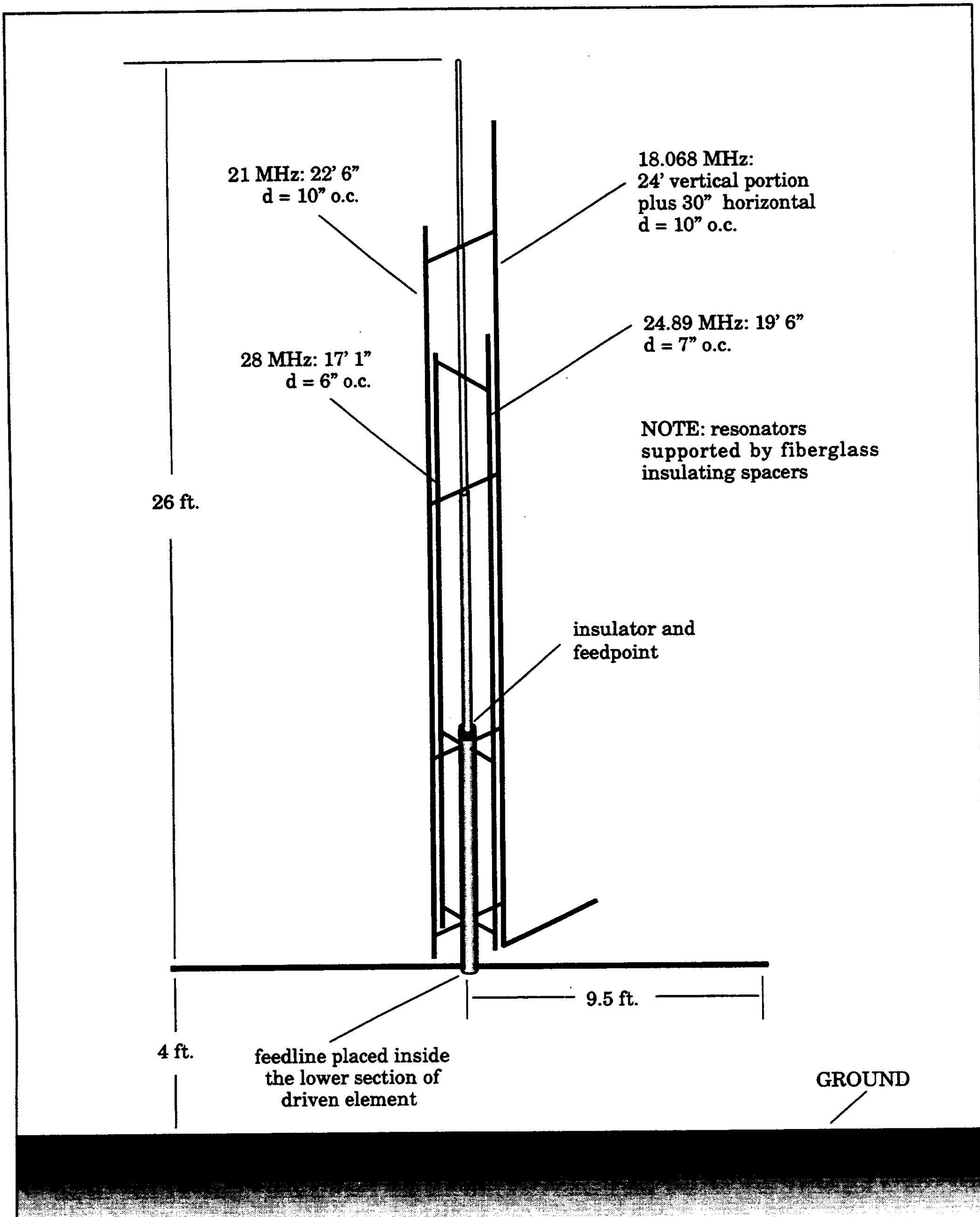

Figure 4. Diagram of the five-frequency vertical dipole antenna described in Example 3.

since the resistive component of impedance also changes with the length. As built, the finished antenna operates with a VSWR 1.2:1 or better at the five center frequencies. 2:1 VSWR bandwidths are as follows:

14 MHz —	>350 kHz (full band)
18.068 MHz —	>100 kHz (full band)
21 MHz —	≈350 kHz
24.89 MHz —	>100 kHz (full band)
28 MHz —	≈450 kHz

It is interesting to note that the bandwidth at 28 MHz is somewhat greater than expected. This is probably due to overlap with the adjacent-frequency 24.89 MHz resonator.

All coupled-resonator elements include an adjustable section at the bottom of the antenna. It should also be noted that the resonators are not symmetrical with respect to the feedpoint. This does not cause a significant variation in the required spacing, compared to a symmetrical design. Finally, the 18.068 MHz resonator is not a continuous, straight conductor; 2.5 feet of its total length is bent at 90 degrees, to maintain the desired overall height. This changes the coupling, and the required spacing was reduced from that required for a resonator coupled over its entire length.

Experimentation was needed to optimize the spacing for the 24.89 and 28 MHz resonators. MININEC modeling indicated that they should be spaced 7 and 8 inches, respectively, from the driven element. After construction, these spacings were reduced to 6 and 7 inches for best performance. The proximity to ground is the likely cause for the deviation, although the error is quite small, given the limitations of MININEC in modeling antennas near real ground.

Summary

Three antennas using the coupled-resonator antenna design technique have been described. The two three-frequency dipole examples offer a comparison of bandwidths obtained using small and large diameter conductors. The five-frequency vertical dipole antenna illustrates how this design method allows antennas to be built with arbitrary impedances at each frequency of operation. Below is a summary of the most significant characteristics of antennas designed using the coupled-resonator principle:

- Multiple frequency operation with low VSWR at each frequency
- No reactive components
- Control of impedance at each frequency
- No matching network required
- Independent fine tuning at each frequency (very little interaction)
- Some mechanical complexity
- Narrower VSWR bandwidth than a simple dipole or monopole

Although several methods are available for the construction of multi-frequency antennas, the coupled-resonator technique has flexibility as its principal advantage. Antennas built using this method are electrically simple, requiring no reactive components such as traps, stubs or matching networks. In cases where these characteristics are judged important, the technique's mechanical requirements may be deemed acceptable.

Further work is planned to develop design equations that encompass a wider range of impedances and antenna dimensions, as well as including effects of the number of resonators in the system.

References

[1] Gary A. Breed, "Development of the Coupled-Resonator Antenna Principle: A Computer Modeling Case History," *Proceedings*, 11th Annual Review of Progress in Applied Computational Electromagnetics, 1995.

[2] Gary A. Breed, "A Method of Constructing Multiple-Frequency Dipole or Monopole Antenna Elements Using Closely-Coupled Resonators," U.S. Patent application (approved, awaiting issue).

Brief Notes on the Construction of Practical Coupled-Resonator Antennas

The electrical simplicity of coupled-resonator antennas comes at the expense of mechanical complexity. Multiple conductors must be supported in a manner that maintains a consistent spacing distance.

Flexible wire conductors require either a large number of spacers, or they can be kept under tension. For end-supported dipole configurations, an equalizer assembly can be fabricated that will maintain tension on all wires, as shown in Figure A below. Swivel connections or bearings at the ends are also needed to avoid twisting. In general, wire antennas become extremely difficult to manage beyond three conductors.

Rigid conductors, such as aluminum tubing, are much easier to use. If supported at the center, typically two additional spacers are sufficient to prevent excessive motion in the wind. They should be placed about 2/3 of the distance from the center to the end of the resonator element.

Common insulating materials with sufficient strength include fiberglass and ABS plastic. Brittle materials like acrylic, or materials with insufficient insulating properties (e.g., wood), should be avoided. If the antenna is to be permanently installed outdoors, weatherproofing and ultraviolet protection should either be inherent in the material used, or accomplished with paints or other protective coatings.

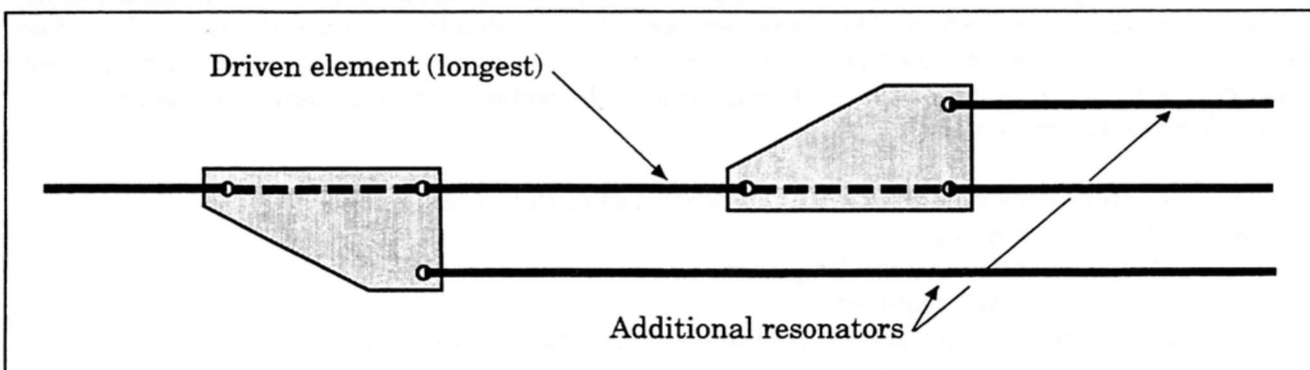

Figure A. Tension can be equalized among wire conductors using three-point spacer / insulators.

TUTORIAL ARTICLE

The tutorial contribution for this issue of the newsletter entitled "A Primer on Gaussian Quadrature Rules" is contributed by A.W. Mathis and A.F. Peterson.

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Andrew F. Peterson received the PhD Degree in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1986, and is currently an Associate Professor in the School of Electrical and Computer Engineering at Georgia Tech. He teaches undergraduate and graduate courses and is conducting research in computational electromagnetics with application to electromagnetic scattering, microwave devices and electronic packaging. He received the National Science Foundation Young Investigator Award in 1992. Professor Peterson is an elected Director of ACES and currently Chairman of the ACES Finance Committee.

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

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I would greatly welcome suggestions and contributions.

A PRIMER ON GAUSSIAN QUADRATURE RULES

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I. INTRODUCTION

In a typical finite element method (FEM) or method of moments (MoM) analysis arising in electromagnetics, one has to integrate functions numerically. A typical impedance matrix in a MoM program requires numerical integration of the Green's function several hundred or several thousand times; hence, efficient methods for numerical integration are required. By definition the most efficient numerical integration is Gaussian quadrature. The accuracy of an n–point Gaussian quadrature is such that it integrates polynomials up to degree $2n-1$ exactly.

Before we can proceed we must introduce some common terms. A quadrature formula approximates the integral of a function using only the value of the integrand at certain discrete points, or nodes. Consider the integral of a function f with respect to a weighting function w

$$If = \int_a^b w(x)f(x)dx \tag{1}$$

An N point quadrature rule approximates the integral as

$$If \simeq Q_n f = \sum_{i=1}^{n} w_i f(x_i) \tag{2}$$

where w_i is the weight of the ith node, x_i. If all the weights, w_i, are non–negative, then quadrature scheme is called positive. A positive quadrature scheme is desirable since it is easier to establish convergence and the damping of round off errors. A node is called an interior node if $x_i \in (a,b)$, a boundary node if $x_i = a$ or b, and an exterior node if $x_i \notin [a,b]$. A minimal quadrature is one in which the error norm, $||If - Q_n f||$ is a minimum.

Before 1814 it was assumed that nodes should be equally spaced (*e.g.* the quadrature rules of Newton and Simpson). But Gauss noted that if one changed the nodes slightly, the accuracy of the quadrature improved. In 1814 Gauss generalized the earlier methods to include properly chosen, different node spacing [1], and in 1826 Jacobi proved the superiority of Gauss's new method over the methods of Newton and Simpson [2]. Thus in determining a Gaussian quadrature, both the nodes and the weights are unknowns. It was Markoff who noticed the connection between the Gaussian quadrature and Hermitian interpolating polynomials, and from 1950 to 1955 Krein extended the results of Gauss and Markoff to include arbitrary Chebyshev systems [3].

There are two main drawbacks to Gaussian quadratures. For a Gaussian quadrature to be effective the integrand has to be well approximated by polynomials. The reasons for this will become clear in the next section. Also, Gaussian quadratures converge slowly if the function is not smooth, *i.e.*, it only has a few orders of differentiability. These two drawbacks usually coincide since, in general, polynomials approximate smooth functions very well. A typical example is the logarithmic singularity of the Hankel function encountered in 2D method of moments problems. Recently, it has become clear that the use of generalized Gaussian quadrature rules can circumvent these drawbacks (Section III).

Overall Gaussian quadrature works extremely well in one dimension, and the natural progression is to extend Gaussian quadratures to higher dimensions. This was posed by Radon in 1948 [4]. The work of Radon was carried on by Mysovskih who found two dimensional minimal node cubature formulas of degree 1,3, and 5. Möller extended the results of Radon and Mysovskih to odd degree cubature formulas of arbitrary dimensions [5,6]. Finding these higher dimensional Gaussian quadratures has proven problematic, even though considerable progress has been made in determining cubature rules.

II. GAUSSIAN QUADRATURE RULES

A. Basic Theory

Although the practical use of classical Gaussian quadrature is well known to engineers, the theory behind classical and generalized Gaussian quadrature tends to be murky at best. Gaussian quadratures are interpolatory quadratures, *i.e.*, instead of approximating the integral directly, they interpolate the integrand using functions that are integrable analytically and then integrate this approximation. Gaussian quadratures actually integrate the Hermite interpolation of the integrand.

A Hermite interpolation, H_n, of the function f approximates the function using the function f and its first derivative f'; thus the function f is approximated as

$$f(x) \simeq H_n(f,x) = \sum_{i=1}^{n}[\mu_i(x)f(x_i) + \nu_i(x)f'(x_i)] \tag{3}$$

where μ and ν are the Hermite coefficients which satisfy

$$\begin{aligned} \mu_i(x_k) &= \delta_{ik} \\ \mu_i'(x_k) &= 0 \\ \nu_i(x_k) &= 0 \\ \nu_i'(x_k) &= \delta_{ik} \end{aligned} \tag{4}$$

and μ and ν must be differentiable in a neighborhood of each x_k. From (4) it is easy to show that Hermite interpolation has the properties

$$\begin{aligned} H_n(f,x_k) &= f(x_k) \\ H_n'(f,x_k) &= f'(x_k) \end{aligned} \tag{5}$$

for $1 \leq k \leq n$. This means we can approximate the integral of a function by

$$If \simeq \int_a^b w(x)H_n(f,x)dx = \sum_{i=1}^{n}[A_i f(x_i) + B_i f'(x_i)] \tag{6}$$

where A_i and B_i are defined as

$$\begin{aligned} A_i &= \int_a^b w(x)\mu_i(x)dx \\ B_i &= \int_a^b w(x)\nu_i(x)dx. \end{aligned} \tag{7}$$

The above scheme is a perfectly valid approximation of the integral, but it is inefficient and inconvenient since the first derivatives must be known. However, we note that μ_i and ν_i are functions of the node x_i, so if we find the node positions such that $B_i = 0$ for all i, then the above scheme becomes very efficient. It is possible to have some nodes preassigned, *e.g.*, the endpoints, and still have $B_i = 0$ for all i [7]. In addition if $B_i = 0$, one can show the resulting quadrature scheme is positive. This general framework establishes what are commonly called Gaussian quadrature rules. Furthermore, Gaussian quadratures are minimal quadratures. A detailed derivation of the above is found in [5].

We have not put any constraints on μ_i and ν_i, except that they must satisfy (4). One of the difficulties in developing generalized Gaussian quadrature formulas is determining the Hermite coefficients. Typically, μ_i and ν_i are written in terms of basis functions $\{\phi_1, \phi_2, \ldots \phi_{2n}\}$. If we expand μ_i and ν_i in terms of the basis functions

$$\begin{aligned} \mu_i(x) &= \sum_{m=1}^{2n} \alpha_m^i \phi_m(x) \\ \nu_i(x) &= \sum_{m=1}^{2n} \beta_m^i \phi_m(x) \end{aligned} \tag{8}$$

and impose the constraints of (4), we can formulate a matrix equation for the unknown coefficients α_m^i and β_m^i. Since the interpolants depend on the node x_i, a modified Newton's method must be used to determine the x_i such that $B_i = 0$. Once the nodes are determined, the weights are given by A_i in (7).

The most troublesome difficulty in computing the Hermite interpolant's coefficients α and β is the extremely ill-conditioned matrices one has to solve. This can be ameliorated by orthogonalizing the basis functions via a Gram–Schmidt procedure, but even then one has to use excessively large numerical precision. The above is only a brief description of the algorithm used to determine the generalized Gaussian quadrature formulas; for a more detailed description, including numerical techniques to circumvent the ill-conditioned matrices, the reader is referred to [8].

B. A Simple Example

In this example we determine a quadrature rule for the integral

$$\int_0^{2\pi} f(x)dx \tag{9}$$

where f is a periodic function. Since f is periodic, using trigonometric functions as interpolating functions seems reasonable. If we let

$$\nu_i(x) = \frac{\prod_{j=1}^{n} \sin^2(x - x_j)}{\sin(x - x_i)}, \quad i = 1, \ldots, n \tag{10}$$

then ν_i will satisfy (4). Hence, we must determine x_i such that

$$\int_0^{2\pi} \nu_i(x)dx = 0. \tag{11}$$

Since f and ν_i are periodic, the range of integration can be changed to

$$\int_{x_i-\pi}^{x_i+\pi} \nu_i(x)dx. \tag{12}$$

The denominator of ν_i is an odd function over the domain; thus the integral will equal zero if the numerator is an even function. Setting $x_i = 2\pi i/n$ ensures that the numerator is an even function with respect to every x_i. Thus the nodes of the quadrature formula are $x_i = 2\pi i/n$. Since the nodes are known we can write (10) in a more convenient form

$$\nu_i(x) = \frac{\sin^2 n(x - x_i)}{n \sin(x - x_i)} \tag{13}$$

To determine the weights, w_i, the Hermite coefficient μ_i must be determined. Through tedious algebraic manipulation, one finds

$$\mu_i(x) = [1 - 2\lambda_i'(x_i)\sin(x - x_i)]\,\lambda_i^2(x) \tag{14}$$

where

$$\lambda_i^2(x) = \nu_i(x)/\sin(x - x_i). \tag{15}$$

Although ancillary to the present discussion, we point out to those readers who are familiar with Lagrange interpolation that λ_i is the Lagrange interpolation coefficient. Thus the weights are determined by

$$w_i = \int_0^{2\pi} [1 - 2\lambda_i'(x_i)\sin(x - x_i)]\,\lambda_i^2(x)dx \tag{16}$$

The second term of the integrand is a ν_i multiplied by a constant; hence, it integrates to zero. Thus the weights become

$$w_i = \int_0^{2\pi} \lambda_i^2(x)dx = \frac{2\pi}{n} \tag{17}$$

This Gaussian quadrature rule is identical to the trapezoidal rule.

C. Classical Gaussian Quadrature

If the basis functions equal $\phi_k(x) = x^{k-1}$, one recovers the classical Gaussian quadrature rules. For polynomial basis functions, the nodes are easy to determine since they correspond to the zeros of the nth degree orthogonal polynomial on the given interval with respect to the weight function $w(x)$. The classical Gaussian quadratures are divisible into three main types according to orthogonal polynomials induced from a given weight function and domain:

$$\begin{aligned} \text{Jacobi:}\quad & w(x) = (1-x)^\alpha(1+t)^\beta, \quad \text{on } (-1,1), \\ & \qquad \alpha,\beta > -1 \\ \text{Laguerre:}\quad & w(x) = x^\alpha e^{-x}, \quad \text{on } (0,\infty), \quad \alpha > -1 \\ \text{Hermite:}\quad & w(x) = e^{-x^2}, \quad \text{on } (-\infty,\infty). \end{aligned} \tag{18}$$

The Jacobi polynomials subsume the Legendre polynomials ($\alpha = \beta = 0$), the Gegenbauer polynomials ($\alpha = \beta = \lambda - \frac{1}{2}$), and the Chebyshev polynomials of the first ($\alpha = \beta = -\frac{1}{2}$), second ($\alpha = \beta = \frac{1}{2}$), third ($\alpha = -\frac{1}{2}, \beta = \frac{1}{2}$), and fourth ($\alpha = \frac{1}{2}, \beta = -\frac{1}{2}$) kinds. For example, given $w(x) = 1$, the Legendre polynomials form an orthogonal basis on the interval $(-1,1)$. The zeros of the nth degree Legendre polynomial, P_n, are the nodes of the Gaussian quadrature formula

$$Q_n f = \sum_{i=1}^{n} w_i f(x_i), \tag{19}$$

and the weights are determined from

$$\begin{pmatrix} P_0(x_1) & \dots & P_0(x_n) \\ P_1(x_1) & \dots & P_1(x_n) \\ \vdots & \ddots & \vdots \\ P_{n-1}(x_1) & \dots & P_{n-1}(x_n) \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = \begin{pmatrix} \int_a^b P_0(x)dx \\ 0 \\ \vdots \\ 0 \end{pmatrix} \tag{20}$$

A more important relationship comes from the recurrence relations for the orthogonal polynomials. For any given positive weight function and interval, one can find a set of orthogonal polynomials that satisfy the recurrence relation

$$\pi_{k+1}(x) = (x - \alpha_k)\pi_k(x) - \beta_k(x) \tag{21}$$

where π_k represents the kth degree orthogonal polynomial and we define

$$\pi_0(x) = 1, \quad \pi_{-1}(x) = 0. \tag{22}$$

The nodes x_i are the eigenvalues of the nth order Jacobi matrix

$$J_n = \begin{pmatrix} \alpha_0 & \sqrt{\beta_1} & & & 0 \\ \sqrt{\beta_1} & \alpha_1 & \sqrt{\beta_2} & & \\ & \sqrt{\beta_2} & \ddots & \ddots & \\ & & \ddots & & \sqrt{\beta_{n-1}} \\ 0 & & & \sqrt{\beta_{n-1}} & \alpha_n \end{pmatrix} \tag{23}$$

The weights are expressible in terms of the associated eigenvectors. If $\mathbf{v}_i$ is the normalized eigenvector corresponding to the eigenvalue x_i, then

$$w_i = \beta_0 v_{i,1}^2 \tag{24}$$

From the above relations the nodes and weights of Gaussian quadrature corresponding to the weight functions of Legendre, Chebyshev, Laguerre, Hermite, and Jacobi are easy to determine [9,10]

D. The Radau, Lobatto, and Kronrod Extentions

In the classical Gaussian quadratures all the nodes are unknowns, or free, but occasionally it is desirable to have preassigned nodes. There are three common extentions of Gaussian quadrature that incorporate preassigned nodes. Gauss–Radau and Gauss–Lobatto rules use one or both of the endpoints as preassigned nodes. Gauss–Kronrod uses the nodes of an n point Gauss–Legendre formula as preassigned nodes of a $2n+1$ point quadrature routine.

For the classical Gaussian quadratures of (9), the set of nodes $\{x_i\}_1^n$ comprise interior nodes. This is usually a beneficial feature, but occasionally one wants to include the endpoints. We define x_0 and x_{n+1} to be the boundary nodes. The Gauss–Radau formula has one preassigned node x_0,

$$Q_{n+1}f = w_0 f(x_0) + \sum_{i=1}^{n} w_i f(x_i) \tag{25}$$

and has an algebraic degree of exactness $2n$. The Gauss–Lobatto formula has two preassigned nodes, x_0 and x_{n+1},

$$Q_{n+2}f = w_0 f(x_0) + \sum_{i=1}^{n} w_i f(x_i) + w_{n+1} f(x_{n+1}) \tag{26}$$

and has an algebraic degree of exactness $2n+1$. Both these formulas can be interpreted in terms of the eigenvalues and eigenvectors of a slightly modified Jacobi matrix. For the Gauss–Radau rule, α_n of the $n+1$ order Jacobi matrix, J_{n+1} is redefined as

$$\alpha_n = x_0 - \beta_n \frac{\pi_{n-1}(x_0)}{\pi_n(x_0)} \tag{27}$$

The Gauss–Lobatto formula requires the eigenvalues and eigenvectors of an $n+2$ order Jacobi matrix, J_{n+2}. The quantities α_{n+1} and β_{n+1} are redefined as

$$\begin{pmatrix} \pi_{n+1}(x_0) & \pi_n(x_0) \\ \pi_{n+1}(x_{n+1}) & \pi_n(x_{n+1}) \end{pmatrix} \begin{pmatrix} \alpha_{n+1} \\ \beta_{n+1} \end{pmatrix} = \begin{pmatrix} x_0 \pi_{n+1}(x_0) \\ x_{n+1}\pi_{n+1}(x_{n+1}) \end{pmatrix} \tag{28}$$

These rules are useful when the value at one or both of the endpoints is known explicitly.

For smooth functions the classical Gaussian quadratures converge uniformly and exponentially, thus an error estimate of an n point quadrature rule can be obtained from $\|Q_m f - Q_n f\|$ where $m > n$. For Gaussian quadratures, the nodes of an n point formula do not coincide with the nodes of any $m (\neq n)$ point formula, and this makes obtaining an error estimate computationally expensive. In 1964 Kronrod advanced the idea of embedding an $n+1$ point Gaussian quadrature formula in an n point Gauss–Legendre formula [11]. The nodes inserted are the zeros of the $n+1$ degree Stieltjes polynomial. An $n+1$ degree Stieltjes polynomial is orthogonal to all lower degree polynomials with respect to the weight function of an n degree Legendre polynomial. The result is a $2n+1$ point formula that has an algebraic degree of exactness of $4n+1$. This gives a convenient method of estimating the error, $\|Q_{2n+1}f - Q_n f\|$. At present there are Gauss-Kronrod formulas for the weight functions of Legendre, Chebyshev (all four kinds), Gegenbauer, and Bernstein–Szegö (a Chebyshev weight function divided by a polynomial) [12,13].

E. Generalized Gaussian Quadratures

The classical Gaussian quadrature rules work very well when approximating a sufficiently smooth function. This is because a polynomial interpolation will converge exponentially to an infinitely differentiable function. If the integrand is not approximated well by polynomials then classical Gaussian quadrature will not work well. However, choosing basis functions that better approximate the integrand facilitates the construction of an efficient quadrature scheme. The basis functions $\{\phi_n\}$ must form an extended Chebyshev (ET) system [14], *i.e.*, they must satisfy (29) for all $x_i \neq x_j, x \in (a,b)$.

$$\det \begin{pmatrix} \phi_1(x_1) & \phi_1'(x_1) & \cdots & \phi_1^{(n-1)}(x_1) & \phi_1(x_2) & \cdots & \phi_1(x_n) & \phi_1'(x_n) \\ \phi_2(x_1) & \phi_2'(x_1) & \cdots & \phi_2^{(n-1)}(x_2) & \phi_2(x_1) & \cdots & \phi_2(x_n) & \phi_2'(x_n) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \phi_{2n}(x_1) & \phi_{2n}'(x_1) & \cdots & \phi_{2n}^{(n-1)}(x_1) & \phi_{2n}(x_1) & \cdots & \phi_{2n}(x_n) & \phi_{2n}'(x_n) \end{pmatrix} \geq 0 \tag{29}$$

This constraint allows the basis functions to uniquely represent ν_i and μ_i and satisfy (4). In addition the weight function must be positive. If the above conditions are met, then there exists a unique set of n nodes and n weights that will exactly integrate the first $2n$ basis functions. Some ET systems are

$$\begin{aligned}
&\{1, x, x^2, \ldots, x^{n-1}\} \\
&\{1, \ln x, x, x\ln x, \ldots, x^{n/2-1}, x^{n/2-1}\ln x\} \text{ on } (0,1) \\
&\{J_0(x), J_1(x), \ldots, J_n(x)\} \text{ on } (n/2, n) \\
&\{x^{-\alpha}, 1, x^{1-\alpha}, x, \ldots, x^{n/2-\alpha}, x^{n/2-1}\} \text{ on } (0,1) \\
&\qquad \text{where } 0 < \alpha < 1 \\
&\{1, \cos\gamma_1 x, \sin\gamma_1 x, \ldots \cos\gamma_n x, \sin\gamma_n x\} \text{ on } (0, 2\pi) \\
&\{1, \cosh\gamma_1 x, \sinh\gamma_1 x, \ldots \cosh\gamma_n x, \sinh\gamma_n x\}
\end{aligned} \tag{30}$$

where J_n is the nth order Bessel's function, α is some positive constant less than one, and $\{\gamma_i\}_{i=1}^{n}$ is a strictly increasing series of real numbers. The first system is the standard polynomials discussed above. Formulas based on the next three systems can be found in [8]. The "linlog" basis of the second system is also found in [15]. The last two systems are known as the trigonometric and hyperbolic polynomials, respectively.

The zeros of the trigonometric and hyperbolic polynomials can be determined analytically. A Gaussian quadrature based on the trigonometric basis functions (let $\gamma_i = 2\pi i$) is identical to trapezoidal rule; this accounts for the trapezoidal rule success in integrating periodic functions (Section II.B). Formulas for trigonometric and hyperbolic polynomials are found in [16,17].

III. SINGULARITIES

A. Common Techniques

The convergence of Gaussian quadrature breaks down if there is a singularity in the domain. For the one dimensional case there are three basic methods to circumvent this problem: singularity subtraction, singular weighting functions, and singular expansion functions.

The most commonly used and simplest of the three methods is singularity subtraction. In this method one extracts the singular part of the integrand and then integrates the singular part analytically. Thus the function f is written as

$$f(x - x') = [f(x - x') - f_s(x - x')] + f_s(x - x') \tag{31}$$

where f_s is singular part of the kernal. The term in brackets is well behaved and can be integrated numerically while the last term can be integrated analytically. Since most singularities occur when $x \rightarrow x'$, k_s is usually the small argument approximation of k. The main drawback of this method is that the term in brackets usually has a low order of differentiablity, and thus convergence is slow.

Another seemingly simple way to numerically integrate a domain containing a singularity is to incorporate the singularity in the weight function. For a logarithmic singularity, one can construct a quadrature scheme of the form

$$\int_0^1 f(x)\ln\frac{1}{x}dx \simeq \sum_{n=1}^{N} w_n f(x_n). \tag{32}$$

This scheme converges rapidly if the integral to be evaluated can be written in the above form. Many functions, *e.g.* the Hankel function, have a small argument approximation in the form of

$$f(x) = f_1(x)\ln\frac{1}{x} + f_2(x) \tag{33}$$

where f_1 and f_2 are simple polynomial functions. The first term can be integrated using the scheme in (32) and second term can be integrated analytically or using the standard Gauss-Legendre quadrature. The weighted scheme of (32) will not accurately integrate the second term of (33), and, hence, one must split the integrand as above. Proper use of (32) can efficiently integrate functions with a logarithmic singularity. Here we must pause, and amend the above statement with a warning. One must be careful and not naively apply this method since many of these rules are not invariant under coordinate stretching. More explicitly,

$$\begin{aligned}
\int_0^h f(x)\ln\frac{1}{x}dx =& h\int_0^1 f(hx)\ln\frac{1}{hx}dx \\
\neq& h\sum_{n=1}^{N} w_n f(hx_n)
\end{aligned} \tag{34}$$

The main drawbacks of this method are that one must use the proper weighting function and then properly apply it. If the singularity is not a common type, then one may have to construct a quadrature rule – a non-trivial task. Even if a quadrature rule is available, naive use of the routine may significantly slow convergence rates.

The last method is the most complicated in theory but simplest in practice. A generalized Gaussian quadrature is used where the expansion functions themselves account for the singularity. For a logarithmic singularity at one of the endpoints, the "linlog" sequence of (30) can be used

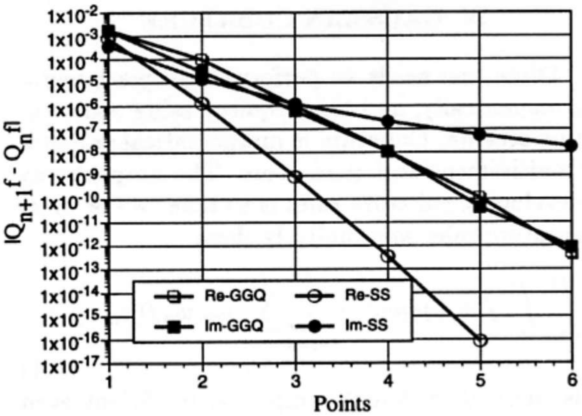

Fig. 1 A comparison of the convergence of the real and imaginary parts of the (36) using "linlog" generalized Gaussian quadrature (Re–GGQ and Im–GGQ) and using singularity subtracition (Re–SS and Im–SS).

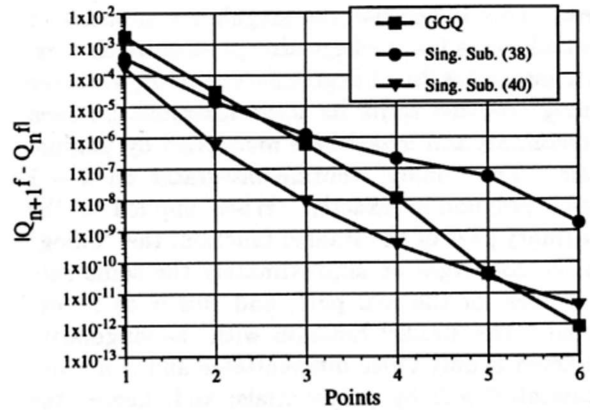

Fig 2. A comparison of the convergence of the singular imaginary part of the integral (36) using the "linlog" (GGQ) with subtracting the singularity of (38) and (40).

as a basis for the interval $(0, 1)$. This method is invariant under coordinate stretching. Using the above basis, an integral of the form

$$\int_0^1 f(x)dx \simeq Q_N f = \sum_{n=1}^{N} w_n f(x_n) \qquad (35)$$

is performed exactly for any linear combination of the first $2N$ basis functions. This type of rule integrates polynomials and polynomials multiplied by a logarithm equally well; hence, one does not have to split the integrand or extract a singularity. The main disadvantage is that the construction of generalized Gaussian quadratures is more difficult than the standard Gaussian polynomial quadratures. Once constructed, these rules are very simple to use, but very few have been constructed so far.

B. Integrating the Hankel Function

In electromagnetic analysis, the logarithmic singularity is probably most often encountered in two–dimensional method of moments problems where the Green's function is a Hankel function of the second kind. Consider the following singular integral (which arises from collocation in a TM method of moments problem)

$$If = \int_0^a H_0^2(2\pi x)dx \qquad (36)$$

where the Hankel function of the second kind is defined as $H_0^2(x) = J_0(x) - jY_0(x)$. J_0 and Y_0 are the Bessel functions of the first and second kind, respectively. Writing the Bessel functions in a series expansion yields (37).

The Hankel function has a singularity of the form $-j\frac{2}{\pi}\ln\frac{x}{2}$ as $x \to 0$. Fig. 1 shows a comparison of the convergence $|Q_{n+1} - Q_n|$ versus the number of points n for the singularity subtraction method and the generalized Gaussian quadrature method. For this comparison, $a = 0.05$. Using the singularity subtraction method one approximates the integral as

$$\int_0^a H_0^2(2\pi x)dx \simeq Q_n[H_0^2(2\pi x) + j\frac{2}{\pi}\ln \pi x] - j\frac{4a}{\pi}(\ln \pi a - 1) \qquad (38)$$

To approximate the integral using generalized Gaussian quadrature, a straightforward application of the nodes and weights found in [15] is used. Since the real part of the integral is well approximated by polynomials the singularity subtraction method converges at a rate that is about twice as many decades per point compared to the "linlog" quadra–

$$J_0(x) = 1 - \frac{(x/2)^2}{(1!)^2} + \frac{(x/2)^4}{(2!)^2} - \cdots$$
$$Y_0(x) = \frac{2}{\pi}(\ln\frac{x}{2} + \gamma)J_0(x) + \frac{2}{\pi}\left[\frac{(x/2)^2}{(1!)^2} - \left(1 + \frac{1}{2}\right)\frac{(x/2)^4}{(2!)^2} + \left(1 + \frac{1}{2} + \frac{1}{3}\right)\frac{(x/2)^6}{(3!)^2} - \cdots\right] \qquad (37)$$

tures. This is because the singularity subtraction method uses a Gauss–Legendre quadrature that exactly integrates $2n-1$ degree polynomials, while the "linlog" routine splits its basis functions between polynomials and logarithms multiplied by polynomials. The "linlog" routine integrates an $n-1$ degree polynomial exactly. When applied to the imaginary part of the Hankel function, the "linlog" routine converges at approximately the same rate as it does for the real part, and this is to be expected. The Hankel function with the singularity extracted is only twice differentiable and is not approximated well by polynomials; and, hence, the singularity subtraction method converges at a much slower rate. If high accuracy is required, the singularity subtraction method becomes computationally expensive. A disquisition very similar to the above is found in [18].

If we let

$$k_s(x) = -j\frac{2}{\pi}J_0(2\pi x)\ln \pi x \tag{39}$$

then $H_0^2(2\pi x) - k_s(x)$ and all of its derivitives will be non–singular. Although we obtain exponential convergence for the quadrature of the non–singular part of the integrand, we can not integrate k_s analytically. Even though obtaining exponential convergence using the singularity subtraction technique is not realizable, we can dramatically improve convergence by using the first two terms of the Bessel function expansion (37). The singular part the integrand becomes

$$k_s(x) = -j\frac{2}{\pi}(1-\pi^2x^2)\ln \pi x. \tag{40}$$

The resulting non–singular function has four orders of differentiability. Fig. 2 compares the convergence of the imaginary part of the integral in (36) when using the "linlog" method with the singularity subtraction with two and four orders of differentiability. The singularity subtraction with four orders of differentiability significantly outperforms its counterpart that only has two orders of differentiability. Since singularity subtraction has algebriac convergence and the "linlog" has exponential convergence, the "linlog" routine will eventually converge faster than singularity subtraction with finite order of differentiability. The crossing point is between $n = 2$ and $n = 3$ for two orders of differentiability and about $n = 5$ for four orders of differentiability. The singularity subtraction technique with four orders of differentiability has already obtained a relatively high accuracy when the crossing point has been reached.

IV. GAUSSIAN CUBATURE

Often one needs to perform multiple integration numerically, and this requires using some cubature scheme. Cubature is mathematical parlance for multidimensional quadrature. The simplest way of developing cubature rules is to take two or more quadrature rules and multiply them

$$\int_a^b\int_c^d f(x,y)dydx = \sum_{m=1}^{N}\sum_{n=1}^{N} w_m w_n f(x_m, y_n) \tag{41}$$

This method, although simple, is inefficient even when multipling Gaussian quadrature rules. It seems natural to ask whether we can extend the relations between orthogonal polynomials and Gaussian quadratures presented in section II.C to multidimensional quadratures.

To answer this question we must first review the theory of multidimensional polynomials. We define the set of nth degree polynomials in d dimensions as

$$\Pi_n^d = \left\{ \sum_{|\alpha|\le n} a_\alpha \mathbf{x}^\alpha : \quad a_\alpha \in \Re, \mathbf{x} \in \Re^d \right\}. \tag{42}$$

The number of linearly independent polynomials of exactly degree n is given by

$$r_n^d = \binom{n+d-1}{n} \tag{43}$$

and the dimension of the set Π_n^d is

$$\dim \Pi_n^d = \binom{n+d}{d}. \tag{44}$$

A sequence of orthonormal polynomials on the domain Ω is denoted by $\{\pi_j^n\}_{j=1}^{r_n^d}{}_{n=1}^{\infty}$. This allows us to introduce the vector notation

$$\mathcal{P}_n(\mathbf{x}) = [\pi_1^n(\mathbf{x}), \pi_2^n(\mathbf{x}), \ldots, \pi_{r_n^d}^n]^T. \tag{45}$$

Similar to (21), there is a three term recurrence relation for $\mathcal{P}$

$$x_i\mathcal{P}_n = B_{n,i}\mathcal{P}_{n+1} + A_{n,i}\mathcal{P}_n + B_{n,i}^T\mathcal{P}_{n-1} \tag{46}$$

where $A_{n,i}$ and $B_{n,i}$ are $r_n^d \times r_n^d$ matrices. The block Jacobi matrix $J_{n,i}$ is defined as

$$J_{n,i} = \begin{pmatrix} A_{0,i} & B_{0,i} & & & 0 \\ B_{0,i}^T & A_{0,i} & B_{1,i} & & \\ & B_{1,i}^T & \ddots & \ddots & \\ & & \ddots & & B_{n-2,i} \\ 0 & & & B_{n-2,i}^T & A_{n-1,i} \end{pmatrix} \tag{47}$$

The point $\Lambda = (\lambda_1, \ldots, \lambda_d)$ is a zero if

$$J_{n,i}\mathbf{x} = \lambda_i \mathbf{x}, \quad 1 \le i \le d \tag{48}$$

and the polynomial $\mathcal{P}$ will only have $N = \dim \Pi^d_{n-1}$ distinct real zeros if

$$B_{n-1,i}B^T_{n-1,j} = B_{n-1,j}B^T_{n-1,i}, \quad 1 \le i,j \le d. \tag{49}$$

For $d = 1$, (49) is obviously satisfied, but in higher dimensions this condition is rarely satisfied. If a $2n-1$ degree cubature formula attains the lower bound $N = \dim \Pi^d_{n-1}$, then it is called Gaussian. However, Gaussian cubatures do not exist in general because (49) is not satisfied. If (49) is not satisfied, then the lower bound (for $d = 2$) is

$$N \ge \dim \Pi^2_{n-1} + \frac{1}{2}\text{rank}(B_{n-1,1}B^T_{n-1,2} - B_{n-1,2}B^T_{n-1,1}). \tag{50}$$

This is called Möller's lower bound. One notes that if (49) is satisfied then Möller's lower bound reduces to $N = \dim \Pi^d_{n-1}$. Any cubature formula that attains Möller's lower bound is called minimal, and, hence, all Gaussian cubatures are minimal. One should note that minimal has a different meaning when modifying cubature than when modifying quadrature.

Minimal cubature formulas are extremely difficult to find. The problems one encounters are similar to the difficulties in determining a one dimensional quadrature rule, but because of the increased number of dimensions, the conditioning of the matrices worsen at a quicker rate. Also these minimal cubatures are usually not unique and may not even exist at all. Two types of cubature rules exist that do attain Möller's lower bound and can be solved analytically, the first is based on the trigonometric polynomials [19] and the second is based on polynomials with a Chebyshev weight function of the first and second kind [20]. This is not surprising considering the close relation between the trigonometric polynomials and the Chebyshev polynomials. General introductions on the subject of cubature are found in [5,21], and an intensely mathematical summary of the latest research can be found in [22].

In Tables I–III, cubature formulas with respect to a unity weight function that attain Möller's lower bound are summarized. Table I shows formulas for a square region C_2, Table II shows formulas for a triangular region T_2, and Table III shows formulas for a tetrahedron T_3. Under the *Quality* heading P means that cubature is positive, N means that it has a least one negative weight, I means that all the nodes are interior nodes, O means there are nodes outside the domain of integration, and B denotes that are boundary nodes. More extensive tables of cubature rules can be found in [23]; these tables include many higher degree schemes that are much more efficient than the product rule (41), even though the rules do not obtain Möller's lower bound.

Table I. Cubature formulae for C_2

Degree	Points	Quality	References
3	4	PI	[21]
4	6	PI	[24,25,26]
		PO	[25]
5	7	PI	[21]
6	10	PI	[24,26,27]
		PO	[24]
7	12	PI	[6,21,25,28,29]
		PO	[21]
8	15	PO	[30]
9	17	PI	[6]
11	24	PI	[32]

Table II. Cubature formulae for T_2

Degree	Points	Quality	References
2	3	PI	[21,32]
		PB	[21,32]
3	4	NI	[21]
		PI	[32]
4	6	PI	[33,34,35,36,37,38]
		?I	[27]
5	7	PI	[21]
7	12	PI	[39]
8	15	PO	[40]

Table III. Cubature formulae for T_3

Degree	Points	Quality	References
1	1	PI	[21]
2	4	PI	[23,41]
		PB	[41,42]
3	5	NI	[21]

The rules in Tables I-III are much more efficient than the corresponding product rule (41). For instance, integration of a square region using the product rule requires 36 points for degree 11 accuracy while a Gaussian cubature rule requires 24 points for the same accuracy. The efficiency of these rules compared to the product rules increases as the number of dimensions increases.

V. CONCLUSION

A general introduction to Gaussian quadrature and cubature has been presented. The relationship of Gaussian quadratures to orthogonal polynomials and to Chebyshev systems of arbitrary functions has been explored. Methods to overcome the limitations of Gaussian quadratures when approximating a singular function are also detailed.

VI. ACKNOWLEDGEMENTS

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BOOK REVIEW

Analysis Methods for Electromagnetic Wave Problems, Volume 2

Publisher: Artech House, 1996, Boston , 393 pages

Editor: Eikichi Yamashita

Reviewer: R. Perez

This book is the second of a two volume series on applied analysis of electromagnetic wave problems. The first volume dealt with some fundamental techniques. This volume deals with more applied aspects of analysis, of a practical nature, such as those used in antennas, random scattering problems, and waveguides.

The first chapter discusses the fundamentals of supercomputers and how they can be applied in solving electromagnetic problems. The chapter covers some details of pipeline type supercomputing, which is widely used in commercially available computers. Some algorithms and programs used on supercomputers are introduced briefly. Other topics discussed in this chapters are scalar versus array processors, hardware for high speed processing, and vectorization support tools. After deriving some fundamental equations, a dielectric waveguide example problem is presented for solution using FEM, BEM, and a combined approach of these two techniques. The objective is representation of the solution in matrix form which can be easily solved using a supercomputer. This chapter shows the usefulness of supercomputers for solving electromagnetic problems requiring intensive computational techniques.

Chapter 2 is dedicated to the finite difference time domain technique, or FDTD which is the direct expression of Maxwell's equations (in space and time domain). This chapter provides an introduction to such techniques, which readers can explore in much more depths in reference [1]. This book was recently reviewed in the ACES Newsletter [2]. Though the FDTD method is not new, its wide acceptance and considerable use is directly related to the tremendous increase in speed and memory capacity of computers, which allowed for much more efficient discretization of space and increased accuracy. The FDTD method lends itself naturally to a supercomputer approach. The chapter starts with the discussion of the Yee algorithm and the derivation of the difference formulas directly from Maxwell's equations. The stability criteria are also discussed. The chapter ends with an example use of FDTD, the propagation of a pulse on a bent strip line - and an analysis of FDTD in dispersive media (useful in the exact analysis of electronic circuits). A particular feature of this chapter is that a listing of a FDTD code is given which has been optimized for supercomputers.

Chapter 3 addresses the well known subject of antenna analysis using integral equations. A historical background is presented on the analysis of wire type antennas, from the early work of Pocklington in the1930's through the development of microstrip antennas in the 1980's. The chapter contains ten sections and three appendices. In the first section the relationship between current distribution and radiation characteristics is established. This is followed by a discussion of current distribution on a straight wire conductor, in which the unknown current distribution is represented using an integral equation. The well known numerical technique of Moment Method follows. Section five describes Mei's integral equation for generalized wire conductors of arbitrary shape. This subject is also extended to other types of integral equations in the following sections. Antenna systems composed of wire and aperture are discussed. A set of integral equations for electric current on the wire and magnetic current in the aperture is derived. Finally, an integral equation for an arbitrary shaped wire antenna printed on a dielectric substrate is reviewed. The chapter ends with a FORTRAN code of a Method of Moment solution for a center-fed dipole antenna.

High frequency techniques such as Physical Optics are introduced in chapter 4. Again, the material is introductory in nature and a more detailed study of this subject can be pursued through the numerous references given at the end of the chapter. Physical Optics is an approximation method for determining the surface current, where it is assumed that the surface is locally planar and the reflection takes place according to Geometrical Optics. In Physical Optics the fields scattered from arbitrary shaped bodies are given by the radiation integral on the surface currents. Surface integration in Physical Optics is of lower efficiency but the predicted fields are uniform everywhere. Physical Optics is free of the discontinuities and singularities common in Geometrical Theory of Diffraction and Geometrical Optics. Physical Optics is widely used on antenna engineering problems such as reflector antennas. This chapter illustrates the basic procedure for Physical Optics and a few examples are discussed for better understanding. The chapter discusses the reduction of the radiation integrals in Physical Optics using stationary phase methods. Material that is not covered in this chapter is the extension of Physical Optics to the Physical Theory of Diffraction (developed by Ufimtsev) which is Physical Optics with correction terms, essentially merging the advantages of Physical Optics and Geometric Theory of Diffraction where the errors in Physical Optics are corrected by the Geometric Theory of Diffraction and the singularities of the latter are eliminated.

Chapter 5 addresses the wave scattering from inhomogeneous surfaces as encountered in radar, radio wave propagation, and remote sensing. This chapter is introductory in nature concerning surface scattering from rough surfaces. Because of the statistical nature of this work, probability theory and stochastic processes are discussed with wave theory. Rough surface scattering is somewhat similar to wave propagation in random media. However, the wave phenomena in a random medium and the wave scattering external to a random surface often have different characteristics (such as the localization phenomena in a random medium). If the conjugated surface is smooth enough relative to wavelength the incident wave can be regarded as reflected from the local tangential plane. This method is called Kirchhoff's approximation and is discussed in the book. This is the simplest technique in the study of rough surface scattering. Another method discussed in the chapter is that of surface perturbation. The wave field is expanded in powers of small roughness parameter and the perturbed wave equation is solved successively. If the surface roughness is not sufficiently smooth, the method of multiple scattering must be used. This is an area of active research, and an introduction to it is given in this chapter.

Chapter 6 is probably the most important chapter in the book, in this reviewer's opinion. This chapter explores the eigenfunction expansion method in boundary value problems of microwave circuits. The eigenfunction expansion method is a sort of mode-matching technique. It is used here to denote a numerical method for solving integral equations using Green's functions, which are expanded in a series of eigenfunctions. This chapter first discusses planar circuits, and then extends to three dimensional circuits. Both are based on the same analytical approaches using Green's functions. The differences in numerical formulation of the integral equations result in utterly different final expression forms. For example, in section 6.2 boundary value problems are reduced to the familiar electric circuit by introducing equivalent voltage and current. In section 6.3 boundary value problems are directly solved as electromagnetic wave problems using Maxwell's equations. In section 6.2 it is demonstrated that the mode impedance can be obtained via eigenmodes of the planar circuit, and the corresponding equivalent network can be represented by parallel resonators (which correspond to the eigenmodes) and their series connection with ideal transformers. In section 6.3 the eigenfunction method first formulates the boundary value problems of electromagnetic fields in the total structure in a set of coupled integral equations. These equations are then solved numerically by applying the Moment Method and reducing them to a set of linear equations.

The final chapter of the book deals with the rectangular boundary division method, which is widely applicable in microwave circuits. The total structure of microwave integrated circuits is not homogeneous since the circuits include both dielectric substrates and air. Electromagnetic waves of the hybrid mode which are neither purely TEM, TE, or TM can propagate along such planar waveguides with inhomogeneous medium. The cross sectional region of the transmission line structure is composed of connected rectangular sub-regions in the rectangular division model. The rectangular boundary division method is an analysis method based on the quasi-TEM wave approximation. It can be applied to effectively analyze complicated structures with partial inhomogeneity and multiconductors, taking into account the thickness of conductors. This method is proposed for characterization of transmission lines composed of connected rectangular regions. Because various structures can be treated effectively, it has been applied to the analysis and design of coupled transmission lines, the analysis of microstrip lines and coplanar waveguides. The method can be applied in cylindrical coordinates as well as in rectangular coordinates. The rectangular boundary division method combines the Fourier series expansion of potential functions and a variational method whose trial function is the potential distribution on boundary surfaces.

The book offers problems at the end of each chapter. I found the references to be up to date and numerous. The book can be recommended as a good reference book in electromagnetic computational methods and as a supplemental text in teaching graduate level electromagnetic theory.

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INDEX TO COMPUTER CODE REFERENCES FOR VOL. 10 (1995) OF THE ACES JOURNAL AND THE ACES NEWSLETTER

This computer code index is usually updated annually in the second issue of each volume of the ACES Newsletter.

LEGEND:

AJ	ACES Journal
AN	ACES Newsletter
SI	Special Issue
*	Pre- or postprocessor for another computational electromagnetics code
**	Administrative reference only: no technical discussion (This designation and index do not include bibliographic references)
Page no.	The first page of each paper in which the indicated code is discussed

NOTE: The inclusion of any computer code in this index does not guarantee that the code is available to the general ACES membership. Where the authors do not give their code a specific name, the computational method used is cited in the index. The codes in this index may not all be general purpose codes with extensive user-orientated features - some may only be suitable for specific applications. While every effort has been made to be as accurate and comprehensive as possible, it is perhaps inevitable that there will be errors and/or omissions. I apologise in advance for any inconvenience or embarrassment caused by these.

Duncan C Baker, Editor-in-Chief, ACES Journal.
7 February 1996.

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ABSTRACTS OF ACES JOURNAL PAPERS

VOLUME 10, 1995

This compilation of abstracts is updated annually and normally published in the second issue of the *ACES Newsletter*. The material was scanned in using a digital scanner and converted to text using a program for character recognition. The document was proofread only once. As Editor-in-Chief, I accept responsibility for any errors and/or omissions which appear in the text. I apologize in advance for any inconvenience or embarassment caused by these.

Duncan C. Baker, Editor-in-Chief, *ACES Journal*.
5 February, 1996.

THE NEC2 RADIATION PATTERNS OF UNDER-SEGMENTED WIRE GRID MODELS OF A FIGHTER AIRCRAFT COMPARED TO MEASUREMENTS

O. Givati and A.P.C. Fourie

This paper presents results of a NEC2 method of moments evaluation of VHF/UHF antennas on a wire grid model of a fighter aircraft. The study shows that practically useful radiation patterns results can be obtained when the grid model is considerably under-segmented in aircraft regions which are electrically far removed from the antennas. Normal modelling guide-lines requires approximately 35000 segments for the fighter grid model at 400 MHz; judicious under-segmentation gave useful results using a model comprising 5000 segments. This reduction in segments reduced computer time by a factor of 343 and memory requirements is reduced by a factor of 18. NEC2 radiation patterns are compared to measurements on a 1/lOth scale model which was performed in an anechoic chamber compact range. **[Vol. 10, No. 1 (1995), pp 5-14]**

A SURFACE INTEGRAL EQUATION FORMULATION FOR LOW CONTRAST SCATTERERS BASED ON RADIATION CURRENTS

Paul M. Goggans and Allen W. Glisson

A new surface integral equation formulation based on radiation currents is presented. Numerical problems have been observed when treating low contrast scatterers with surface integral equation formulations based on the total equivalent currents. These problems result because the total equivalent currents are large compared with the radiation currents for low contrast materials. The surface integral equation formulation presented here avoids this problem by solving directly for the radiation currents. **[Vol. 10, No. 1 (1995), pp 15-18]**

THE MEASURED EQUATION OF INVARIANCE METHOD APPLIED TO RANDOMLY ROUGH SURFACES

John B. Schneider and Shira Lynn Broschat

The Measured Equation of Invariance (MEI) method has received considerable attention recently. Unlike more traditional numerical techniques, MEI solutions are obtained by inversion of a relatively small and sparse matrix. Therefore, the MEI method can potentially provide a solution much more quickly than other techniques. To date, the MEI method has been applied primarily to discrete objects. In this paper, bistatic radar cross sections for one-dimensional, perfectly conducting, randomly rough surfaces are obtained using the MEI method. The implementation suitable for this problem requires some modification and enhancement of the original algorithm to achieve the desired accuracy. These algorithmic changes can be applied to the discrete scattering problem as well. Monte Carlo results for the bistatic scattering cross section for surfaces with Gaussian statistics and satisfying a Gaussian roughness spectrum are compared to those from another technique and excellent agreement is obtained. **[Vol. 10, No. 1 (1995), pp 19-30]**

WIREGRID: A NEC2 PRE-PROCESSOR

C. F. du Toit, D.B. Davidson

WIREGRID is a pre-processor for the widely used public domain method of moments computer code NEC2. WIREGRID was developed for modelling metallic structures using a mesh of wires. In particular, it has powerful facilities for controlling the density of the mesh, permitting the same basic model to be used for different frequencies, with the code automatically generating a suitable mesh for a particular frequency. WIREGRID is not limited to generating wire meshes: it can also be usefully applied to true thin-wire modelling, for instance for Yagi-Uda and log-periodic antennas. In this paper, the basic philosophy of the code is described, and the code capabilities are detailed. Sufficient detail is presented so that the paper can serve as a reference for code users. The meshing algorithm is briefly described. An example is shown of the automatic mesh generation capabilities applied to an automobile. WIREGRID is available in the public domain via anonymous ftp; details of the ftp sites and hardware requirements are given in the appendices. [Vol. 10, No. 1 (1995), pp 31-39]

A GUIDE TO IMPLEMENTATIONAL ASPECTS OF THE SPATIAL DOMAIN INTEGRAL EQUATION ANALYSIS OF MICROSTRIP ANTENNAS

Louis T. Hildebrand & Derek A. McNamara

In the analysis of microstrip radiating structures integral equation methods rate among the more accurate approaches. By far the most demanding part in the use of these methods is the actual numerical implementation. This paper presents a detailed illustrated description of the numerical implementation of a spatial domain mixed-potential integral equation analysis of microstrip radiating structures. [Vol. 10, No. 1 (1995), pp 40-51]

PERFORMANCE OF A CHARACTERISTIC-BASED, 3-D, TIME-DOMAIN MAXWELL EQUATIONS SOLVER ON THE INTEL TOUCHSTONE DELTA

J. S. Shang & Kueichien C. Hill and Donald A. Calahan

A characteristic-based, windward numerical procedure for solving three-dimensional Maxwell equations in the time domain has been successfully ported to the Intel Touchstone Delta multicomputer. The numerical results by concurrent computation duplicated the earlier simulations of an oscillating electric dipole on a vector processor and compared well with the exact solutions. The parallelized code is scalable up to 512 nodes and incurs only up to 7.6% performance degradation. The sustained data processing rate is clocked at 6.551 Gigaops. However, the data I/O process is unscalable on the shared memory system. [Vol. 10, No. 1 (1995), pp 52-62]

ON THE APPLICABILITY OF THE BICONJUGATE GRADIENT FFT METHOD FOR THE THIN CONDUCTING PLATE PROBLEM

T. V. TRAN and A. McCOWEN

The application of the Biconjugate Gradient FFT method to the thin conducting plate problem is investigated. Upon comparing with a Conjugate Gradient FFT method, it is found that the Biconjugate Gradient solution requires a relatively larger error tolerance to achieve a comparatively well-behaved current distribution. Coupled with the requirement of only one matrix-vector product per iteration, the computational cost of the Biconjugate Gradient method is, thus, much smaller than those previously reported in the literature. Of particular importance is the use of the incident electric field as a starting estimate to alleviate the non-convergence behaviour which is usually associated with the application of a Biconjugate Gradient approach to conducting plates at grazing angle. For other angles of incidence, it is shown that this procedure also accelerates the resulting convergence rates as compared to those obtained by simply using zero as an initial estimate. [Vol. 10, No. 1 (1995), pp 63-68]

REVISED INTEGRATION METHODS IN A GALERKIN BOR PROCEDURE

David R. Ingham

Several relatively simple numerical changes improve the speed and accuracy of the early Mautz and Harrington discretization procedure for boundary element method calculations of scattering from axially symmetric bodies. This method is still in common use in programs such as CICERO and GRMBOR. For a fixed set of geometry points, changes in the azimuthal (ϕ) integration reduce computer time, especially when lossy materials are involved. Changes in the integration along the generating curve (t) improve accuracy. The most interesting of these is the use of the equal area rule from parallel wire modeling of solid surfaces to answer the old question of the optimal constant for dealing with an integrable singularity in some of the t integrals. Some of these changes are applicable to a variety of integral equations and boundary conditions. Most of them can be implemented with little programming effort. Tests are shown for difficult cases involving spheres, and Mie series calculations are used for comparison. [Vol. 10, No. 2 (1995), pp 5-16]

HIGHER-ORDER FDTD METHODS FOR LARGE PROBLEMS

Charles W. Manry Jr, Shira L. Broschat, and John B. Schneider

The Finite-Difference Time-Domain (FDTD) algorithm provides a simple and efficient means of solving Maxwell's equations for a wide variety of problems. In Yee's uniform grid FDTD algorithm the derivatives in Maxwell's curl equations are replaced by central difference approximations. Unfortunately, numerical dispersion and grid anisotropy are inherent to FDTD methods. For large computational domains, e.g., ones that have at least one dimension forty wavelengths or larger, phase errors from dispersion and grid anisotropy in the Yee algorithm (YA) can be significant unless a small spatial discretization is used. For such problems, the amount of data that must be stored and calculated at each iteration can lead to prohibitive memory requirements and high computational cost. To decrease the expense of FDTD simulations for large scattering problems two higher-order methods have been derived and are reported here. One method is second-order in time and fourth-order in space (2-4); the other is second-order in time and sixth-order in space (2-6). Both methods decrease grid anisotropy and have less dispersion than the YA at a set discretization. Also, both permit a coarser discretization than the YA for a given error bound.

To compare the accuracy of the YA and higher-order methods both transient and CW simulations have been performed at a set discretization. In general, it has been found that the higher-order methods are more accurate than the YA due to the reduced grid anisotropy and dispersion. However, the higher-order methods are not as accurate as the YA for the simulation of surface waves. This is attributed to the larger spatial stencil used in calculating the fields for the higher-order methods. More research is needed to examine the accuracy of higher-order methods at material boundaries. [Vol. 10, No. 2 (1995), pp 17-29]

RADAR CROSS SECTION OF A RECTANGULAR CAVITY- A MASSIVELY PARALLEL CALCULATION

L. D. Vann, L.T. Willet, J.S. Bagby, and H.F. Helmken

A sequential code that calculates the radar cross section of a rectangular waveguide cavity was modified to execute on a MasPar MP-1 massively parallel computer with a SIMD architecture. The code uses the mode matching method of analysis to produce a set of matrix equations. Steps taken to accomplish the parallelization are discussed and some specific examples of program modification are presented. Timing results for wideband data are given that demonstrate the power of parallel computers for this type of application. Suggestions are made for further improvements as increased memory space becomes available. [Vol. 10, No. 2 (1995), pp 30-45]

A NUMERICAL TECHNIQUE TO DETERMINE ANTENNA PHASE CENTER LOCATION FROM COMPUTED OR MEASURED PHASE DATA

Steven R. Best, James M. Tranquilla

In many antenna applications, it is a requirement to have knowledge of the antenna phase center properties. Many interpretations of antenna phase center and its apparent location exist. This paper will present a formulation for determination of antenna phase center location derived using the antenna phase response. A fortran program, developed from the formulations, is used to calculate phase center location for several examples which include both computed and simulated measured phase data. A simple numerical technique is presented that processes measured phase data allowing accurate phase center determination. [Vol. 10, No. 2 (1995), pp 46-62]

CONFORMAL ARRAY DESIGN SOFTWARE

H.K. Schuman

A powerful conformal array design computer program can be developed by modification of a physical optics based array fed reflector analysis computer program. [Vol. 10, No. 2 (1995), pp 63-74]

COMPARISON OF THE INPUT IMPEDANCE OF MONOPOLE ANTENNAS OBTAINED BY NEC, MININEC, AND MEASUREMENTS

R. J. Bauerle and J. K. Breakall

This paper compares the input impedance of monopole antennas numerically calculated by NEC and MININEC with experimental results. This comparison determines the limitation of these two computer codes used for modeling more complicated structures.

Two groups of monopoles are considered. The first group consists of eight electrically thin monopoles of length .28 meters (.235 wavelengths at 252 MHz) and radii of .4064, . 7874, 1.168, 1.562, 2.390, 3.162, 6.350, and 7.920 millimeters (.341E-3, .661E-3, .981E-3, 1.31E-3, 2.01E-3, 2.66E-3, 5.33E-3, and 6.65E-3 wavelengths at 252 MHz). For this group, impedance calculations were compared to measurements over the band of 237-267 MHz. The second group consists of five electrically thick monopoles of length .2 wavelengths and radii of .0509, .0635, .0847, .1129, and .1270 wavelengths. For the second group impedance calculations were compared with measurements of tubular monopoles with flat ends.

The results of this paper show that the extended kernel option of NEC predicted measured monopole impedance measurements more accurately than MININEC. **[Vol. 10, No. 2 (1995), pp 75-85]**

ACCURATE MODELING OF STEPPED-RADII ANTENNAS

A. I. Bauerle and J. K. Breakall

The LP8, eight element, log periodic antenna made by M^2 Enterprises has recently been modeled at Penn State University using both Version 2 and 4 of the Numerical Electromagnetics Code (NEC). The antenna has a stepped-radii element construction and operates from 10 to 30 MHz. The stepped-radii element construction is difficult to model using NEC Version 2. To model a stepped-radii antenna with this version, equivalent lengths of constant radii are calculated using another method of moments program called ELNEC. These equivalent lengths replaced the original stepped radii elements of the log periodic antenna during the modeling. Fortunately, NEC Version 4 can simulate the stepped-radii elements directly, which makes the modeling procedure much easier and accurate. Both NEC models show good agreement with the measurements when compared to VSWR measurements. The authors hope that this paper will help others with similar modeling problems who cannot yet obtain NEC Version 4. **[Vol. 10, No. 2 (1995), pp 86-95]**

MUTUAL VALIDATION OF THREE PROGRAMS FOR NUMERIC ANTENNA COMPUTATIONS

Andrew A. Efanov, Harald Schopf and Bernhard Schnizer

The numerical results obtained by three different codes, GALNEC, WARAN and NEC-2 are compared for thin dipoles and thick ones with hemispherical end caps and for arrays of such collinear dipoles. The electric field integral equation and Galerkin's method are used in the code GALNEC where solid thick dipole bodies are implemented. Mei's (1965) integral equation and collocation technique are wed in the code WARAN, where thick dipoles are simulated as arrays of thin wires. Good agreement has been obtained for current distributions and input and mutual impedances. **[Vol. 10, No. 2 (1995), pp 96-101]**

SIMPLE FINITE ELEMENT SOLUTIONS FOR EDDY CURRENT LOSSES IN PIPE-TYPE CABLES

T. Loga, F.S. Chute, and F.E. Vermeulen

This paper outlines a simple finite element approach for computing eddy current losses in pipe-type cables Essentially, what is solved for is the eddy current loss in a metallic shell that encompasses one or more power frequency currents, flowing parallel to the longitudinal axis of the shell. The traditional cross sectional model for this type of problem involves an open boundary, which can present difficulties for conventional finite element methods, although some success has recently been reported with asymptotic boundary conditions [1]. For many practical cases, the simplest way to bypass this obstacle is to impose an approximate boundary condition, H= 0, at the outer surface of the metal shell It is demonstrated in this paper that this approximate boundary condition is quite accurate if the shell is, as a rule of thumb, at least three skin depths thick. **[Vol. 10, No. 2 (1995), pp 102-109]**

MODEL-BASED PARAMETER ESTIMATION IN ELECTROMAGNETICS: III--Applications to EM Integral Equations

E. K. Miller

Problem solving in electromagnetics, whether by analysis, measurement or computation, involves not only activities specific to these particular categories, but also some concepts that are common to all. Fields and sources are sampled as a function of time, frequency, space, angle, etc. and boundary conditions are satisfied through mathematical imposition or experimental conditions. The source samples, usually the unknowns in a problem, are found numerically or analytically by requiring them to satisfy both the appropriate form of Maxwell's Equations as relationships between them, together with the applicable boundary conditions. Alternatively, source samples may be measured under prescribed experimental conditions.

These sampled relationships can be interpreted from the viewpoint of signal and information processing, and are mathematically similar to various kinds of filtering operations. It is this similarity that is discussed here in the context of modelbased parameter estimation, where the dependence of electromagnetic fields and sources that produce them are both regarded as generalized signals.

MBPE substitutes the requirement of obtaining all samples of desired quantities (physical observables such as impedance, gain, RCS, etc. or numerical observables such as impedance-matrix coefficients, geometrical-diffraction coefficients, etc.) from first-principles models (FPMs) or from measured data (MD) by instead using a reduced-order, physically-based approximation, a fitting model (FM), to interpolate between, or extrapolate from, FPM or MD samples. When used for electromagnetic observables, MBPE can reduce the number of samples that are required to represent responses of interest, thus increasing the efficiency of obtaining them. When used in connection with the FPM itself, MBPE can decrease the computational cost of its implementation. Some specific possibilities for improving FPM efficiency are surveyed, specifically in terms of using FMs to simplify frequency and spatial variations associated with FPMs. Examples of MBPE applications are included here as well as speculative possibilities for their further development in improving FPM performance. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 9-29]**

AN EXAMINATION OF THE EFFECT OF MECHANICAL DEFORMATION ON THE INPUT IMPEDANCE OF HF LPDA'S USING MBPE

J. Tobias de Beer, and Duncan C. Baker

This article examines the application of Model Based Parameter Estimation (MBPE) to the evaluation of the input impedance of HF Log Periodic Dipole Arrays (LPDA) during mechanical deformation. A study of cases of lengthening, shortening and displacing one element as well as the effect of mechanical sagging of the array is made. It is found that MBPE is a useful tool for minimizing computations and/or measurements in the study of mechanical deformation. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 30-37]**

CURRENT-BASED HYBRID MOMENT METHOD ANALYSIS OF ELECTROMAGNETIC RADIATION AND SCATTERING PROBLEMS

Ulrich Jakobus and Friedrich M. Landstorfer

A current-based hybrid method combining the method of moments (MM) with asymptotic current expansions for the higher frequency range is presented for the analysis of arbitrarily shaped, three-dimensional, perfectly conducting electromagnetic radiation and scattering problems. Some examples demonstrate the drastic saving in memory requirement and CPU-time when applying the hybrid method as compared to the conventional MM. Even though the proposed method is a frequency domain formulation, some time domain results based on a Fourier transform are presented as they show an accurate description of diffracted and creeping waves. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 38-46]**

HYBRID METHOD OF MOMENTS SOLUTION FOR A PERTURBED DIELECTRIC CIRCULAR CYLINDER

William D. Wood, Jr.

A hybrid technique is developed? using the integral equation/moment method solution approach with non-free space Green's functions, for a class of scattering problems involving nearly-circular 2-D dielectric cylinders under TMz illumination. The technique is applicable to other nearly-canonical 2-D penetrable scatterers, and may be extended to certain 3-D geometries. Applications to several 2-D geometries are demonstrated, with scattering predictions compared to those from a standard moment method code. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 47-52]**

A LOW-FREQUENCY FORMULATION OF THE METHOD OF MOMENTS VIA SURFACE CHARGES

Nunzio Esposito. Antonino Musolino, Marco Raugi

In this paper a formulation of the method of moments for the analysis of low frequency problems is presented.

In the considered frequency range, the integral solution of Maxwell equations in terms of magnetic vector potential and electric scalar potential respectively function of currents and charges is obtained imposing the Coulomb gauge.

By combining Gauss law and current continuity at the boundaries among regions with different conductivity a first set of equations is obtained. Writing Ohm's law inside the conductive regions another integral equation set that allows the determination of the conduction current and surface charges unknowns is obtained. The method of moments is then applied to this system of equations.

The use of pulse functions as subsectional bases allows a quick matrix set up especially when regular volume shapes are selected. Calculated results are compared with results obtained with other methods relating to benchmark problems. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 53-57]**

A STUDY OF A RECENT, MOMENT-METHOD ALGORITHM THAT IS ACCURATE TO VERY LOW FREQUENCIES

M. Burton and S. Kashyap

We give an alternative description of a recently published moment-method algorithm, which uses divergence-free and rotation-free basis functions to maintain accuracy down to very low frequencies. The basic algorithm is restricted to simply-connected and non-self-intersecting surfaces. But this restriction has little practical impact--we show how multiply-connected surfaces, self-intersecting surfaces, and one-sided surfaces can easily be converted to the required topology without changing the solution. We examine a claim that the impedance matrix is diagonally dominant, which implies a guaranteed-to-converge Jacobi type of iterative solution of the matrix equation. Finally, we show how to control catastrophic-cancellation errors that occasionally appear in the voltage vector. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 58-68]**

A STUDY OF TWO NUMERICAL SOLUTION PROCEDURES FOR THE ELECTRIC FIELD INTEGRAL EQUATION AT LOW FREQUENCY

Wen-Liang Wu, Allen W. Glisson, and Darko Kajfez

The numerical solution of the Electric Field Integral Equation (EFIE) using two different lowfrequency formulations is investigated. The two procedures are implemented for the triangular patch modeling procedure and results obtained for both methods are compared with the original triangular patch EFIE solution. The comparisons are made on the basis of the computed current values and the inverse condition number of the moment matrix. It is observed that the condition number of the matrix can be significantly different between the two low frequency formulations and that the method used to evaluate the forcing function can affect the results both in the low and high frequency ranges. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 69-80]**

ELECTROMAGNETIC SCATTERING FROM TWO DIMENSIONAL ANISOTROPIC IMPEDANCE OBJECTS UNDER OBLIQUE PLANE WAVE INCIDENCE

Ahmed A. Kishk and Per-Simon Kildal

The surface integral equations of a two dimensional (2D) anisotropic impedance object is formulated to obtain the electromagnetic scattered fields due to oblique plane wave incidence. The surface impedance is anisotropic with arbitrary principle directions. The moment method with pulse basis functions and point matching is used to reduce the surface integral equations to a matrix equation. Four different formulations are generated for the problem. The surface current distributions and the scattered farfields are verified against the analytical series solutions of circular impedance cylinders. Very good agreement between the numerical and the analytical solutions is obtained. A rectangular cylinder made of four soft surfaces is analyzed for oblique incidence to verify that the results behave as expected. The computer code is also verified by comparing the solutions of the different formulations against each other. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 81-92]**

ELECTROMAGNETIC SCATTERING BY AN ARBITRARILY SHAPED SURFACE WITH AN ANISOTROPIC IMPEDANCE BOUNDARY CONDITION

Allen W. Glisson, Mark Orman, Frank Falco, and Donald Koppel

The problem of electromagnetic scattering from arbitrarily shaped, imperfectly conducting surfaces that can be represented by an anisotropic impedance boundary condition is solved numerically using the electric field integral equation and a triangular patch model for the surface. The anisotropic impedance boundary condition function is described by a constant surface dyadic within each triangular face. The procedure is validated by comparison of numerical results obtained with the triangular patch model with body of revolution model results for problems involving scattering by spheres and cylinders having uniform or anisotropic impedance boundary conditions. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 93-106]**

PARAMETRIC MAPPING OF VECTOR BASIS FUNCTIONS FOR SURFACE INTEGRAL EQUATION FORMULATIONS

Andrew F. Peterson and Keith R. Aberegg

A parametric mapping of vector basis functions is presented for curved-patch discretizations of surface integral equations. The mapping of the vector basis function maintains the normal continuity of the surface current density at cell boundaries, and is therefore suitable for use with the electric-field integral equation. Expressions for the matrix elements associated with the electric and magnetic field integral equations are developed. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 107-115]**

A TECHNIQUE FOR AVOIDING THE EFIE "INTERIOR RESONANCE" PROBLEM APPLIED TO AN MM SOLUTION OF ELECTROMAGNETIC RADIATION FROM BODIES OF REVOLUTION

Pierre Steyn and David B. Davidson

Various surface integral equation formulations, including the electric (EFIE) and magnetic (MFIE) field integral equations, suffer from what is commonly known as the "interior resonance" problem. There are a number of remedies to this problem of which many involve modifying the integral equation formulation and result in increased computational effort and computer storage requirements. In an attempt to avoid this the application of a remedy, proposed in the literature, which requires no modification to the formulation has been investigated. This involves the detection of interior resonance frequencies and correction of the current by removing the mode responsible for the 'interior resonance". In the literature, the success of the remedy has been demonstrated for two-dimensional scattering problems involving PEC cylinders. In this work it is demonstrated that, while the correction of the MM (moment method) solution is successful when an "interior resonance" has been detected, the detection of the interior resonance frequencies can be extremely difficult in an MM solution of radiation from composite bodies of revolution. In fact, a foolproof computational algorithm for detecting interior resonance frequencies for this class of problems is yet to be developed. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 116-128]**

COMPUTATION OF MULTIPOLE MOMENTS FOR SHORT THIN WIRE CHIRAL STRUCTURES

Isak Petrus Theron, David Bruce Davidson and Johannes Hendrik Cloete

This paper considers the computation of the multipole moments of small chiral wire structures. The multipole moments are reviewed and it is shown that the charge induced on the wire must be accurately computed. A quasistatic thin-wire Galerkin Method of Moments formulation has been developed to numerically compute the charge distribution.

The chiral structures under consideration are on the borderline of "thin" and a Body of Revolution Method of Moments formulation has also been developed for use as a check on the accuracy of the thin-wire approximations. It is shown that the "standard" thin-wire formulation is not sufficiently accurate, but the relatively simple addition of an end-cap greatly improves the convergence and accuracy of the formulation with acceptable computation cost.

Finally, the formulation is extended to include bent wires, permitting the electric and magnetic dipole moments as well as the electric quadrupole moment to be calculated for a small chiral structure. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 129-138]**

APPLICATION OF THE UMOM FOR THE COMPUTATION OF THE SCATTERING BY DIELECTRICS COATED WITH WEAKLY NONLINEAR LAYERS

Salvatore Caorsi, Andrea Massa, and Matteo Pastorino

The paper describes an iterative approach to the computation of the electromagnetic scattering by isotropic, dielectric objects partially made of weakly nonlinear materials The approach is started by using a perturbative moment-method solution based on the Sherman-Morrison-

Woodbury formula. The nonlinearity is assumed to be of the Kerr type, i e, the dielectric permittivity depends on the square amplitude of the electric field The bistatic scattering width and the field distribution are computed for some test cases, in particular, for infinite cylinders coated and filled with nonlinear materials The convergence of the medium is numerically evaluated and the results are compared with those obtained by the iterative distorted-wave Born approximation. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 139-145]**

EM SIMULATION OF PACKAGED MMIC AND MICROSTRIP ANTENNAS USING "MICROWAVE EXPLORER"

Ali Sadigh, Krishnamoorthy Kottapalli, Peter Petre

A moment method solution is presented for the full-wave electromagnetics analysis of multilayered planar structures of arbitrary shape. The mathematical formulation is based on the spectral domain integral equation and the Galerkin's testing procedure. The method is applied to shielded MMIC as well as radiating systems in the open environment. The inclusion of vertical current elements in the solution enables the method to analyze structures with vias and air bridges in both packaged and open environments Since a periodic structure approach is used in the formulation, extension to the analysis of infinite and finite antenna arrays becomes rather straightforward. Simulated results, obtained from our electromagnetic simulator "Microwave Explorer," are presented and compared with the available data to demonstrate the versatility and the accuracy of the method The numerical results presented include S-parameters and farfield data. **[Vol. 10, No. 3 (1995), Special Issue on Advances in the Application of Method of Moments to Electromagnetic Radiation and Scattering Problems, pp 146-152]**

VIEWS OF THE 12TH ANNUAL REVIEW
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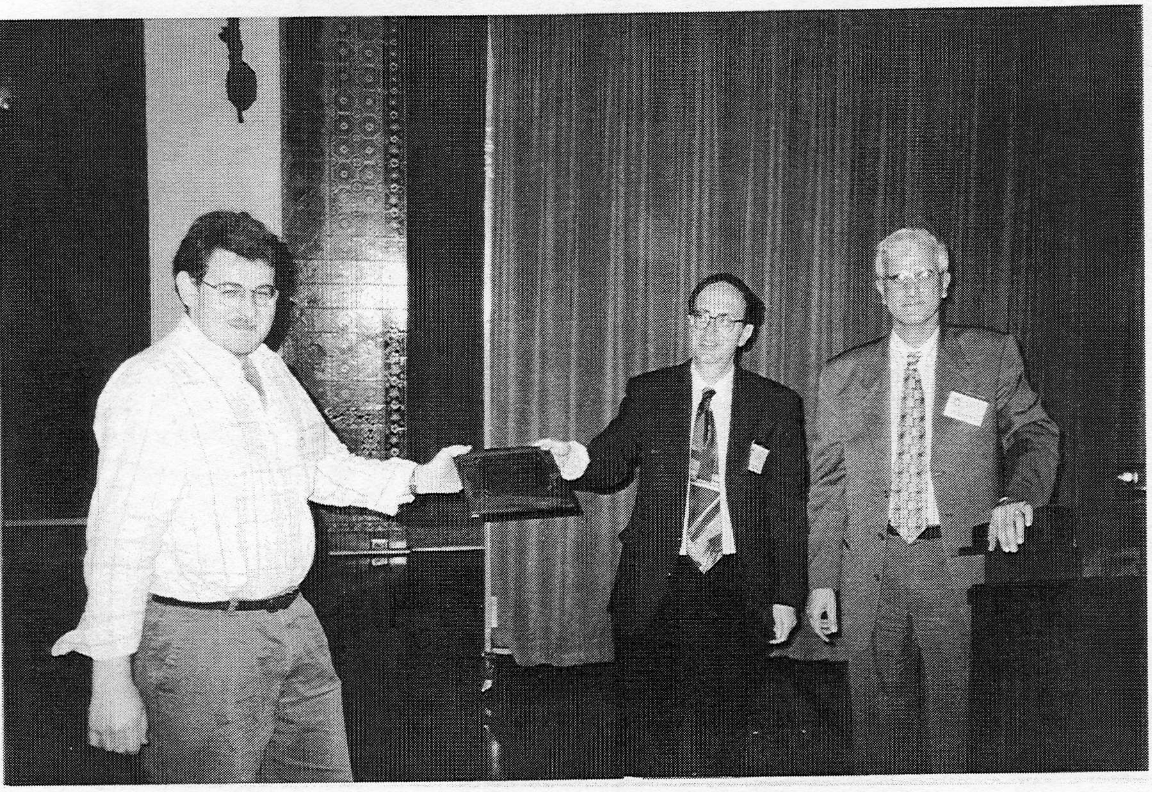

Andy Peterson, ACES Financial Committee Chairman and past Treasurer receives Mainstay Award from John R. Brauer and Hal Sabbagh

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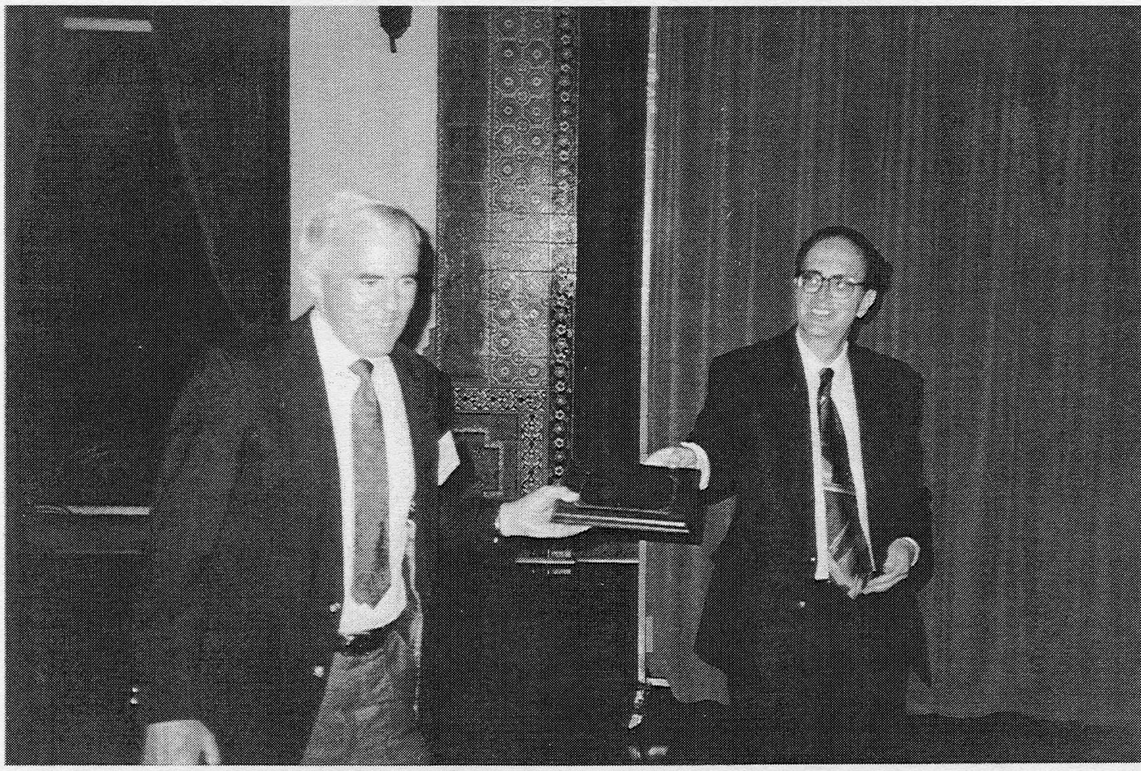
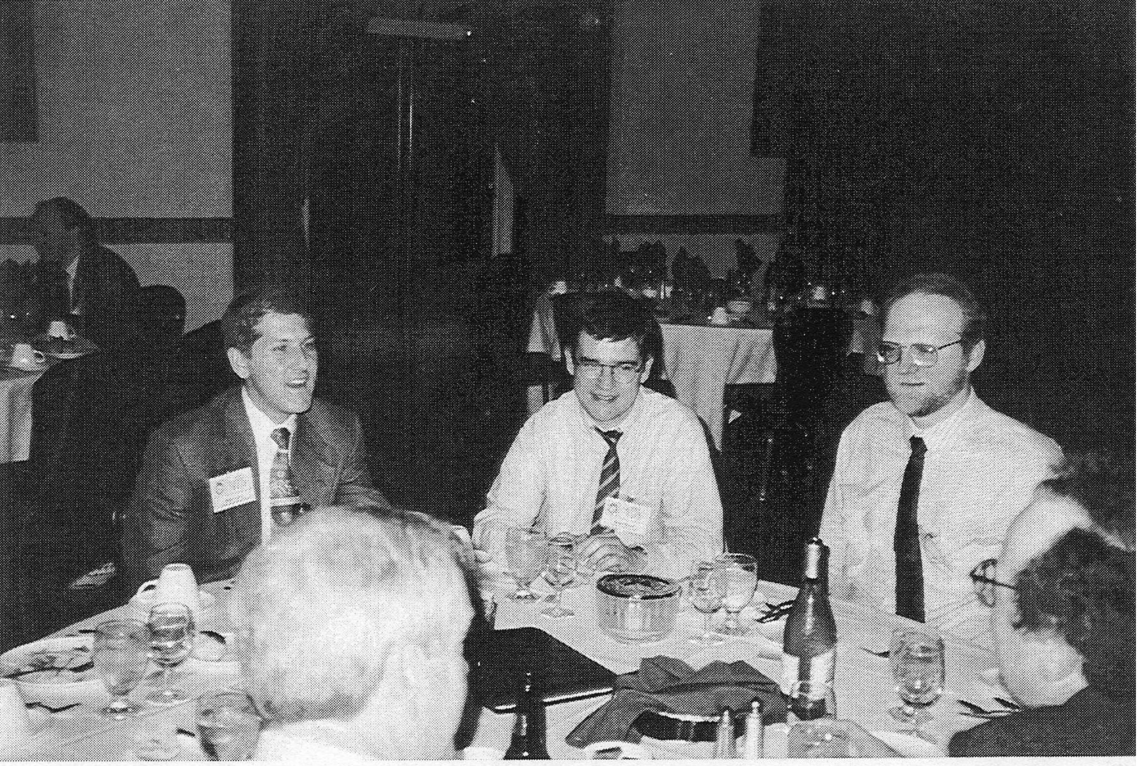
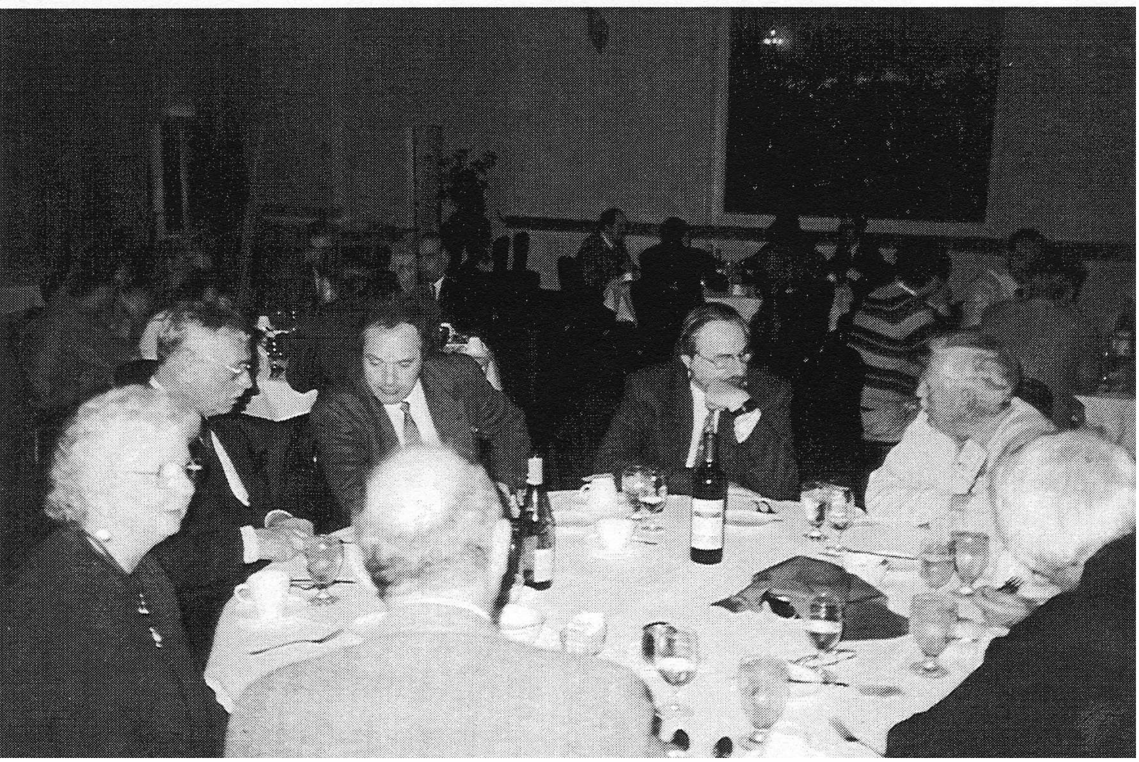


Jerry Burke accepting The 1996 Exemplary Service Award for consistent and sustained contributions to the "Modeler's Notes"column of the Newsletter.

Ulrich Jakobus accepting The 1996 Outstanding Paper Award, which he co-authored with Friedrich M. Landstorfer

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WE WERE NOT ABLE TO IDENTIFY ALL THE ATTENDEES, IN THE PICTURES, ON PAGES 71 THROUGH 75, SO IN ORDER NOT TO OFFEND, WE DID NOT IDENTIFY ANYONE.

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1997 ACES Symposium

Sponsored by:	ACES, NPS, DOE/LLNL, U of KY, U of IL, DOD, SIAM and AMTA
In cooperation with:	The IEEE Antennas and Propagation Society, the IEEE Electromagnetic Compatibility Society and USNC/URSI

THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY

CALL FOR PAPERS

The 13th Annual Review of Progress in Applied Computational Electromagnetics

Papers may address general issues in applied computational electromagnetics, or may focus on specific applications, techniques, codes, or computational issues of potential interest to the Applied Computational Electromagnetics Society membership. Area 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	wave propagation
radar imaging	radar cross section
shielding	bioelectromagnetics
EMP, EMI/EMC	visualization
dielectric & magnetic materials	inverse scattering
microwave components	MIMIC technology
fiberoptics	remote sensing & geophysics
communications systems	propagation through plasmas
eddy currents	non-destructive evaluation

- Partial list of techniques:

frequency-domain & time-domain techniques
integral equation & differential equation techniques
finite difference & finite element analysis

diffraction theories	physical optics
modal expansions	perturbation methods
hybrid methods	moment methods
wavelet & multipole techniques	em modeling methods

INSTRUCTIONS FOR AUTHORS AND TIMETABLE

For both summary and final paper, please supply the following data for the principal author: name, address, Email address, FAX, and phone numbers for both work and home.

October 25, 1996: Submission deadline. Submit four copies of a 300-500 word summary to the Technical Program Chairman.
November 25, 1996: Authors notified of acceptance
January 10, 1997: Submission deadline for camera-ready copy. The recommended paper length is 6 pages, with 8 pages as a maximum, including figures.

The registration fee per person for the Symposium will be approximately $245 for ACES Members; $285 for non-members, $115 for Student, and $150 for Unemployed/retired. The exact fee will be announced later. All Conference participants are required to register for the Conference and to pay the indicated registration fee.

SHORT COURSES

Short courses will be offered in conjunction with the Symposium covering numerical techniques, computational methods, surveys of EM analysis and code usage instruction. It is anticipated that short courses will be conducted principally on Monday, March 17 and Friday, March 21. The fee for a short course is expected to be approximately $90 per person for a half-day course and $140 for a full-day course, if booked before March 3, 1997. Full details of the 1997 Symposium will be available by November 1996. Short Course attendance is not covered by the Symposium Registration Fee!

EXHIBITS

Vendor booths and demonstrations will feature commercial products, computer hardware and software demonstrations, and small company capabilities.

7TH INTERNATIONAL IGTE SYMPOSIUM
ON
NUMERICAL FIELD CALCULATION
IN ELECTRICAL ENGINEERING

SEPTEMBER 23-25, 1996, GRAZ, AUSTRIA

A TEAM workshop is scheduled for September 26, 1996.

The aim of the 7th International IGTE Symposium on Numerical Field Calculation in Electrical Engineering is to provide a special forum for presentation of new developments in the numerical calculation of fields in electrical engineering. In addition, the International IGTE Symposium in Graz traditionally serves as a bridge between researchers of Western and Eastern European countries.

Topics of interest include static and quasi-static fields, wave propagation, optimization and inverse problems, biomedical problems, distant learning utilizing internet facilities like World-Wide-Web browsers and applications in various areas of electrical engineering.

Selected papers from this years symposium will be published in a special issue of the ACES journal.

The venue of the IGTE Symposium, the city of Graz, is located in the center of Europe, combining both the historical flair of a medieval town center and the modern life of a University town.

Additional information about the Symposium is available via World Wide Web:

http://www-igte.tu-graz.ac.at

For further details, please use the electronic services below. Communications and correspondence concerning both the Symposium and the TEAM workshop should be addressed to

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CALL FOR PAPERS

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

COMPUTATIONAL ELECTROMAGNETICS AND HIGH-PERFORMANCE COMPUTING

The Applied Computational Electromagnetics Society is pleased to announce the publication of a 1998 Special Issue of the *ACES Journal on Computational Electromagnetics and High-Performance Computing*. The primary objective of this special issue is to present a survey of the present state of the art of high-performance computing applied to computational electromagnetics.

Papers submitted should concentrate on computational aspects of electromagnetics: these include problem sizes; operation counts; parallel algorithms; and hardware aspects (although the last should avoid great technicalities). High-performance computing includes supercomputing, high-performance workstations and multi-processor networks. Complete simulation packages that consider the integration of mesh generation, electromagnetic solvers, and post-processing are especially relevant. Algorithms developments (such as the Fast Multipole Method) are only appropriate in this context if specifically related to high speed computation. Similarly, papers dealing only with high speed computation, without a CEM application, will be of limited suitability.

SUGGESTED TOPICS

- Supercomputers
- High-performance workstations
- Multi-processor networks
- Performance modelling
- Optimization methods
- Adaptive methods
- Parallel environments - especially portable ones such as PVM
- Computational Electromagnetics Applications including: Moment Method/Integral and Integro-Differential Equation methods; Finite Element method; Finite Difference Time Domain method; Transmission Line Modeling method; Asymptotic methods (GTD, UTD, etc); other methods such as MMP; Linear Algebra techniques for these methods where appropriate.

DEADLINE FOR PAPERS IS JULY 1, 1997

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to avoid possible confusion, to:

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

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

For the ***ACES NEWSLETTER*** send copy to Ray Perez in the following formats:

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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, WORDSTAR , and LATEX 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.

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