APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

Vol. 11 No. 1 March 1996

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ACES NEWSLETTER AND JOURNAL COPY INFORMATION

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

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

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

1. A hardcopy.
2. Camera ready hardcopy of any figures.
3. If possible also send text on a floppy disk. We can read any version of MICROSOFT-WORD and ASCII files on both IBM and Macintosh disks. On IBM disks we can also read WORDPERFECT, 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.

NEWSLETTER ARTICLES AND VOLUNTEERS WELCOME

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

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OFFICER'S REPORTS

PRESIDENT'S COMMENTS

As I write these comments on 13 January 1996, I can look out my office window and see the effects of the Great Northeast (and Midwest) Blizzard of '96. It is impressive, and perhaps even measures up to the Great Blizzard of '78. There's a lot of snow on the ground, and that's very pretty, but it's not quite as cold as it was in '78, and that's very pretty, too. Some of the Western ski resorts were complaining about the lack of snow; too bad they didn't look further east, where we have plenty to spare. I know that the West has been a little skimpy in the snow department, because I just drove my daughter to Tucson, Arizona, where she is enrolled at the University of Arizona. The weather there was 79 degrees; it was the first time I had been warm since September, it seems.

But now it's March in Monterey, and there is no snow, and we have our Twelfth Annual Review to keep us warm. Dick Gordon and his crew have done an excellent job in developing a program for ACES'96. Everybody, whether a skier or not, whether from the Great Northeast (and Midwest) to the Great Southwest, will enjoy this show. If you are attending this Review for the first time, you should note the great variety of papers being presented, and the international quality of the attendees. I hope that this will inspire you to present a paper next year, and, perhaps to offer your services to ACES as a committee worker. You'll get a good warm feeling if you do, and that's no snow job. Have a good time at the conference.

I have just received the news that our good friend and colleague (and a past-president of ACES), Prof. Stan Kubina, was elected to the grade of IEEE Fellow. His citation reads, 'For leadership in computational electromagnetics for EMC analysis and design and in electrical engineering education'. ACES supported Stan's nomination, so I know that you will all join me in congratulating Stan.

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THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY, INC.

NOTICE OF THE ANNUAL BUSINESS MEETING

Notice is hereby given that the annual business meeting of the Applied Computational Electromagnetics Society, Inc. will be held on Tuesday 19 March 1996, in 102 Glasgow Hall at the Naval Postgraduate School, Monterey, CA. The meeting is scheduled to begin at 7:30 AM PST for purposes of:

1. Receiving the Financial Statement and Treasurer's Report for the time period ending 31 December 1995.
2. Announcement of the Ballot Election of the Board of Directors.

By order of the Board of Directors
Perry Wheless, Secretary

ANNUAL REPORT 1995

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

MEMBERSHIP REPORT

As of 31 December 1995, the paid-up membership totaled 466, with approximately 38% of those from non-U.S. countries. There were 9 students, 80 industrial (organizational) and 377 individual members. The total membership has increased by 3% since 1 Jan 1995, with non-U.S. membership increasing by 24%.

Perry Wheless, Secretary

MEMBERSHIP RATES EFFECTIVE 1 APRIL 1995

AREA	INDIVIDUAL SURFACE	INDIVIDUAL AIRMAIL	ORGANIZATIONAL (AIRMAIL ONLY)
US & CANADA	$65	$65	$115
MEXICO,CENTRAL & SOUTH AMERICA	$68	$70	$115
EUROPE FORMER USSR TURKEY SCANDINAVIA	$68	$78	$115
ASIA, AFRICA MID EAST, PAC RIM	$68	$85	$115

1995 FINANCIAL REPORT

ASSETS

BANK ACCOUNTS	**1 JAN 1995**	**31 DEC 1995**
MAIN CHECKING	43,650	31,092
EDITOR CHECKING	2,373	3,002
SECRETARY CHECKING	3,952	4,039
SAVINGS	311	317
CREDIT CARD	5,035	57,680
CD #1	11,776	12,304
CD #2	11,776	12,304
TOTAL ASSETS	$78,872	$120,738

LIABILITIES:	$0
NET WORTH 31 December 1995:	$120,738

INCOME

Conference	76,390
Short Courses	14,005
Publications	4,268
Membership	38,386
Software	812
Interest & misc.	8,697
TOTAL	$142,558

EXPENSE

Conference	30,285
Short Courses	7,979
Publications	27,978
Software	107
Services (Legal, Taxes)	3,902
Postage	10,733
Supplies & misc.	19,708
TOTAL	$100,692
NET INCREASE FOR 1995	$41,866

In 1994 we enjoyed a net gain of $25,929. This year the net increase was $41,866, which came from increased conference income and reduced conference expenses.

Todd Hubing
Treasurer

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COMMITTEE REPORTS

ACES PUBLICATIONS

Members of the ACES Journal Editorial Board and ACES Newsletter staff traditionally gather at the annual Symposium in March for a "Publications Dinner." The location for this year's dinner has not been finalized, and details are usually mailed during the month of February. However, it is now known that the Publications Dinner this year will be on Sunday night, 17 March 1996. If you are a participant in this event, please be aware of these plans as you make your travel arrangements to Monterey. Since many conference registrants arrive on Saturday in order to take advantage of the most favorable air fares, I hope this time will be convenient for you. One advantage of Sunday night is that we can leisurely enjoy our evening together, before the (sometimes hectic) conference pace begins on Monday morning. All ACES Publications folks, from near and far, should plan to enjoy the fellowship and an excellent meal at one of Monterey's outstanding restaurants.

The Publications Committee has prepared a poll of the ACES membership, which is bundled as a loose-sheet enclosure with this mailing of the Journal and Newsletter. All ACES members are asked to please complete this short form and return it at your earliest convenience. The mission of ACES Publications is to provide timely and useful news and technical information to practitioners of Computational Electromagnetics. Everyone working with the ACES Journal and Newsletter is dedicated to maximizing the relevance of the content of our publications to the information needs of our Society. A serious reflection on the status and future direction of ACES Publications is now in process, and constructive feedback from the ACES membership will be given full and careful consideration. The Committee strives to maintain due and appropriate respect for the priorities of those who pay the bills for these activities! Please take advantage of this opportunity for your voice and views to be heard.

The majority of Journal papers and Newsletter articles continue to come from non-members of ACES. We strongly encourage the membership to share their CEM experiences and expertise by authoring material for ACES publications, and the availability of these important outlets for the results of your work should be viewed as an advantage of membership. Even as we speak, Duncan Baker and Ray Perez probably are checking their mailboxes in hopes of finding a manuscript from you!

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

SOFTWARE EXCHANGE REPORT

ACES will be offering a new tool for NEC-MOM modelers, available at Conference. NECVU Version 1.4 (for DOS) will be available. This is an upgraded version of the viewer seen last March as part of NEC-WIN Basic. NECVU has proven invaluable, during our beta tests, both as a 3-D viewer of wire structure on a VGA-equipped PC, and as a diagnostic tool for locating errors in wire structure geometry. Several large 10 year old often-used NEC data sets for structures were recently found to be defective via NECVU. (BLUSH!)

Richard W. Adler, for the Software Exchange Committee.

LETTER TO THE EDITOR

Concerning the Article "Wire Antennas with Real Conductors" by Perry Wheless, Vol. 10, No. 3 Newsletter.

Dear ACES Newsletter Editor,

It was a disappointment to read the article by Wheless on "Wire Antennas with Real Conductors" in the Volume 10, Number 3 Newsletter, as there was no mention of the pioneering work on this subject done by Professor Jack Richmond at Ohio State in the 1970's. The statement by Wheless that finite conductivity has only been included in wire moment method code is, of course, not true. The OSU Richmond "WIRES" code, which is a piecewise sinusoidal Galerkin code, has an elegant formulation for wire conductivity. As this code is used by many people, I am surprised at the omission. OSU makes this code and documentation available for a nominal handling charge.

Sincerely yours,

Robert C. Hansen
PO Box 570215
Tarzana, CA 91357-0215

AUTHOR'S RESPONSE

The subject article was motivated by several recent accounts I have heard of renewed quests for directional wire HF antennas with ultra bandwidth and, simultaneously, tremendous gain. It is reasonable to expect that clever new configurations which substantially increase bandwidth will be forthcoming. However, it is clear that some analysts, principally CEM newcomers, are using the assumption of perfect conductors exclusively and, therefore, are misled about the apparent efficiency of their various designs. The subject article was intended to convey, to the uninitiated, that the price for synthetic bandwidth gains, demanded by basic physics, is increased loss.

A computer-based method for Q-factor determination would be useful to antenna designers concerned with this issue. Acceptable procedures exist for high Q resonances, as illustrated in the article, but the extension to an accurate and reliable technique for low Q resonances apparently remains to be completed. The principal objective of the article, therefore, is to invite an effective solution to this practical problem from the ACES Newsletter readers. This invitation remains open.

The article Introduction's first-paragraph sentence 'Earlier computer programs ... generally assumed idealized ... wires' was not intended to imply that finite conductivity was absent from ALL earlier wire moment method codes. The first sentence of the second paragraph, however, is obtuse because it has a missing operative and should read 'analysis codes are starting to provide conveniently for wires of finite conductivity.' I believe most code users would agree that the pop-up menus of PC implementations such as NEC-WIN, which directly ask for the material of preference - PEC, copper, aluminum, etc. - are convenient in comparison to the loading (LD) data cards required with older, mainframe versions of NEC, and the like. I regret any misunderstanding that has resulted from this omission.

Jack Richmond's code did, in fact, make provision for finite wire conductivity. I do not concur that omission of this reference is problematic in the context of the subject article, where the specifics of any particular code are parenthetical, but I am pleased to acknowledge here the outstanding work and contributions of Jack Richmond so that the awareness and understanding of ACES Newsletter readers might be enhanced. Unlike the ACES Journal, which is a rigorous peer-review publication, the ACES Newsletter is an informal forum for the exchange of news, experiences, and expertise. Enriching information, such as that submitted by Dr. Hansen, is always welcome.

It would be interesting to know how many readers have used the finite wire conductivity features in Richmond's code and pre-PC implementations of NEC, and how extensively. If readers will drop me an email or land mail note, I will tally the responses and include a summary report in the next Newsletter.

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CEM NEWS FROM EUROPE

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INTRODUCTION

The URSI Symposium on Electromagnetic Theory was held in St. Petersburg from 23rd to 26th May 1995. Since it is difficult to divorce Electromagnetic Theory from CEM, there was a considerable amount of information on the CEM interests in Russia and the previous USSR states as well as Eastern Europe. Well over half the papers were given by authors from this group of countries and, out of a total of 270 papers, 98 came from Russia alone. This was followed by 28 from the Ukraine. Few Ukrainians actually arrived at the Conference to present their papers.

The general impression was that the academic standard of old Soviet bloc is very high indeed but that they are not accustomed to presenting papers in the same way as Western authors and did not make as good a job of "selling" themselves as a Western author would. There was a general unfamiliarity with Overhead Projectors - even among the technicians. Indeed, the general level of presentation was poor - not helped by audience behaviour which ranged from the peculiar to the offensive.

Topics which were covered in depth were diffraction theory, Chiral media, integral equations, mode-matching, radomes and indeed the standard topics which one might find in any Conference on Electromagnetic Theory. There was not much on Time Domain techniques, Integral Equations, machine design or low frequency techniques.

The Russian hosts were very hospitable and the Symposium included a river cruise past all the palaces and attendance at Swan Lake at the Marinsky Theatre. If I have my conversion factors correct, it cost me $4.00 for a seat in the stalls. We also had a banquet in the Russian style in a restaurant which used to be reserved for the Security personnel. This involved a lot of vodka and a great deal of food. There was also a live band and dancing.

COMPUTATIONAL TOPICS

There were a few descriptions of computers used which seem to be restricted to 80486 and below. One startling conversation I had produced the remark that 'PENTIUM is just a word here in the Ukraine. I do not think one has ever been imported'. The other remark which provides food for thought was that, 'of course, all the compilers have been copied so much that they are very unreliable and we have no manuals'.

There was little reference to methods of computations and I have discovered that the authors do not like to publish details of methods used in CEM for commercial reasons. Many groups appear to have a rule forbidding this kind of publication. However, it is easy to see from the results included in papers that computational results are available. Occasionally an author would volunteer information on the computer or on runtimes during questioning. The computer involved was almost always a 386 or 486. I heard no references at all to UNIX or workstations.

CEM CENTRES

Several establishments stood out as providing papers on a wide range of topics. These included:

(1) The University of St. Petersburg

This has a very substantial group working on diffraction (acoustic and electromagnetic). They hold 'Diffraction Days' here every year[1]. The meeting for 1996 is from June 4th to 6th. A three-day conference implies a lot of interest in diffraction in Russia. The University also has a group working on RCS and RCS

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[1] Contact Professor V.S. Buldyrev of St. Petersburg University by email on bvs@onti.phys.lgu.spb.su

reduction. The mathematicians I met from this Establishment are very good indeed. One mathematician, S. Yu Slavyanov, gave a superb paper entitled "The Land beyond Hypergeometric Functions". His interest was that his group is writing a mathematics-manipulation program (similar to Mathematica). This program will be ready for distribution in 1996.

2) Mosow Power Engineering Institute

Work is being carried out on RCS, high gain antennas, radomes and microwave components. This is of interest because they have several computer programs for the design of microwave components using standard techniques, some based on Marcuvitz.

3) There were also contributions from other large Universities such as Moscow State University and Ukrainian Universities.

Several groups are marketing software for component design. One in the Ukraine (Kiev) headed by Dr. Dubrovka has a suite of programs using modal matching to design waveguide components. Although the method is standard, because they lack powerful computers, they have come up with an optimisation technique which avoids too many data runs using the modal matching part of the software. Another is attached to the Moscow Power Institute under the Company name of Vega-star. This firm has a single powerful program TAMIC, which will analyse many different types of components. Another Ukrainian firm is based in Kharkov and also provides programs for waveguide components.

An interesting point here is that, although there were one or two papers on Integral Equations, there were no details of usage of any such programs nor was there any evidence of the use of FDTD programs. This may have been accidental but it did seem to me that there is much more interest among the papers in frequencies above 1 GHz.

CONCLUSIONS

There is a remarkable amount of high grade work being carried out in electromagnetic theory in the old Soviet Bloc and I would envisage the workers being much widely known in a few years time. The provision of work-stations will make a big difference to what they can accomplish.

MODELER'S NOTES

Gerald J. Burke

For this issue we can balance some of the excess Macintosh coverage in this section with some data for PCs. Larry Laitinen, WA6JYJ has provided an extensive collection of data on various configurations of PCs running NEC–2 and 4.1. Larry is a Research Associate at the University of Oregon, providing radio system, instrumentation, computer and network services to the campus community during the past 16 years. PC performance evaluations have been ongoing there for the past several years in order to get the best performance for the purchasing dollar. Larry reports that double precision NEC programs have been very useful for evaluating Pentium systems, since industry standard evaluation programs are often small enough to execute out of the cache system, and hence do not give a good picture of the CPU and motherboard performance for real-world applications.

Larry's results include execution times for NEC–4 and NEC–2. However, the two NECs appear to have been compiled with different compilers, so the times cannot be compared directly. His NEC–2 was faster in filling the matrix than NEC–4 but slower in factoring it. NEC–4 should be faster than NEC–2 in the basic evaluation of the matrix elements, since it uses a fast series approximation of the integral over each segment while NEC–2 integrates numerically after subtracting the singular component. However, NEC–4 does more things, like an end-cap approximation and solution for charge at junctions, so it may take somewhat longer to fill the matrix than NEC–2 for complicated structures. For a single wire with many segments, as Larry has modeled, NEC–4 should be faster in filling, and it is when codes compiled with the same compiler are run on a Macintosh and DEC Alpha, as shown in the following table for the TEST299.NEC input file.

Computer	Clock MHz	Matrix Fill		Matrix Factor		Total Exec.	
NEC version:		4.1	2	4.1	2	4.1	2
Quadra 650/PPC card	66	14.78	20.60	6.15	6.10	24.10	28.77
PowerMac 8100/80	80	11.81	15.51	4.37	4.42	16.72	20.52
PowerMac 8100/100	100	9.00		3.65		15.55	
DEC-3000/400		6.20	9.90	2.37	2.36	9.24	12.62

The two codes should factor the matrix at the same speed, since they use identical algorithms. However, a difference could result from whether the interchange of indices in routines FACTR and SOLVE has been done, as described in Modeler's Notes in the July 1995 Newsletter. The times for the PowerMac 8100/100 were questionable, since the computer seemed to be occupied with some other activity. The times given were rounded up from the fastest, but some were much slower. The 8100/80 times were very consistent. The data from John Grebenkemper in the last Newsletter showed the PowerMac 7500/100 to be about 13% faster than the 8100/80 in filling the matrix and 24% faster in factoring. This and Larry's data also show the importance of the compiler and optimization options in determining performance.

Thanks to Larry Laitinen for providing the extensive comparison data on PCs. 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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On other NEC matters, once again Roy Lewallen has found a bug in NEC–4. This one involves the use of the RP1... command to compute ground wave over perfectly conducting ground rather than over real ground as it is intended. Using RP1... with perfectly conducting ground in NEC–3 resulted in division by zero and a crash. We fixed that by calling the free-space far field routine, but did not notice that the resulting field would not get multiplied by the e^{-jkR}/R factor further down in the code. This problem can be fixed by adding two lines to subroutine RDPAT after the first call to FFLD:

```
        CALL FFLD (THA,PHA,ETH,EPH)
        ETH=ETH*CEXP(-(0.,1.)*XKU*RFLD)/RFLD      !NEW
        EPH=EPH*CEXP(-(0.,1.)*XKU*RFLD)/RFLD      !NEW
        ERDM=0.
        ERDA=0.
      END IF
    ELSE
      CALL FFLD (THA,PHA,ETH,EPH)
    END IF
```

There is not much need to use RP1... with perfectly conducting ground, since there is no surface wave, but it does accept cylindrical rather than spherical coordinates. Also, it is used in the TEST299.NEC input file that Larry Laitinen used in the article that follows.

Roy also rediscovered that NEC–4 does not give the "right" result for a wire ending on the surface of a finitely conducting ground with GE1 to connect it to the ground. This trick was used with NEC–2 when we could not model a ground stake. It should give a reasonable current distribution on the wire connected to the ground, but is not accurate for input impedance. However, NEC–4 gives a very bad impedance since the field of the point charge at the end of the wire is not computed. The point charge is canceled if the wire ends on a perfectly conducting ground or is continuous, and in other cases, such as a wire ending on a surface patch or crossing the air-ground interface the point charge field is included. However, it was not done for a wire ending on a finitely conducting ground. We probably should fix this so that NEC–4 will agree with NEC–2 and 3, but have not had a chance yet. For now the solution is to include the ground stake or screen in the model.

PC PROCESSOR AND MOTHERBOARD BENCHMARKS USING THE NEC METHOD OF MOMENTS ANTENNA ANALYSIS CODES

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I. INTRODUCTION

NEC4.1 and NEC2 double precision Method of Moments antenna analysis codes were used to compare the performance of various 80x86 CPU chips and motherboards. The total execution time and the impedance matrix fill and factor times reported by NEC are shown in Table 1 for a half-wave dipole antenna over ground with 299 segments (input file in Section IV). The NEC codes were compiled using 32-bit DOS extenders, and do not take advantage of the Pentium's pipeline architecture. Compilers generating Pentium optimized code are expected to speed up the matrix factorization by 50 to 100%.

Although the NEC2 fill, factor and execution times are less precise than those for NEC4.1, they are included here because NEC2 is more widely distributed than NEC4.1. Further, some configurations tested here were not tested under NEC4.1. It should be noted that the NEC2 and NEC4.1 times may not be directly comparable, since the codes may have been compiled with different versions of the Lahey Fortran compiler. The NEC2 code was the fastest executing code found on ftp.netcom.com in /pub/ra/rander/NEC directory (contributed by Jozef R. Bergervoet), and was compiled with the Lahey F77L-EM/32 FORTRAN 77, Version 5.10 compiling for the 80386/80486.

Table 2 compares the cost and NEC4.1 performance ratios of the various CPU chip and motherboard configurations using the 90-MHz Intel Neptune motherboard as a baseline reference. The normalized times are also shown adjusted for clock frequency. Normalized ratios of approximately 1.00 indicate that the board performed as expected for the test conditions relative to the reference Intel P54C-PCI/Neptune 90-MHz board. A ratio significantly less than 1.0 represents a motherboard that performed poorly.

Several factors affect the performance of the NEC codes in the above systems, including: Primary (CPU internal) cache size and bandwidth, secondary (board level) cache size and bandwidth, main memory bandwidth, the CPU's internal clock multiplication factor and bus speed. All the Pentium CPU chips tested here are believed to have a 16-KB internal (primary) cache. Presumably Intel designed the cache to be fast enough to keep the CPU supplied with instructions and data when present in the cache. Secondary (board level) cache memory size and bandwidth are under the control of the motherboard designer. Most Pentium motherboards have at least a 256-KB board level SRAM cache. Some can be expanded to 512-KB. Newer motherboards have the option of using the faster pipeline burst (PBURST) cache memory technology expandable to 1-MB. Gateway chose not to use board level cache in their Pentium P5-75 system. Gateway claims that it is not needed with extended data output (EDO) main memory. The new (EDO) memory provides some improvement in main memory bandwidth compared to the fast page mode (FPM) memory

Table 1. Execution times in seconds for the TEST299.NEC input file run in NEC4.1 and NEC2 on various processors.

	CPU/Motherboard	Board Cache	RAM	Matrix Fill		Matrix Factor		Total Exec.	
	NEC version:			4.1	2	4.1	2	4.1	2
1.	Pentium 120-MHz Gigabyte/Intel Triton	256KB PBURST	32MB FPM	14.07	11	7.88	11	22.75	22
2.	Pentium 100-MHz Triton Super Micro P55CMS	512KB PBURST	16MB EDO	15.87		8.53		25.15	
3.	Pentium 100-MHz Gigabyte/Intel Triton	256KB PBURST	32MB FPM	15.96	13	8.73	12	25.45	25
4.	Pentium 100-MHz Triton Super Micro P55CMS	512KB PBURST	64MB FPM	16.12		8.63		25.50	
5.	Pentium 100-MHz Triton Micronics M54Hi PCI/ISA	256KB PBURST	64MB FPM	16.22		8.93		25.85	
6.	Pentium 120-MHz Gigabyte/Intel Triton	256KB SRAM	32MB FPM	15.42	13	10.18	12	26.40	25
7.	Pentium 100-MHz Intel P54C-PCI/Neptune	256KB SRAM	16MB FPM	16.97	13	9.58	13	27.30	27
8.	Pentium 90-MHz Gigabyte/Intel Triton	256KB PBURST	32MB FPM	17.71	15	9.73	13	28.49	28
9.	Pentium 100-MHz Gigabyte/Intel Triton	256KB SRAM	32MB FPM	17.16	14	10.77	14	28.69	28
10.	Pentium 90-MHz Dell/Intel Neptune?	256KB SRAM	32MB FPM	18.76		10.57		30.19	
11.	Pentium 90-MHz Intel P54C-PCI/Neptune	256KB SRAM	16MB FPM	18.80	15	10.60	14	30.23	29
12.	Pentium 90-MHz Intel ZAPPA/Triton	256KB SRAM	16MB FPM		15		17		32
13.	Pentium 90-MHz Gigabyte/Intel Triton	256KB SRAM	32MB FPM	18.91	15	11.97	16	31.78	31
14.	Pentium 60-MHz Dell system	256KB SRAM	16MB FPM	27.09		16.92		45.16	
15.	Pentium 75-MHz Gateway-2000 P5-75	NONE	8MB EDO	29.89	18	15.02	21	48.35	40*
16.	Intel 80486DX4-100 Gigabyte PCI "AM" MB	256KB SRAM	16MB FPM	32.59 (memory = 0-wait state)	32	21.16	25	55.38	57
17.	Intel 80486DX4-100 Gigabyte PCI "AM" MB	256KB SRAM	16MB FPM	33.08 (memory = 1-wait state)		23.50		58.33	
18.	AMD AM486DX4-100 Gigabyte PCI "AM" MB	256KB SRAM	16MB FPM	36.63 (memory = 0-wait state)		22.26		60.53	
19.	AMD AM486DX4-100 Gigabyte PCI "AM" MB	256KB SRAM	16MB FPM	40.36 (memory = 1-wait state)		24.96		67.06	
20.	Intel 80486DX2-66 Gigabyte EISA MB	512KB SRAM	16MB FPM	56.29	49	32.78	38	93.01	88

Notes: FPM = Fast Page Mode; PBURST = Pipeline Burst cache; EDO = Extended Data Output; SRAM = Static RAM cache

* No board level cache and only 8-MB of RAM may adversely affect the performance of the Gateway-2000 P5-75 system.

technology that has been in use for the past several years. EDO memory provided a marginal (1% to 2%) improvement in NEC4.1 performance in a 100-MHz Pentium system.

The Pentium 90-MHz and 120-MHz systems have a 30.0 MHz bus. The 100-MHz and 133-MHz systems have a 33.3 MHz bus. Thus the bus transfer speed is approximately 10 percent faster on the 100-MHz and 133-MHz systems when compared with the 90-MHz and 120-MHz systems. The 90-MHz and 100-MHz Pentium chips internally multiply the external clock by 1.5. The 120-MHz and 133-MHz chips use 2X internal clock multiplication. The higher the CPU internal clock multiplication factor, the greater the CPU's dependence on it's internal cache since the CPU's bus operates at 25-MHz (75-MHz Pentium chips) and 30-MHz or 33.3-MHz (90 MHz and above Pentiums).

The Gigabyte GA-586AT motherboard comes with either SRAM or PBURST (pipeline burst) cache. The SRAM cache version of this motherboard lacks adequate cache memory bandwidth, particularly when running the 120-MHz Pentium CPU chip. The matrix factorization time for this combination is worse than the 100-MHz Intel Neptune motherboard and only 4.1% better than the 90-MHz version. PBURST cache memory on the Gigabyte motherboard improves the matrix factorization time by 29.2% at 120-MHz, 23.4% at 100-MHz and 23.0% at 90-MHz when compared with SRAM cache memory.

Table 3 shows the performance ratios of the Gigabyte motherboards for the NEC4.1 matrix factorization with the 90-MHz SRAM cache version is the reference, and Table 4 shows the result with the 90-MHz PBURST motherboard as the normalizing reference. For each type of cache memory the speed increase was proportional to the clock frequency increase from 90-MHz to 100-MHz. But the performance fell short for both types of cache at the 120-MHz clock frequency. For the PBURST cache the speed increase was 70.3% of the expected increase based on the 90-MHz to 120-MHz CPU clock frequency. For the 20% clock increase from 100-MHz to 120-MHz, the speed increased 10.7% – about 54% of the increased clock speed. Cache and CPU memory bus bandwidth are inadequate. Intel's use of "clock doubling" technology and the CPU bus speed remaining at 30-MHz probably exacerbates the overall bandwidth problem.

With SRAM cache the problem was worse. The performance increase from 90-MHz to 120-MHz was 52.8% of the increased clock speed. From 100-MHz to 120-MHz it was 5.8%, only 29% of the increased clock speed. Not very good. Clearly the Gigabyte motherboard should not be purchased with the SRAM cache. It's performance is worse than the Intel Neptune motherboard. The Gigabyte board performs much better at all speeds with the PBURST cache, though there is still room for improvement in the PBURST cache and CPU memory bus bandwidth at the 120-MHz CPU speed.

Of the Pentium motherboards tested, only the Intel Neptune board supports memory parity generation and checking. This is an important consideration for long-term reliability, file system integrity and protecting computed results from soft memory and other transient hardware errors.

Table 2. Comparison of cost and performance ratios for NEC4.1 on various CPU chip and motherboard configurations.

CPU/Motherboard	Cost Ratio	Clock Ratio	M-Fill Ratio	M-Fact Ratio	Exec Ratio	Norm. by CPU clock		
						M-fill	M-fact	T-exec
1. Pentium 120-MHz PBURST Gigabyte/Intel Triton	1.40	1.333	1.336	1.345	1.329	1.002	1.009	0.997
2. Pentium 120-MHz SRAM Gigabyte/Intel Triton	1.26	1.333	1.219	1.041	1.145	0.914	0.781	0.859
3. Pentium 100-MHz PBURST Gigabyte/Intel Triton	1.26	1.111	1.178	1.214	1.188	1.060	1.093	1.069
4. Pentium 100-MHz SRAM Intel P54C-PCI/Neptune	1.12	1.111	1.108	1.106	1.107	0.997	0.995	0.996
5. Pentium 100-MHz SRAM Gigabyte/Intel Triton	1.12	1.111	1.096	0.984	1.054	0.986	0.886	0.949
6. Pentium 90-MHz PBURST Gigabyte/Intel Triton	1.14	1.000	1.062	1.089	1.061	1.062	1.089	1.061
7. Pentium 90-MHz SRAM Intel P54C-PCI/Neptune	1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8. Pentium 90-MHz SRAM Dell/Intel Neptune?	n/a	1.000	1.002	1.003	1.001	1.002	1.003	1.001
9. Pentium 90-MHz SRAM Gigabyte/Intel Triton	1.00	1.000	0.991	0.886	0.951	0.991	0.886	0.951
10. Pentium 75-MHz SRAM Gateway-2000 P5-75	n/a	0.833	0.629	0.706	0.624	0.755	0.847	0.749*
11. Pentium 60-MHz SRAM Dell system	n/a	0.667	0.694	0.626	0.669	1.042	0.940	1.004
12. Intel 80486DX4-100 Gigabyte PCI “AM” MB	0.53	n/a	0.576	0.501	0.546	n/a	n/a	n/a
13. AMD AM486DX4-100 Gigabyte PCI ”AM” MB	0.49	n/a	0.513	0.476	0.499	n/a	n/a	n/a
14. Intel 80486DX2-66 Gigabyte EISA MB	n/a	n/a	0.334	0.323	0.325	n/a	n/a	n/a

Notes: Clock speed ratios between Pentium and 80486 CPU chips are not applicable (n/a). Cost ratios are approximate and based on recent prices for the CPU chip and motherboard with cache memory, but without the main memory cost. The cost of some configurations is unknown and thus the cost ratio is not available (n/a). The reference cost for the Pentium-90 CPU on the Intel Premiere-II (Neptune) motherboard is $433 (Nov 95).

* No board level cache and only 8 MB of RAM may adversly affect the performance of the Gateway-2000 P5-75 system.

Motherboard costs (Nov 95, w/o CPU) are as follows: Micronics $540, Intel P54C-PCI (Premiere-II/Neptune/Plato) $178, Super Micro P55CMS $420 (approx), Gigabyte GA-586AT (256KB Pburst cache) $240, and Gigabyte PCI 80486AM $123. Intel Pentium CPU prices have decreased significantly since Aug 95. Recent Nov 95 prices: Pentium-133 ($535), Pentium-120 ($365), Pentium-100 ($305), Pentium-90 ($255), Intel 80486DX4-100 ($108), AMD 80486DX4-120 ($116), AMD 80486DX4-100 ($89).

Table 3. Performance ratios of the Gigabyte motherboards for NEC4.1 matrix factorization. The 90-MHz SRAM cache version is the reference.

GIGABYTE MB CPU SPEED	CLOCK RATIO	SRAM CACHE M-FACT RATIO	PBURST CACHE M-FACT RATIO
120-MHz	1.333	1.176	1.519
100-MHz	1.111	1.111	1.371
90-MHz	1.000	1.000 (ref)	1.230

Table 4. Performance ratios of the Gigabyte motherboards for NEC4.1 matrix factorization with the 90-MHz PBURST motherboard as the reference.

GIGABYTE MB CPU SPEED	CLOCK RATIO	PBURST CACHE M-FACT RATIO
120-MHz	1.333	1.234
100-MHz	1.111	1.115
90-MHz	1.000	1.000

II. MOTHERBOARDS AND CONFIGURATION ISSUES

For PC systems with 16-MB or more of memory and fast disk I/O, the total execution time is usually less than a second more than the sum of the matrix fill and factor times. Less memory and slow disk I/O will generally increase the total execution time to several seconds beyond the sum of the matrix fill and factor times. The following is a brief description of the Pentium motherboards and packaged systems evaluated:

1. Intel P54C-PCI Neptune motherboard (aka Premiere-II, Plato).

   This motherboard has gone through many revisions during the past two years. Early versions had many problems and BIOS revisions seemed to be coming out every month or so. For the past six months or so the board has been relatively stable. The board was at one time sold in a 75/90-MHz version and a 100-MHz version. Now, one board is jumperable for 75, 90 and 100-MHz. This board uses Intel's Neptune chipset. If parity memory is present, it will perform memory parity generation and checking. 256-KB of SRAM cache memory is soldered to the board. There are four 72-pin SIMM memory sockets.

2. Gigabyte GA-586AT

   This motherboard is available with up to 512-KB of (socketed) SRAM cache or 256-KB of (soldered in) pipeline burst cache. The board does not make use of parity memory. It supports Pentium CPUs from 75-MHz to 120-MHz and possibly to 180-MHz. It uses Intel's Triton chipset. Various distributors may sell this as their own "house" board.

3. Intel ZAPPA motherboard.

   This is one of Intel's newest motherboards with the Triton chipset. It appears to be made for low-end Pentium PCs. Distributor hyperbola touted it as being a new fast motherboard. But early testing showed it to be slower than the Intel Neptune motherboard. Further, it does not perform memory parity generation and checking. At this time (Nov 95) the street price for this board is comparable to the Neptune motherboard. Given the poor performance during the early evaluation and lack of parity generation and checking, additional testing of this motherboard is not being considered.

4. Micronics M54Hi PCI/ISA Motherboard.

   This motherboard would not run with any of four different PCI bus video boards. No video and the CMOS got scrambled. Testing was done with an ISA bus video board. No further consideration was given to this board due to the video problems. Note that this board at $540 w/o CPU (Oct '95) was the most expensive motherboard tested.

5. Miscellaneous Motherboards and Systems

   Older EISA bus 80486DX2-66 and a current PCI bus 80486DX4-100 motherboards are included in these tests to provide benchmark references for users of similar technology. The 80486 PCI bus motherboard was tested with both the Intel and AMD DX4 100-MHz chips. Note that the Intel DX4-100 CPU chip has a 16-KB internal cache memory while the AMD version is only 8-KB. This may be a factor in the AMD chip's slower matrix fill (by 4 seconds), factor (by 1.1 seconds), and execution (by 5 seconds) times.

   Occasionally opportunities to test various name-brand systems arise. The results are included herein. Generally, there was no control over the configuration (software, memory, etc). The Gateway-2000 P5-75 is one such system. It uses an Intel motherboard (probably a variant of the Intel ZAPPA with the Triton chipset). In the tested configuration the Windows (tm) video and disk drive performance (as measured by PC Magazine's Winbench program) were on par with 80486DX-33 systems.

III. CONCLUSIONS

At this time the Intel P54C-PCI/Neptune motherboard with the 100-MHz Pentium CPU is recommended for applications requiring reliability and cost effective speed. For applications where speed is paramount, then the PBURST version of the Gigabyte GA-586AT motherboard with the 120-MHz or 100-MHz Pentium CPU should be considered. It will be interesting to see how this board performs with the 133-MHz Pentium CPU chip when it becomes more widely available at a reasonable price.

American Megatrends International (AMI) just announced the new Atlas/PCI-II motherboard with features supporting Pentium processors up to at least 133-MHz, EDO memory, interleaved FPM parity and non-parity memory, PCI bridging, Intel's COAST cache standard, etc. This board will take a plug-in cache module with 256-KB of SRAM cache, 512-KB of pipeline burst (PBURST) cache, as well as other configurations to be announced. At this time (Nov 95) this board is priced on the order of $300 with 256-KB of SRAM cache and $500 with 512-KB of PBURST cache. It will be benchmarked with NEC4.1 in the near future.

IV. INPUT DATA FOR TIMING TESTS

David Pinion, P.E., submitted the following NEC "card deck" TEST299.NEC used in these tests:

```
CE CENTER FED HORIZONTAL HALF-WAVE DIPOLE OVER EXCELLENT GROUND.
GW 1,299,–139.,0, 6.,+139.,0, 6., .001,
GE 0,
GN 1,
FR 0,0,0,0, 0.54,
EX 0, 1,150,0,1., 0.,
RP 1, 1, 1,0000, 1.5, 0., 0., 0., 1000.,
EN
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ABCs: from Theory to Practice

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I. INTRODUCTION

If we were to think of Sommerfeld condition as the first absorbing boundary condition (ABC), then the history of ABCs dates back to the beginning of the century. Absorbing boundary conditions, or mesh-truncation techniques in general, have fascinated and continue to fascinate the electromagnetics community. This fascination is due to the fact that the an ABC attempts to approximate the wave behavior, and thus, understanding ABC "theory" can lead to tremendous insight into the wave propagation phenomenon. But more importantly, the fascination has a very solid practical side: a good ABC can save computer memory and time, which both translate into resources and money. The computer super-revolution of the fourth quarter of this century made the direct integration of partial differential equations (typically referred to as Finite Methods) very feasible, and thus the interest in Finite Methods grew as the computers became more powerful and cheaper. It is then a natural consequence that the interest in, and the development of ABCs will follow suit.

This article is intended to first give a brief historical look at the development of ABCs. The intention is not to be exhaustive but rather to highlight key contributions. Next, we discuss the performance of ABCs from a theoretical perspective and comment on the importance of effective adaptation of the ABC to numerical techniques. No attempt will be made to make any comparison of the different ABCs, nor will the superiority of any method willbe proven. We then discuss aspects that are critical to effective and uniform numerical evaluation of ABCs. This is intended to prevent unforeseen future numerical-surprises. For this, we propose a numerical experiment that can test ABCs for their effectiveness in absorbing evanescent waves as well as traveling waves incident at arbitrary angles. For the practically inclined modeler who needs a "working ABC" and who at times can be confused by the avalanche of publications in the field, we offer few practical suggestions. Finally, we discuss some of the challenges we are faced with in our pursuit of the more perfect ABC.

As there are more than one numerical technique in Finite Methods, to provide a discussion of ABCs without adhering to the unique intricate features of each of these techniques can at times prove counterproductive. It is the belief of this author that analysis and numerical implementation of each ABC needs to be tied to the particular numerical scheme. To accomplish this in a short article is simply impossible. However, despite the limited discussion presented here, it is hoped that conceptual generalizations can be made that will transcend the particularities of implementation schemes.

II. PAST AND PRESENT

The interest in ABCs took a dramatic leap when it became feasible to solve Maxwell Equations by direct integration, i.e., discretization of the partial differential equation (PDE) over the domain of the problem. This is not to say that the interest did not exist before, but the scale of development was very limited since the bulk of methodologies favored either analytical techniques or the elegant Green's function formalism. The earliest work on ABCs dates back to Sommerfeld who found that to guarantee uniqueness of the solution to the radiation problem, the behavior of the field at infinity must be included in the formulation. Judging from the available literature, there was a lull in the development (and perhaps interest) in ABCs until the late 1960s when the interest resurfaced amongst the acoustics, fluid dynamics and electromagnetics communities. Chen [1] and Taylor et al. [2] used extrapolation techniques to approximate the boundary field, while Smith used a combination of the Dirichlet and Neuman conditions to eliminate reflections [3]. Taflove and Brodwin used an averaging process to accommodate waves of different angles of incidence at the boundary [4]. Lindman, using the projection operators, developed ABCs which accommodate the traveling as well as the evanescent waves, however, at the cost of compromising the locality of the operator [5]. These early techniques found limited use until some of the brilliant minds of applied mathematics took interest in the subject, most notably Engquest who saw the need to replace the Sommerfeld condition by a new one which can be enforced at a much closer distance from the radiating object. Engquest along with Majda developed a series of approximations to the non-local exact absorbing boundary conditions [6]. This early work was important in more than one respect: first, it introduced a methodology by which simple and local ABCs can be constructed. Second, it emphasized the fact that the availability of an ABC is not sufficient; the ABC has to be reasonably local to render its application efficient, but more importantly has to be well-posed. What is considered reasonably local can be a subjective judgment, however, well-posedness has to be guaranteed for the ABC to be useful. We will not attempt to give a definition for well-posedness since mathematicians differ on what is meant by that. It suffices for the purpose of practitioners in the field of electromagnetics to view a well-posed solution as a solution which is unique and does not grow in time.

Since the introduction of the Engquest and Majda ABCs, a large number of papers were published presenting alternate derivations for new classes of ABCs. In the early 1980s, Bayliss, Gunzburerger and Turkel introduced ABCs based on the Wilcox field expansion in cylindrical and spherical coordinates [7]. The construction of Bayliss et al., or the BGT operator had a direct appeal on Finite Element enthusiasts. Several adaptations of the BGT operators were later developed to accommodated rectangular boundaries to allow for bringing the outer boundary closer the surface of the scattering object as would be the case when analyzing elongated or flat objects [8]. Because of their dependence on the Wilcox expansion, the BGT operators affect the two-dimensional and three-dimensional problems in fundamentally different ways. The Wilcox expansion is valid only in the asymptotic region for two-dimensional radiation, i.e., the series converges only in the asymptotic region, whereas, in three-dimensions, the convergence is uniform. In the mid 1980s, Higdon presented a very simple technique for generating ABCs that can be optimized to annihilate wave packets incident at specific angles [9]. Higdon's ABCs were later found to be very versatile and particularly well-suited for dispersive media as well as special class of scattering objects that have infinite extent [10,11]. Other ABCs were also developed based on entirely different premises, such as in the work of Liao et al., where the a series of ABCs were constructed based on the extrapolation of the field behavior in time and space [12].

While all these boundary conditions have different evolutionary backgrounds, they have one thing in common: they are expressed by a *single* analytical or difference equation. While the single-equation ABCs has shed considerable insight into the mechanism by which waves can be annihilated or partially annihilated at the boundary, these ABCs have stopped short of delivering a level of accuracy that has become necessary in many modern and advanced applications. (Even if computer resources were plentiful, the desired accuracy cannot necessarily be guaranteed even if the ABC were to be enforced at considerably far distances from the radiating object as will be explained below.)

It is perhaps pre-mature at this time to speculate on whether the single analytical boundary condition has reached its maximum potential. What is apparent, however, is that the trend in the pursuit of a more effective truncation scheme has deviated from the use of a single analytical expression. The Numerical Absorbing Boundary Condition (NABC) and the Measured Equation of Invariance (MEI) [13-15] are techniques in which the ABC is expressed as an algebraic equation whose coefficients are obtained from an auxiliary numerical solution. A more radical mesh-truncation scheme was introduced by Berenger in 1994. In this approach, which can be viewed as a radiacal deviation from all the previous techniques, Berenger's unconstrained thinking led him to develop a non-physical *layer* which has a theoretically reflectionless properties [16]. Consequently, other researchers found that the Perfectly Matched Layer (PML) can alternatively be obtained through a lossy anisotropic mapping [17,18]. De Moerloose et al. and Pekel and Mittra [19,20] showed that while the PML gives perfect matching for traveling and evanescent waves, in numerical applications, the layer has to be substantially thick to annihilate evanescent waves, which results in substantial increase in computational cost. Chen et al. showed that through some adjustment of the PML parameters, evanescent waves can be effectively suppressed without affecting the annihilation of the traveling waves [21]. As a follow up to his first publication, Berenger has introduced an optimized version of the PML which is intended to specifically address the problem of wave-structure interaction, and to further reduce the thickness of the matched layer [22]. The concept of the PML has generated tremendous excitement in the field and it is expected that further development and applications will be forthcoming.

Recently, the Complementary Operators Method (COM) was introduced [23]. The COM theory makes use of two complementary ABCs. Each of which can be thought of as generating severely damped resonance in the computational domain. The COM requires solving the problem twice, each time using a single analytical ABC. At a first glance, this makes the method look time consuming, but this extra burden can be offset by the significant decrease in memory and eventually run time since the outer boundary can be brought "very" close to the radiating structure. Since the most elementary boundary conditions pair, the Dirichlet and Neuman are complementary, the COM concept can be considered a logical extension of the work by Smith [3]. In COM, the independence of the operation on the wave number is a powerful feature which results in the annihilation of the first-order reflections of not only the traveling waves, but also the evanescent waves. Interestingly enough, the introduction of COM has renewed interest in the single equation type ABC. This is because the joint performance of the complementary pair is directly linked to the performance of each individual ABC.

III. TESTING THE ABC'S PERFORMANCE

Traditionally, the merits of an ABC can be established by analyzing the an associated reflection coefficient. For the purpose of illustration, let us assume we have a terminal boundary normal to the x-axis and located to the right hand side of the radiating object. Then if we express the field as outgoing and reflected waves :

$$U = e^{-jk_xx-jk_yy-jk_zz+j\omega t} + Re^{jk_xx-jk_yy-jk_zz+j\omega t} \qquad (1)$$

We can define the time-harmonic reflection coefficient, R, due to the ABC as:

$$R(k_x, k) = -\frac{B[e^{-jk_xx-jk_yy-jk_zz+j\omega t}]}{B[e^{jk_xx-jk_yy-jk_zz+j\omega t}]} \qquad (2)$$

where B represents the absorbing boundary operator. To emphasize the dependence of R on the wave number, we have expressed R as a function of k and k_x.

For an ABC to be effective, this theoretical reflection coefficient has to be small. The smaller the reflection coefficient, the better the ABC. This analysis has been adopted to test mostly the class of ABCs that can be expressed in an analytical form. While equation (1) gives a simple expression for the reflective properties of ABCs, it should be emphasized that it is derived through time-harmonic analysis, and as we will see later, understanding this aspect can prevent what might otherwise appear as paradoxical numerical results.

If the theoretical performance of the ABC, as based on its reflective properties, is satisfactory, then the next step is to discretize the analytical expression of the ABC into a finite-difference approximation, as would be the case in the Finite Difference Time Domain (FDTD) method, or adapt the ABC (at times using some approximations) to the line integral expression in the Finte Element (FE) method.

The solution of partial differential equations through the FDTD or FE methods entails a transformation from the analytical to the discretized domain. This transformation produces discretization errors which largely depend on the differencing scheme that is chosen to discretize the partial differential operators. In addition to these discretization errors, the FDTD method, for instance, introduces two other sources of errors: grid anisotropy and numerical dispersion. The effect of grid anisotropy can be felt only if the mesh density is very low, and is typically very small to pose serious numerical hazards. The second source, numerical dispersion, however, is capable of introducing significant errors, especially if the waves propagate for long distances within the solution domain. In a similar fashion, the implementation of the ABC calls for transformation from the analytical to the discretized domain. Furthermore, discretization of the ABC brings along its own *numerical* errors which should be distinguished from the *theoretical* reflection errors that we typically obtain through equation (2). These numerical ABC errors can be attributed to several factors that are all directly linked to discretization. For instance, consider the reflection coefficient analysis given above in equation (2). When discretizing the wave equation, the wave number k_x is no longer governed by the familiar dispersion relationship in free space, but rather by a more complex equation (see [24], pp. 97-98). Additionally, for many ABCs, the theoretical R in equation (2) is independent of frequency. Once the ABCs is discretized, the frequency independence of R is no longer guaranteed.

There is no substantial data to indicate whether the numerical errors introduced by many ABCs are significant or not. It is highly likely, however, that, irrespective of the differencing scheme adopted, the numerical errors of the FDTD or FE simulation, including the ABC implementation, will put a limit on the overall potentially achievable accuracy. This could partially explain why when implementing higher order ABCs, their numerical reflection properties do not necessarily correlate with theory. For instance, consider Higdon's ABCs. Theory would predict that the 4th order ABC would substantially increase the annihilation of reflected waves over the 3rd order ABC. However, this pattern is not observed in numerical simulations (see, for instance, the numerical results presented in [23].)

When the theoretical reflection due to the ABC is larger than the discretization errors, it would be fruitless to investigate such discretization errors in great detail. However, the recent introduction of truncation techniques that provide unprecedented levels of suppression has highlighted the need to take a fresher and closer look at these discretization errors. The development of the Complementary Operators Method further underscores the significance of the discretization errors since the complementariness of these operators can be dramatically affected if the discretization errors, arising from each of the two operators, is not balanced. (For further discussion, see [25,30].)

Another equally important consideration is the susceptibility of the discretized ABC to numerical round-off errors which are capable of creating numerical catastrophes. The particular scheme of discretization can have very significant impact on the final solution and in many cases on its stability [26]. Numerical instability should be differentiated from the "analytical instability" which is prevented by the well-posedness of the analytical ABC. Several techniques were introduced to prevent instabilities as in the work of Higdon [26] and Moghaddam and Chew [27]. However, stabilizing an ABC comes with a cost. The stabilizing (or damping) parameters that are typically introduced have a direct impact on the frequency performance of the ABC. For applications where the accuracy is desired over a limited band of the frequency spectrum, these stabilizing parameters can be chosen such that the effect on the overall solution is very minimal. But for many FDTD applications such as transmission line characterization and EMI/EMC studies where a single run is needed to give the solution over a very wide band of frequencies, the effect can be very undesirable.

IV. NUMERICAL TESTS OF ABCS

Once a stable discretization scheme is adopted, the ABC needs to be tested within a numerical scheme to demonstrate its usefulness. Testing ABCs can be a truly challenging exercise. To study the effectiveness of an ABC by applying it to a specific example might give a qualitative feeling of its performance in comparison to other ABCs. However, such tests might not show the strengths or the weaknesses of that ABC. Since the solution to Maxwell's equations is unique, every electromagnetic radiation problem is therefore expected to be different from the other. More specifically, the size and geometry of each scatterer dictate its harmonic spectrum which reacts with the ABC in its own way. The same ABC which can be very effective in solving a scatterer that fits within a sphere having a radius of a fraction of a wavelength, might be very inaccurate when treating a much larger structure.

On the other hand, evaluating the reflective properties of ABCs in the time-domain can be potentially deceptive. Fort instance, in [24] a comparison between several ABCs were presented based on the instantaneous reflection of a propagating time-pulse as it approaches the terminal boundary. These tests show a puzzling conclusion; while the third order ABCs are theoretically superior to 2nd order ABCs, this particular methodology used in testing these ABCs showed that the improvement offered by the 3rd order ABCs is marginal, contrary to what theory predicts. While this could in part be due to discretization errors, as alluded to above, it is speculated that the missing link here is the fact that the theoretical reflective properties of ABCs that are being compared to were derived for the time-harmonic field. The instantaneous reflection coefficient, which what was effectively calculated in [24], needs to be compared to the theoretical time-domain error to make a meaningful correlation between theory and experiments. The error due to the ABC, which is given by the second term in equation (1) corresponds to a convolution in the time domain which makes extracting a time-domain reflection coefficient difficult in general. Therefore, the time domain, or instantaneous reflection error, is not expected to correspond to the frequency-domain reflection coefficient. In fact if the instantaneous reflection coefficient were to be observed at a later time step, a possibly different behavior can result. Since the *implemented* ABC is dependent on the frequency, as explained earlier, the instantaneous reflection of the trailing edge of a time pulse, which contains the lower frequencies, might be considerably higher than the reflection from the leading edge of the pulse, which arrives at the boundary first. While such time-domain reflection analysis can give some qualitative perspective, it does not offer a conclusive judgment on the effect of the ABC on neither the higher nor the lower frequencies. To do that, the proper Fourier weighting of the spectrum has to be taken into account. A recent paper by Kamel [28] provides a fresh perspective into the instantaneous reflective properties of ABCs and it is hoped that further research can be pursued in this direction. The thread offered by Kamel can have a further significance in the context of COM. If a time-domain version of the complementary operators technique can be devised, the perfect ABC can readily be developed. This is because the annihilation of the error can be performed "on-the-fly", and multiple_reflections can be completely eliminated.

Therefore, if we believe that the time-harmonic analysis (as in (1) and (2)) is a good measure of the reflective properties of ABCs, it then behooves us to produce a numerical experiment that would allow for testing the response of any mesh-truncation technique to evanescent or traveling plane waves at any frequency of interest or angle of incidence. In other words, can we devise an experiment that would attempt to emulate the theoretical test in (2)?

To test the reflection coefficient due to a plane wave having a specific frequency, the entire terminal boundary must be subjected to a single plane wave. Furthermore, no multiple reflections should be allowed either from the radiating structure itself or from the corners of the computational domain as would be the case in rectangular geometries. Here we propose a test which has proven very useful and uniform [29]. Consider the parallel plate waveguide. We position a current sheet at a distance from one end of the guide. On this end, the ABC to be tested is applied. The other end of the guide is taken very far and an exact absorbing boundary condition is positioned at this far end to completely annihilate any reflection from this end. The exact ABC placed on the far end can be either a non-local surface integral boundary condition, or a Higdon ABC where the coefficients are chosen with the advance knowledge of the excited plane wave. The current source is tuned such that it generates a single traveling or evanescent wave. To eliminate any effects due to the transient fields, the simulation is run for very large number of time steps. The usefulness of this test-experiment is threefold: first, it can test ABCs for their effectiveness when encountering purely evanescent waves. Second, it can test for the reflection due to traveling waves incident on the boundary at any angle desired. Third, any desired frequency can also be tested. This procedure has been applied and showed that a good measure of correlation can be established between the theoretical and numerical tests.

V. SUGGESTIONS FOR THE PRACTICAL MODELER

Electromagnetics engineers deal with a variety of applications. The level of computational accuracy desired for each of these applications can expectedly vary. What is a highly accurate ABC to one engineer can be a mediocre ABC to another. For instance, an engineer interested in optimizing the performance of a dish antenna that is to scan a certain geographical area, obtaining accuracy to within a fraction of a dB is a necessity. To an EMC engineer, whose only concern is to meet FCC standards, a code that provides errors within few dBs can be very sufficient since the measurements that are to be performed in the final stages of the design have errors that fall within this margin. Thus, for the second engineer, a simple ABC that provides a reflection error of -20dB (relative to the radiated field) across the entire frequency band of interest can be very adequate indeed. For our antenna engineer, on the other hand, a sophisticated ABC will enable him/her to fine tune the antenna and avoid unnecessary power loss.

In critical applications where a high level of suppression is needed, the costs associated with a technique that yields high accuracy such as the PML can be very well justified. Enlarging the computational domain, while using a relatively low cost and simple ABC does not guarantee higher accuracy in general. Aside from dispersion errors which increase with the size of the computational domain, having a large computational domain results in a large amount of energy impinging on the terminal boundary at oblique incidence, especially at or near the corner regions, and thus significant reflection arrives back [31]. Of course one can window out the unwanted reflections if one is only interested in higher frequencies as would be possible in the FDTD simulations. (In frequency-domain techniques, this would be impossible since the reflections cannot be filtered from the outgoing signal.) Nevertheless, windowing out unwanted reflections has its limitations if one is interested in the frequency response over a wide band. Accurate prediction of the response towards the lower end of the spectrum requires registering the time-pulse for a long duration.

Also, depending on the application, the field observation point(s) can lie in the close proximity of the radiating object, as in calculating the characteristic impedance of microstrip transmission lines, or at a distance from the object, as in the case of EMI/EMC and RCS calculations. In the former case, the field of interest is a direct product of the numerical simulation. In the lateral case, field extension techniques need to be employed. These field extension methods are based on the integration of the Huygen's (equivalent) current sources over a surface that fully encloses the radiator. The location of this Huygen's surface affects the accuracy of the field. The terminal boundaries in effect act as sources of evanescent waves, and since these evanescent waves decay in the direction of the scattering object, it is recommended that the integration surface be brought as close to the object as possible.

VI. FUTURE CHALLENGES

The development of ABCs has come a long way. A significant body of work has been published on the subject, and ABC presentations in annual electromagnetics symposia continue to attract large audiences. But the unfinished work remains enormous. We give here a partial list of topics that need further treatment:

1. The concept of the Perfectly Matched Layer has proven effective in treating many problems, but judging from the recent publications, the implementation cost can be high. The follow-up paper by Berenger [22] will therefore be anticipated with great enthusiasm.

2. The discretization of the analytical forms of ABCs is an area that has to be untangled. Perhaps a more robust and stable discretization of higher order ABCs can be developed which makes revisiting old ABCs a worthwhile exercise. Perhaps we can find discretization schemes that make ABCs live up to their theoretical expectations.

3. The effect of discretizing ABCs on grid dispersion needs to be better understood.

4. The interest in time-domain techniques has been growing rapidly. The appeal of these techniques is that they give the response of the system for a wide frequency band in one computer run. For ABCs to work well in time-domain techniques, their stability has to be analyzed in more detail. Presently, many ABCs are stable only when double precision arithmetic is used. If single precision arithmetic is used then the accuracy of the ABC will be limited to a smaller portion of the frequency band. Further work on the development of stable discretization schemes that do not sacrifice accuracy is certainly desirable.

4. Standard tests can prove very useful in studying the effectiveness of new ABCs as they are developed. Good numerical tests can help avoid unpleasant numerical surprises.

VII. ABC, THE NEXT GENERATION

A Final note. Would it be possible to develop a simple, low cost ABC, that will eliminate reflection from traveling and evanescent waves; that will work wonders for all frequency from dc to light. Perhaps, we have a clue in the *non-physical* reflectionless layer introduced by Berenger. Now that we have entered the realm of the non-physical, would it be possible to come up with a new non-physical, layer. This time, however, it is to have a fourth dimension! If one day we can make such 3D to 4D interface a reality, then perhaps we can find a way to channel the transmitted field into the fourth dimension, to be lost forever....

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The Practical CEMist

- practical topics in communications -

Perry Wheless, K4CWW

First, I would like to thank the authors who came forward and submitted a slate of interesting papers for the "CEM Applications in Amateur Radio" session to be held at the ACES '96 Symposium. The latest information on the conference appears elsewhere in this Newsletter. All advance indicators are positive for the biggest and best annual conference yet, one which will be both educational and enjoyable. If you have never attended an ACES conference, it is a unique and rewarding experience - make this the year to pack your bags and come join us at the Naval Postgraduate School in Monterey in March! Although the final agenda is not set for ACES '96 at this writing, the present plan is to experiment with our session as an unprecedented Monday evening offering. This will afford Hams in ACES, and others interested in practical radio communications, to become acquainted and interact prior to the start of the "firehose" technical paper session pace which will begin on Tuesday morning.

Preliminary planning is also underway for a social get together prior to the Monday session at one of Monterey's many excellent restaurants. We are now considering several locations within reasonable driving distance of NPS and with typical meal prices in the $15-20 range. The present schedule is for the social to begin at 5 pm and conclude about 7:15 pm, which should allow us to return to NPS in time for a 7:30 pm session start. Please send me an e-mail or land mail note if you can attend the dinner, because the Monterey restaurants like to have a reasonably accurate head count for planning purposes. An electronic distribution of final arrangements will be made to those of you with e-mail capabilities. Others will find the information available at the conference registration site in Monterey.

There are numerous VHF/UHF repeaters in the Monterey area, but Dick Adler (K3CXZ, our NPS host) recommend's use of the 146.97/37 repeater. There is a PL requirement of 94.8 Hz to access this repeater. It is possible to override the PL requirement by entering '081' from your keypad, which kills PL as long as you transmit and for 30 seconds after each transmission.

Thank you for your interest in starting these special activities at the ACES conference, and for the support which The Practical CEMist has received since its inception in the ACES Newsletter some two years ago. The outlook for Practical CEMist submissions has improved recently, so you can look forward to several new authors and their informative articles in future installments. Your manuscripts, as well as comments, are both invited and welcome at all times!

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The Twin-Delta Loop Antenna

A Novel Approach to the Ultimate Multiband Antenna

Part I

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1. Introduction

Of the two basic antenna concepts to cover all five amateur HF DX bands between 20m and 10m with only one antenna the multiband antenna concept has distinct advantages over the broadband antenna concept. Unlike true broadband antennas, like the log-periodic dipole array (LPDA) covering the 13-30 MHz range, multiband antennas are not subject to the wideband noise accumulation or indiscriminate receiver front-end overloading from strong out of (amateur) band broadcast signals.

Among the multiband antennas currently widely in use is the common boom arrangement of 5 interlaced monoband YAGI-UDA antennas, and the 5-band cubical quad, both excited in parallel fashion from one feed line, as well as the (improperly named) 5-band Log-YAGI antenna.

2. Structure efficiency

All of the above antennas suffer from low structure efficiency. Structure efficiency is defined as:

$$\eta_{str} = \frac{\text{active region}}{\text{total structure}} \qquad (1)$$

where the 'active region' is that portion of the structure which actively contributes to radiation. With the 5 band multiband Quad loop for instance only one loop is active on each band with some activity from weakly coupled neighboring loops.

With about 20% or slightly higher the structure efficiency of all of the above mentioned multiband antennas is considerably less than the 100% structure efficiency of fixed direction antennas like the Rhombus antenna[1], the Quad-Rhomb (QR-60/30) [2], or the G5RV multiband dipole[3]. Low structure efficiency, also known as 'heavy metal' effect means that more wire or aluminum tubing will be put up in the air than is actually necessary, which not only puts excess weight on the rotator but also needlessly increases the windload.

3. The Wideband Twin-Delta Loop Element

The horizontally polarizing Twin-Delta Loop antenna presented in Fig. 1 is a 100% structure efficient octave band (2:1 wideband) antenna, which due to its manageable size, unlike the above fixed direction multiband antennas, will be fully rotatable. The design comprises two co-planar triangular wire loops arranged like the outline of an hourglass or keyhole. Each of the loops has the shape of a rectangular isosceles triangle with the rectangular corner facing the respective corner of the other loop. The loops are cut open at the facing corners, connected in parallel, and fed by a balanced transmission line (Zl=300Ohm) attached at the common terminals.

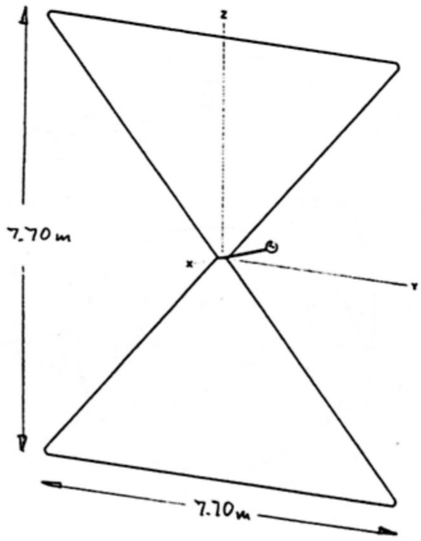

Fig. 1 Perspective view of the 2:1 wideband Twin-Delta Loop element

If optimized for operation in the 14.0-30.0 MHz range the TDL element spans an outline quadrangle of 7.70m x 7.70m (25.25ft by 25.25ft). Rather than for full-wave resonance at the lower frequency, the side length is determined by the maximum stacking distance of the parallel (outer) loop bases to prevent high vertical sidelobes on the upper frequency, Fig. 2. The dimensions are not at all critical.

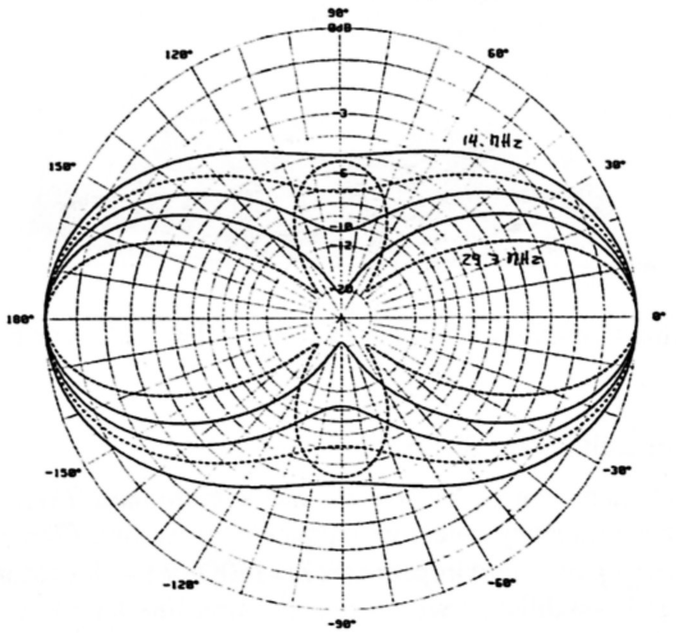

Fig. 2 Vertical cut farfield (azimuth 0°) of the 14.0-30.0MHz TDL element in free space

Resonance in the 20/15/10m band is established by means of a short 1.25m/4.1ft run of balanced transmission line attached to the TDL center terminals. The wideband characteristic of the TDL in the 14.0-30.0MHz range becomes further apparent from the input impedance response,shown in Fig. 3, and from the vertical cut farfield patterns for a central height of 21.3m/70ft over average ground, Fig. 4.

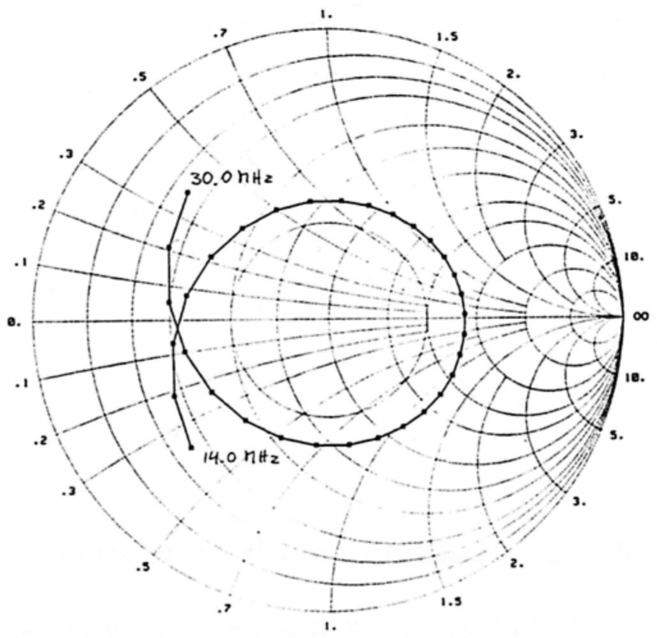

Fig. 3 Input impedance of the 14.0-30.0MHz TDL element normalized to 300Ohm, in free space

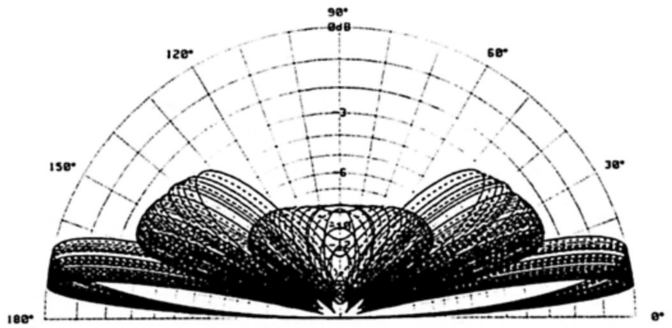

Fig. 4 Vertical cut farfield (azimuth 0°) of the 14.0-30.0MHz TDL element, at height 21.3m/70ft

4. The Multiband Twin-Delta Loop Element

The wideband TDL element can be converted into a multiband TDL element with passband response by means of a frequency selective balanced feeder line (Zl=300Ohm) of appropriate length, Fig. 5. Optimized[2] low input impedance(Zi=140Ohm) series resonance in each of the five 20/17/15/12/10m bands is established with a transmission line length of 33.1m/108.6ft (v=1.0), Fig. 6. If equipped with a 3:1 balun at the feeder input operation into or from asymmetric 50Ohm coaxial feed line is possible.

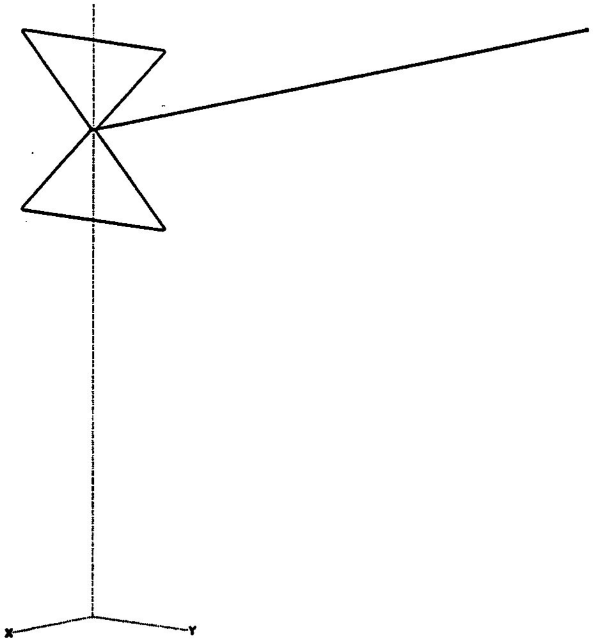

Fig. 5 Perspective view of the 14.0-30.0MHz TDL element in multiband operation mode

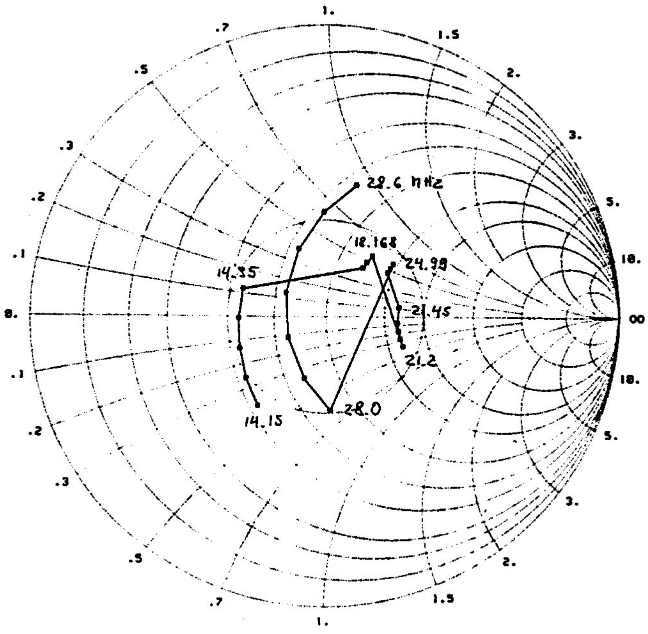

Fig. 6 Input impedance of the 20/17/15/12/10m TDL element, normalized to Zl=140Ohm

With slightly more than twice the geometrical aperture of a 20m Quad element, the TDL element offers a 1dB higher gain (free space) of G=1.75dBd on 20m increasing to G=4.35dBd on 10m. The ground related absolute gains at a center height of 21.3m/70.0ft over average ground are G=7.1 dBd on 14.0MHz and G=9.75dBd on 29.7 MHz respectively, Fig. 7.

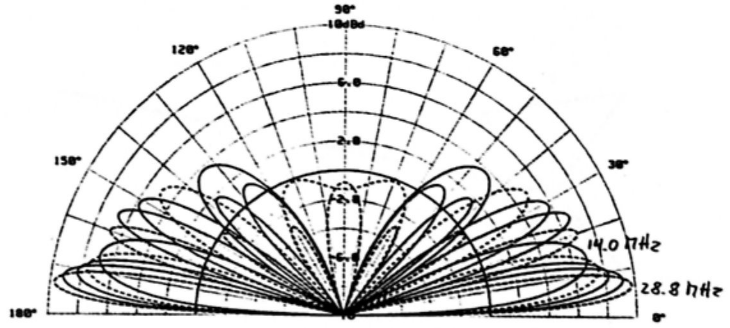

Fig. 7 Vertical gain (azimuth 0°) of the 20-10m TDL element, at height 21.3m/70ft over ground

Some of the outstanding features of the TDL is the small beamwidth variation over frequency in the horizontal plane, as shown in Fig. 8, and the superb suppression of high angle radiation, Fig. 9.

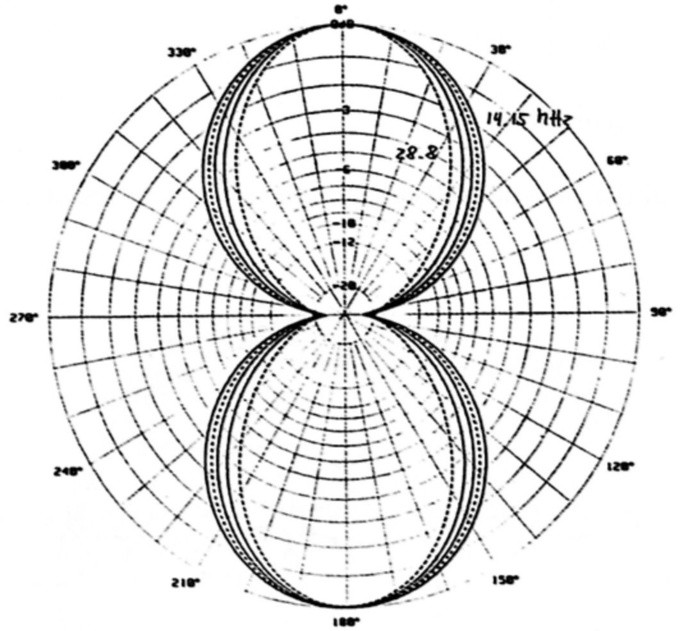

Fig. 8 Horizontal cut farfield (elevation 9°) of the 20-10m TDL element, a height 21.3m/70ft

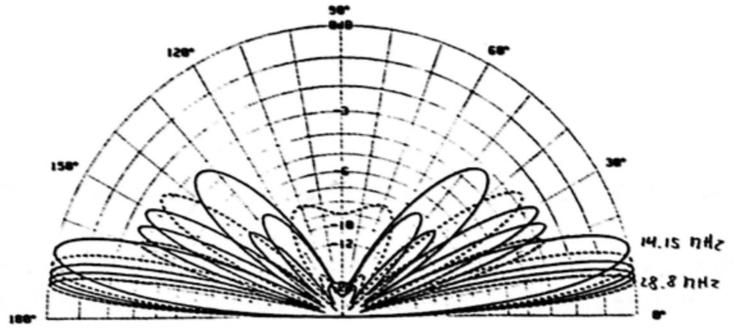

Fig. 9 Vertical cut farfield (azimuth 0°) of the 20-10m TDL element, at height 21.3m/70ft

Due to the closed loop design the TDL element experiences virtually no sensitivity to precipitation static. Common mode grounding can be established either at the center locations of the outer parallel wires or via the transmission line.
Based on the wide 65-85° horizontal beam width, convenient 360° coverage will be possible with two TDL elements arranged at 90° angle offset w.r.t the vertical axis and switched for two ortogonal directions.

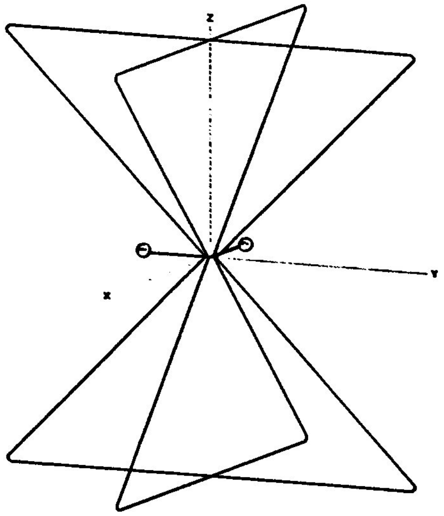

Fig. 10 Perspective view of 2 orthogonal TDL elements for 360° coverage

5. Conclusion

The Twin-Delta Loop antenna has been presented for multiband operation on the 20/17/15/12/10m amateur HF DX bands. Unlike the 5-band Quad loop the TDL offers 100% structure efficiency and delivers less weight and considerably lower windload in the air. The geometrical shape of the TDL provides for little frequency variation of the horizontal beam width, while the internal loop stacking results in gain increasing with frequency with decreasing vertical beam openings. The trapless closed loop design provides high performance and virtual insensitivity against precipitation static.

Part II of this paper, which follows in a later issue, will present the TDL element as basis for the trapless 2-element TDL multiband beam.

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TUTORIAL ARTICLE

The tutorial article for this issue "Model-based parameter estimation in electromagnetics: II - Applications to EM observables", is a continuation of a series of three articles contributed by Dr. E.K. Miller on MBPE. The first part, "Model-based parameter estimation in electromagnetics: I - Background and theoretical development", appeared in the previous issue of the *ACES Newsletter*. This article is Part II of that series, and Part III, "Model-based parameter estimation in electromagnetics: III - Applications to EM integral equations" appeared in a special issue of the ACES Journal (Vol 10, pp. 9-29).

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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.

MODEL-BASED PARAMETER ESTIMATION IN ELECTROMAGNETICS:
II--Applications to EM Observables

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0.0 ABSTRACT

The electromagnetic observables of interest for analysis and design purposes are normally sampled as a function of time, frequency, angle, and space. The sampling intervals employed are driven by the anticipated variability of an observable and the perceived importance of missing fine-scale details in its response function. In practice, this has usually come to mean that a high sampling density is employed together with simple linear interpolation between the sampled values develop a continuous approximation of the observable. The oversampling that can often result from this approach would not be of concern were there no cost impact on acquiring the needed data, whether obtained via experimental measurement or numerical computation. However, the cost of oversampling becomes more significant as problem size and complexity grows. For example, a frequency-domain integral equation (FDIE) can require a number of unknowns of order $(L/\Delta L)^2$ for a conducting three-dimensional object of characteristic dimension L and resolution cell ΔL, with a corresponding interaction-coefficient order of $(L/\Delta L)^4$ and a numerical-solution operation count of order $(L/\Delta L)^4$ to $(L/\Delta L)^6$ at a single frequency. When information is sought for such common observables as input impedance and radiation and scattering patterns over the wider bandwidths of increasing interest, the benefit of minimizing the number of samples needed can be substantial.

A means of reducing the number of observable samples is provided by model-based parameter estimation (MBPE) in which a low-order analytical formula, preferably physically based (the model), is fit to the data samples to quantify its adjustable coefficients (the parameters). This MBPE fitting model (FM) yields a continuous representation of the first-principles, or generatin model (GM) observable on whose discrete data samples it is based while also making possible analytical operations on that observable for optimization or other purposes as opposed to the strictly numerical operations that would otherwise be necessary. The FM can reveal behavior that might otherwise be missed and also forms a basis for adaptive sampling in which new data samples are placed where FM uncertainty is estimated to be greatest. This article contains a brief review of MBPE in electromagnetics including exponential- and pole-series and other kinds of FMs and provides a wide variety of illustrative applications.

1.0 WAVEFORM-DOMAIN AND SPECTRAL-DOMAIN MODELING

In contemplating the use of MBPE in electromagnetics (EM), the first issue to consider is what fitting models might be appropriate. It's important to note that unless a FM is physically based, MBPE is basically a curve-fitting procedure. While curve fitting can itself be a useful tool, MBPE is potentially much more powerful because the problem physics are then explicitly involved in the process and it might therefore be described as "smart" curve fitting. As discussed in the first part of this article [Miller (1995a), hereafter referred to as RI; a third part in Miller (1995b) is referred to RIII], exponential and pole series occur in numerous ways in EM, and thus provide obvious choices for FMs. Furthermore, the two most frequently used domains for formulating and solving EM problems, and for many other physical phenomena as well, are the time domain (TD) and frequency domain (FD), for which generic descriptions are given by exponential and pole series respectively, which together form a Laplace-transform pair. As mentioned in RI, the same transform relationship exists between other observable pairs that are also described by exponential and pole series (see Table I of RI). Thus, we use the terms "waveform domain" (WD) and "spectral domain" (SD) respectively for phenomena that are described by exponential series and pole series as a generalization of their more specific and familiar TD and FD forms. While a pole series does not fully describe an electromagnetic transfer function, it can be a good approximation to that response and provide a concise way to represent it. For purposes of the present discussion, which is to reduce the number of samples of EM observables that are needed in the first place, the FM does not have to be exact so long as it provides an acceptably accurate and parsimonious representation.

The generic WD and SD FMs can be expressed as

$$f(x) = f_p(x) + f_{np}(x) = \Sigma R_\alpha \exp(s_\alpha x) + f_{np}(x), \ \alpha = 1, \ldots, P \qquad (1)$$

and

$$F(X) = F_p(X) + F_{np}(X) = \Sigma R_\alpha/(X - s_\alpha) + F_{np}(X), \ \alpha = 1, \ldots, P \qquad (2)$$

where "x" represents the WD independent variable and "X" is its SD, or transformed, counterpart. For the time-frequency transform pair, x would be the time variable t and X would be the complex frequency s, in general, but for most purposes would be limited to radian frequency iω. The exponential or pole series contributions are designated respectively by $f_p(x)$ and $F_p(X)$, and represent what we might call the "resonant" response, with the non-pole part denoted by $f_{np}(x)$ and $F_{np}(X)$. The FM parameters, the complex resonances (or poles), "s_α," and the modal amplitudes (or residues), "R_α," (or their polynomial counterparts) are quantified by fitting samples of the relevant observable to the desired model, $f_p(x)$ or $F_p(X)$. Once these parameters are available from one domain, they can be used to obtain the observable they represent in the transform domain as well. The various FMs and their estimated parameters provide a mathematically-concise and physically insightful way to characterize electromagnetic and other wave-equation phenomena.

In deciding to begin with the generic FMs (1) and (2), the question of how to select a model has already been decided. A good rule of thumb is to base any FM on physical properties of the process whose data is to be modeled. Much previous work has shown that exponential-series and pole-series models are appropriate for representing various kinds of EM processes and data. This does not rule out the possibility of using other FMs as well. The problem of selecting a FM for a problem for which there is no previous experience to provide guidance is a general one that is referred to as system identification in a system's context.

2.0 USING GENERATING MODEL SAMPLES TO QUANTIFY WAVEFORM DOMAIN AND SPECTRAL DOMAIN FITTING MODELS

2.1 Sampling in the Waveform Domain

A conceptually simple starting point for function sampling in the WD is provided by Prony's method, a procedure whose presence can be discerned in much of modern signal processing, even though developed originally 200 years ago [Prony (1795)]. A fairly detailed description of Prony's method was included in RI, and only the basic equations are outlined here. Also observe that other approaches, such as the matrix-pencil technique [Sarkar and Pereira (1995)] should be considered for WD FM computation, since their performance may be better especially when applied to noisy data.

Whatever approach is used for WD sampling, the availability of uniformly-spaced samples of the exponential series (1) is assumed since this is needed to generate a polynomial data form. This process is referred to here as function sampling, i.e.,

$$f_i = f(x_i) = f(i\delta x) = \Sigma R_\alpha \exp(s_\alpha x_i) = \Sigma R_\alpha \exp(s_\alpha i \delta x),\ \alpha = 1 \text{ to } P,\ i = 0, . . . ,D - 1 \quad (3)$$

where δx is the sampling interval and there are a total of $D \geq 2P$ samples. Upon letting $X_\alpha = \exp(s_\alpha \delta x)$ and using

$$\begin{aligned} A(X) &= a_0 + a_1X + a_2X^2 + \cdots + a_PX^P = (X - X_1)(X - X_2) \cdots (X - X_P) \\ &= \Pi(X - X_\alpha) = 0,\ \alpha = 1 \text{ to } P \qquad (4) \end{aligned}$$

which is known as the characteristic equation, the following system of equations is obtained for the characteristic-equation coefficients

$$f_0a_0 + f_1a_1 + \cdots + f_Pa_P = 0 \qquad (5a)$$

$$f_1a_0 + f_2a_1 + \cdots + f_{P+1}a_P = 0. \qquad (5b)$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

$$f_{D-P-1}a_0 + f_{D-P}a_1 + \cdots + f_{D-1}a_P = 0. \qquad (5c)$$

Eq. (5) forms the basis for finding the coefficients of the characteristic equation from which its roots, X_α, and the FM poles, $s_\alpha = \ln(X_\alpha)/\delta$, can then be computed. The R_α can then be obtained by returning to the original sampling equations in (3). Because Eq. (5) is homogeneous, it requires some additional information, or a constraint on the characteristic-equation coefficients, for the problem specification to be completed, for which a common choice is $a_P = 1$, leading to the "linear-predictor" equation

$$f_{D-P}a_0 + f_{D-P+1}a_1 + \cdots + f_{D-2}a_{P-1} = -f_{D-1}, \qquad (6a)$$

so-called because having the P coefficients $a_0,\ldots,a_{P-1}$ and the past P samples of the sequence enables prediction of the next sample in the sequence, etc. Numerous variations of the basic Prony's method have been developed, one example of which is given by Carriere and Moses (1992).

An analogous approach can be used when the samples are available as derivatives of an exponential series, a process we refer to as WD derivative sampling. Function sampling and derivative sampling can be used together, providing still another possibility for quantifying a FM. If more data samples than 2P are used, a pseudo-inverse solution can be employed or an auto-covariance estimates of the data can be developed from the original samples. Since the condition number of the data matrix can be high, a pseudo inverse must be used with care. The analytical details of these approaches in both the WD and SD are discussed more fully in RI.

2.2 Sampling in the Spectral Domain

Spectral-domain function sampling begins with the FM given by Eq. (2) and assumes the availability of samples denoted by

$$F_i = F(X_i) = \Sigma R_\alpha/(X_i - s_\alpha) + F_{np}(X_i),\ \alpha = 1, . . .,P;\ 1 = 0,...,D - 1 \qquad (7)$$

where, in contrast to waveform sampling, there is no requirement that the samples X_i be uniformly spaced. However, in contrast to waveform sampling, where the FM can be a purely exponential series at late times, spectral sampling can not avoid the presence of the non-pole term which is generally unknown. The possibility of using various numerator and denominator polynomials orders provides a way to approximate the effect of the non-pole term by simply increasing the order of the numerator polynomial. For example, an increase of one in the numerator order has the effect of representing F_{np} by a constant, which, when absorbed into the rational function results in equal numerator and denominator orders. If F_{np} is represented by a constant and a term linear in X, this has the effect of making the numerator order one greater than the denominator. Thus, by varying the relative orders of the polynomials which comprise the FM, various approximations of the non-pole, SD contribution are included.

Therefore, in general we use a SD FM given by

$$F(X) = N(X)/D(X) \tag{8a}$$

where the numerator and denominator polynomials N(X) and D(X) are given by

$$N(X) = N_0 + N_1X + N_2X^2 + \cdots + N_nX^n, \tag{8b}$$

and

$$D(X) = D_0 + D_1X + D_2X^2 + \cdots + D_dX^d. \tag{8c}$$

The coefficients of the SD FM are also obtained from sampled values of the response. How this is done is easy to see by rewriting Eq. (8) as

$$F_iD_i = N_i, \ i = 0,\ldots,D - 1 \tag{9a}$$

where

$$F_i = F(X_i), \tag{9b}$$

$$D_i = D_0 + D_1X_i + D_2(X_i)^2 + \cdots + D_d(X_i)^d, \tag{9c}$$

and

$$N_i = N_0 + N_1X_i + N_2(X_i)^2 + \cdots + N_n(X_i)^n. \tag{9d}$$

There are d + n + 2 unknown coefficients in the two polynomials D(X) and N(X), and as for the previous cases, a constraint or additional condition is needed to make the sampled equations inhomogeneous. Again, there is no unique choice for this constraint, but if we set $D_d = 1$, then the following equations result:

$$F_0D_0 + F_0X_0D_1 + \ldots + F_0(X_0)^{d-1}D_{d-1} - N_0 - X_0N_1 - \ldots - (X_0)^nN_n = -(X_0)^dF_0$$
$$F_1D_0 + F_1X_1D_1 + \ldots + F_1(X_1)^{d-1}D_{d-1} - N_0 - X_1N_1 - \ldots - (X_1)^nN_n = -(X_1)^dF_1$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$F_{D-1}D_0 + F_{D-1}X_{D-1}D_1 + \ldots + F_{D-1}(X_{D-1})^{d-1}D_{d-1} - N_0 - X_{D-1}N_1 - \ldots - (X_{D-1})^nN_n$$
$$= -(X_{D-1})^dF_{d-1} \tag{10}$$

where $D \geq n + d + 1$ is again required. Note that the matrix coefficients are now comprised of a product of a data sample and the the frequency at which the sample is taken raised to a power, in contrast to the time-domain situation where the data samples alone are the matrix coefficients.

Also observe that the poles in the SD arise directly as the roots of D(x) whereas in the WD, the poles are natural logarithms of the roots of the characteristic equation, Eq. (4). The exponentiation of the sampling frequencies suggests that large dynamic numerical ranges in the matrix coefficients may result if d and n are very large. One way to avoid this is to scale the frequency, so that, for example, if the sampling range is centered at 1 GHz, a scaling of 10^9 in the frequencies leads to nominal scaled values near unity. It is also possible to center the SD model about a frequency in the interval of interest so that terms like $(X_s - X_{ref})^n$ result. Combing scaling and translation similarly produces terms like $[(X_s - X_{ref})/X_{ref}]^n$.

An over-sampled system, i.e., one where $D > n + d + 1$, can be handled in various ways, one of which is to employ a pseudo inverse for the solution. Another approach is to employ overlapping windows of different data sets to compare performance of their respective, lower-order FMs. A third is to progressively increase the number of data samples while retaining the same total number of FM coefficients and comparing the FM spectra to observe their trends, using either of these procedures.

Derivative sampling can also be performed in the SD, as can various combinations of function and derivative sampling. One result is that the samples can be spaced more widely. A more important consideration is that in some circumstances a derivative sample can be obtained for a computation operation count that is of order 1/N of the first function sample alone, where N is the number of GM unknowns. If a derivative sample provides information concerning the response from which it is obtained that is equivalent to a function sample, an obvious computation advantage is achieved. Using derivative sampling in the context of a FDIE is discussed more fully in RIII. Although determining the time or frequency derivatives of some response has not been commonly done and such derivatives are unlikely to be measurable (beyond the first time derivative), there are situations where computing such derivatives is worthwhile. Whether using WD or SD data, the corresponding FM is seen to be quantifiable using a variety of sampling strategies and approaches, one of which Prony's method.

3.0 SOME REPRESENTATIVE APPLICATIONS OF WAVEFORM- AND SPECTRAL-DOMAIN MBPE

3.1 Spectral-Domain MBPE

3.1.1 Antenna Applications--The MBPE procedure described in RI above has been tested for a variety of wave-equation phenomena, of which several examples are included here. Plotted in Fig. 1 are the input conductance and susceptance of a monopole as a function of antenna size in wavelengths. These results were obtained by sampling a GM (NEC) at 0.15 intervals in L/λ, shown by the open crosses, which are connected by the dashed lines to show the result of straight-line interpolation where the MBPE results are the solid line.

The fitting model used a $d = n = 3$ rational function, which requires seven data points. The first model, M_1, was used to develop the solid, fitting-model plot out to the fourth data sample. The second model, M_2, was "slid" up in frequency by adding the eighth data sample and dropping the first, and it was used to plot the solid line between the fourth and fifth data samples. This process was continued until model M_{14} was reached, which completed the fitting-model plot from data points 16 to 20. This particular procedure is not unique as other approaches might be used but it produces results within a few per cent of the GM between the data samples actually used to quantify the fitting model. Extensions of this idea include comparing the FMs for mutual consistency in their regions of overlap to estimate the relative uncertainty of the FM result and to determine whether additional GM samples are needed.

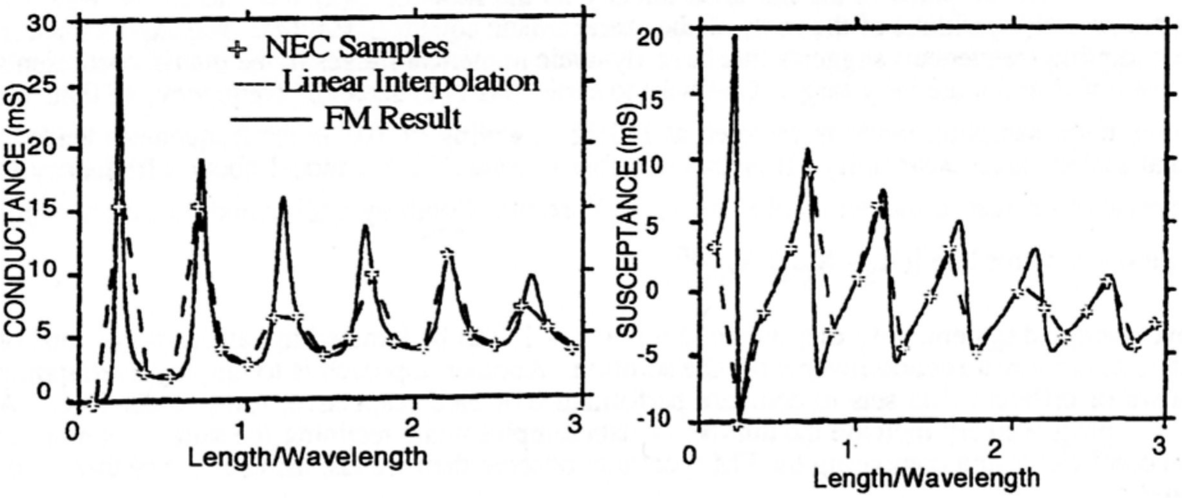
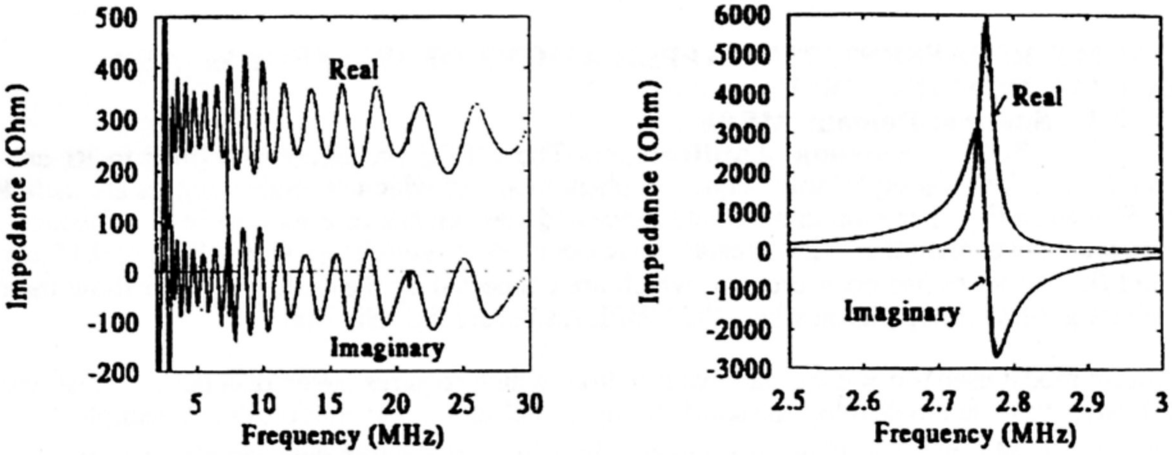


Figure 1. Input conductance (left) and susceptance (right) of monopole antenna versus length in wavelengths as obtained from a series of overlapping rational-function fitting models using d = n = 3 (the solid line) based on 20 GM samples spaced 0.15 apart in L/wavelength which are shown as open crosses and joined by a dashed line (after G. J. Burke, private communication). A comparison of the FM values with GM samples at other frequencies reveals a numerical agreement of 1% or better.

A similar use of MBPE for a more complicated problem, representing the input impedance of a log-periodic dipole array (LPDA) due to de Beer and Baker (1994,1995) is demonstrated in Fig. 2. (Note that the rational-function FM can be applied equally well to admittance functions, as shown in Fig. 1, or impedance functions as in Fig. 2 since one is the reciprocal of the other.) The application in this case required accurate representation of the antenna frequency response over its nominal operating range so that the effects of various mechanical deformations could be realistically determined.



(a) (b)

Figure 2. Wide band input impedance of a 20-element LPDA with an apex half-angle of 30 degrees, and element reduction factor of 0.87 with a rear-element total length of 42.13 m as obtained using a FM with n = d = 4 sliding through a total of 80 GM samples (the solid line) compared with 640 GM samples connected by straight lines, (a), and (b), a closer examination of the region about the low-frequency singularity to more clearly demonstrate the accuracy of the FM over this region for the LPDA of Fig. 2a [de Beer and Baker (1994)]. On this scale, the results are graphically almost indistinguishable. The short used at the end of the LPDA's transmission line is responsible for the singularity seen at about 2.8 MHz. The additional "glitches" at about 8 and 22 MHz are not explained.

An example of varying the FM parameters in the vicinity of a sharp resonance is shown in Fig. 3 for the admittance of a "forked-monopole" antenna [a short, straight dipole with V ends where one arm is slightly shorter than the other, Burke et al. (1989)]. The two fitting models, one using D = 7 (d = n = 3) and the other using D = 5 (d = n = 2) are based on GM samples at 0.5 MHz intervals. On this expanded scale, the 7-sample FM model coincides graphically with 21 additional GM samples spaced 10-4 MHz apart starting at 0.717 MHz, indicating that the higher-order FM is highly accurate and that the fitting error is probably comparable with the accuracy provided by the NEC model.

A further example of modeling a sharply resonant antenna is demonstrated in Fig. 4 for the admittance of a fan antenna (a bottom-fed monopole consisting of a three unequal-length wires spreading outward from the feed). Two sets of FM curves are plotted here as obtained from two different sets of GM samples, one set of 15 beginning at 2 MHz and spaced at 0.5 MHz intervals. The other set consists of 51 samples also beginning at 2 MHz but spaced at 0.14 MHz intervals. In plotting these results, each new FM is shifted upwards in frequency by their respective GM sampling intervals.

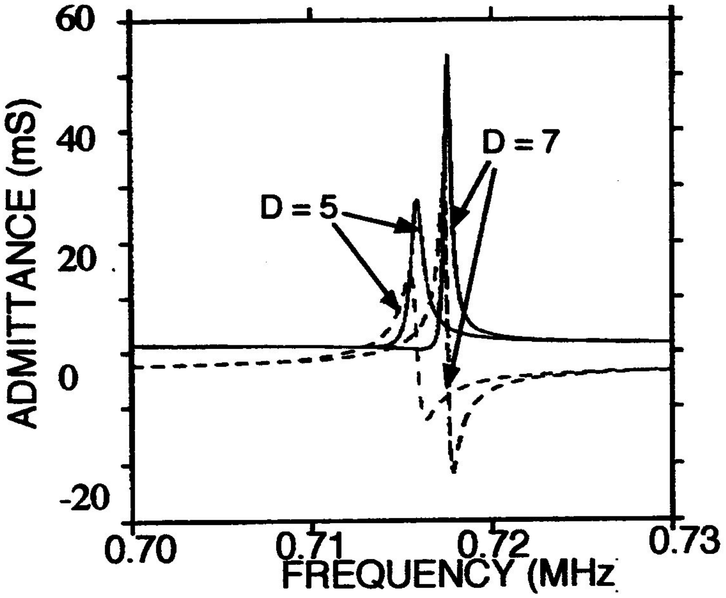


Figure 3. Results for the input admittance (solid line is conductance, dashed line is susceptance) of a forked-monopole antenna in the vicinity of a sharp resonance, where a differential-mode current can exist on the two unequal-length arms of the dipole. Although the resonance is quite accurately located (to within 1% or so in frequency), there is some variation in the admittance values provided by two FMs, one using D = 5, and the other D = 7, function samples. The 7-sample model is the more accurate, as it is found to agree within a few percent with 21 additional GM samples spaced 10^{-4} L/wavelength apart beginning at 0.717 MHz.

A broader view of applying MBPE to the fan antenna is illustrated in Fig. 5 where its input impedance (referred to 50 ohms) is plotted on a Smith chart for two different FMs. One FM uses D = 7 (d = n = 3) and the other D = 8 (d = 3, n = 4), both based on GM data sampled at 1-MHz intervals from 2 to 8 MHz and 2 to 9 MHz, respectively. The curve labeled "truth" is based on 51 GM samples beginning at 2 MHz and spaced at 0.14 MHz intervals. The 7-point FM produces a negative resistance in the vicinity of the resonance "loop," a problem that is corrected by increasing the order of the FM by one and using the 9 MHz GM sample. Over most of the frequency range covered here, the 8-point FM is in a few-percent agreement with the GM data, indicating the good accuracy of the MBPE representation.

When attempting to realize a specified performance of some electromagnetic component such as an antenna over some bandwidth, it is often neither feasible nor economical to sample the response so finely as to ensure that important features are not missed. A sparsely sampled set of frequency samples is therefore normally used in the initial design, resulting in the possibility that a final evaluation might discover features that invalidate the design or reduce its effectiveness. An example of such an application was reported by Fermelia et al. (1993) in connection with optimizing the performance of a corrugated-horn antenna. Initially, the design was developed over a several GHz bandwidth from samples spaced at 1 GHz intervals using a minimax procedure as illustrated by the crosses in Fig. 6a. Upon fitting a SD FM to this data, the solid line shown in this figure was obtained, a result confirmed upon subsequent experimental investigation that revealed a spike in the return loss between two of the sampled values. By incorporating MBPE into the design optimization procedure, this spike and its effect were essentially mitigated as shown in Fig. 6b.

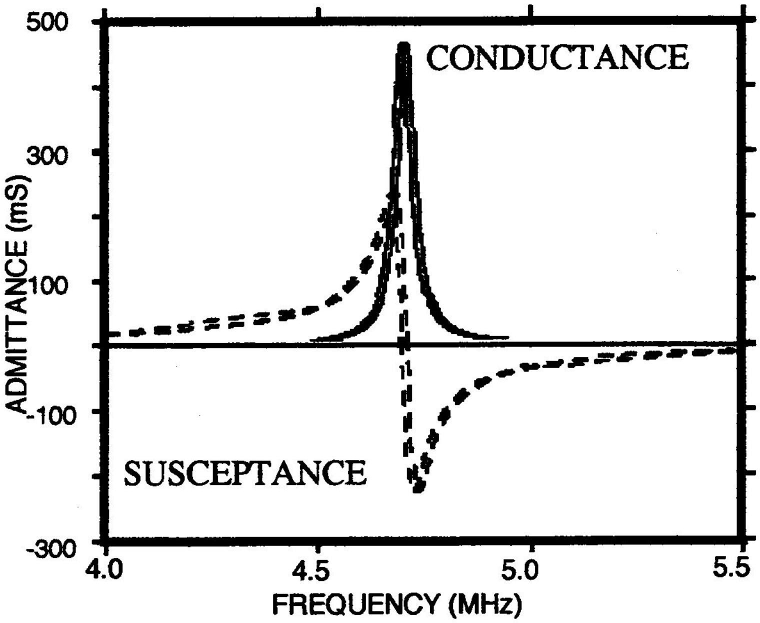
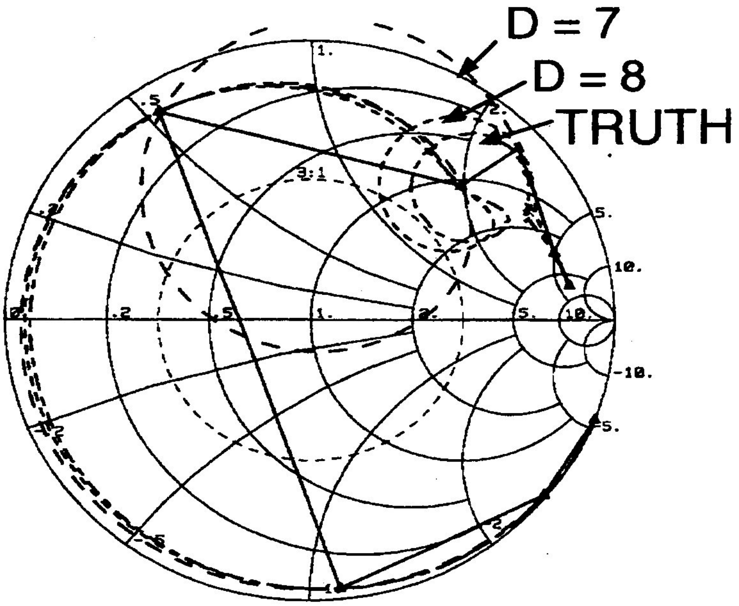
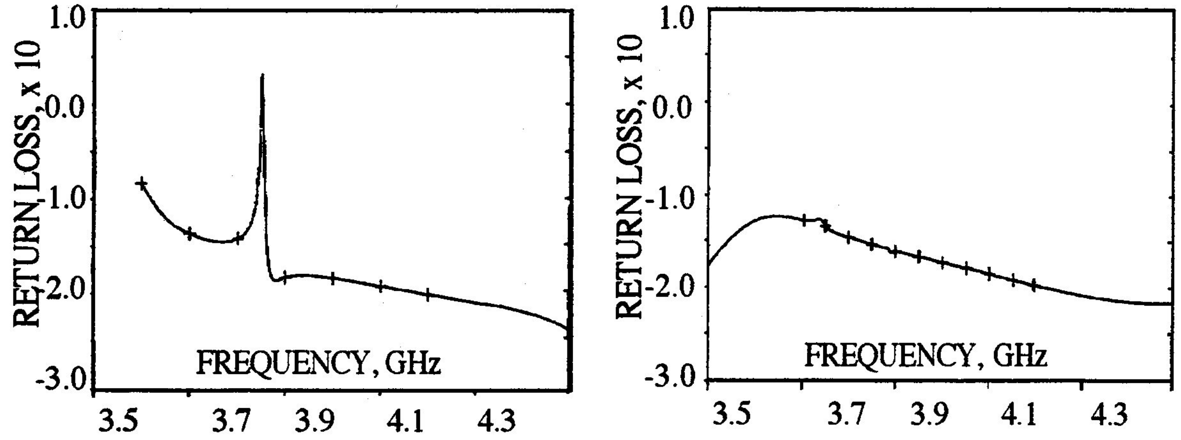


Figure 4. Results for the input admittance of a fan antenna using different sets of GM data and various FMs (solid, conductance; dashed, susceptance). Two FMs, one using D = 7 (with d = n = 3) and the other having D = 11 (d = n = 5), both using GM samples at 0.5 MHz intervals, yield the curves having the rightmost resonances. The other model, having D = 9 (d = n = 4) and using GM samples at 0.14 MHz intervals, yields the curves having the leftmost resonances. As before, these curves are obtained by plotting each FM over the its center sample interval, with each new FM shifted upward one interval. The agreement of the 9-sample FM with the 51-sample GM indicates it is the more accurate of the FMs.

Figure 5. Smith-chart representation of the input impedance of the fan antenna over the frequency range 2 to 9 MHz. The GM samples are shown by the triangles and are connected by a straight, solid line. The 7-sample FM (d = n = 3) produces a nonphysical input resistance near the resonance "loop." Simply increasing the FM order by one brings it into to close agreement with the GM samples labeled "truth" which are computed at 0.14 MHz intervals and connected by straight lines.





(a) (b)

Figure 6. Results obtained from synthesizing a corrugated-horn antenna without using MBPE, (a), and when incorporating a SD FM as part of the synthesis procedure [Fermelia et al. (1993)]. The FM revealed the sharp spike in the return loss that was not apparent in the original design, permitting it to be removed in the MBPE-based design.

3.1.2 Scattering Applications--Use of MBPE for scattering is not much different from its use for representing antenna transfer functions, but where the observable would generally be a far-scattered field rather than input impedance as illustrated above. An example of determining the wideband scattered response of a two-dimensional hollow cylinder with a narrow aperture or slot is presented in Fig. 7 [Kottapalli, et al. (1991)]. The GM result for the scattered field in (a) obtained from an analytic solution, sampled at 949 points in ka to produce an essentially continuous curve, is shown in Fig. 7a. In Fig. 7b, a FDIE model is used to obtain the cylinder current and its first four derivatives at ka values of 2,3,4,5, and 5.3 from which the FM results are obtained for comparison with the GM response. It may be observed that the resonances exhibited by the slotted cylinder are extremely sharp, and can be easily missed unless the GM is sampled using appropriately small ka steps, or unless revealed by a FM whose underlying mathematical behavior is capable of estimating the actual solution accurately enough.

3.1.3 Filtering Noisy Spectral Data--One application of FMs, whether in the WD or SD, is exploiting redundancy in over-sampled data as a way of reducing noise effects. Of course, without any knowledge about how the data of interest has originated, filtering can be done using an averaging, low-pass filter, where several sequential data points are averaged over a moving window. However, such a procedure does not exploit knowledge of the process from which the data has been obtained, whether an experimental measurement or from a GM. Using a parametrized FM offers the possibility of more effective noise reduction because the FM itself adds information beyond that available from the data samples themselves.

This possibility has been explored by Lin (1991) who applied rational-function FMs to noisy SD data for which one result is presented in Fig. 8. It can be observed that the over-sampled noisy spectrum is well-represented by the 4 sequential FMs that were used, demonstrating the potential benefit of combining redundant data and an appropriate fitting model to reduce noise effects in spectral data. It should be realized that successful use of MBPE for the kinds of examples shown here will usually require some experimentation to establish the range of FM parameters that yield the best results. The ill-conditioning of the data matrix that very often occurs also requires the FM computation to be done in higher precision (at least 16 digits, preferably higher) than normally used for the GM

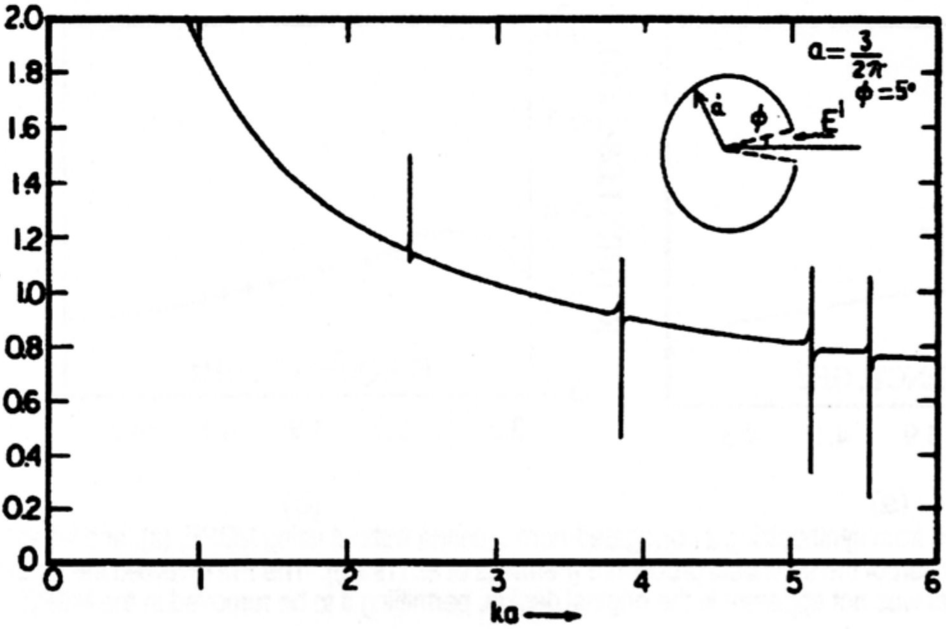


Figure 7a. Analytical GM backscattered far field as a function of ka for a slit cylinder for a TM field normally incident on the 20 degrees slit [Kottapalli, et al. (1991)]. This response is characterized by a series of extremely sharp resonances and thus provides a challenging problem if the transfer function is to be reliably developed using point-wise sampling.

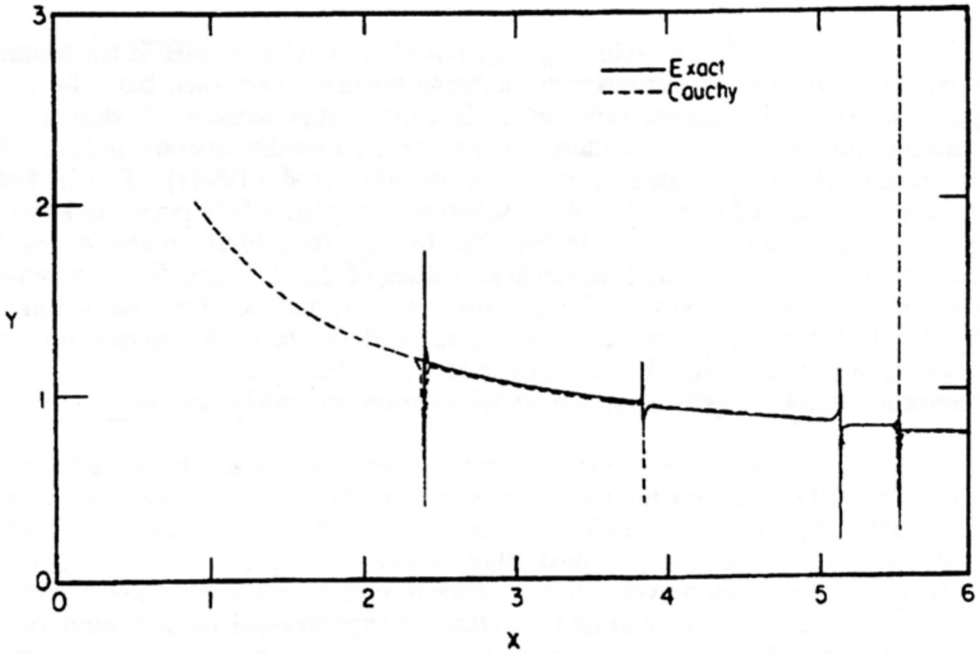


Figure 7b. Comparison of GM (continuous line) and FM (dashed line, denoted as Cauchy) results for the backscattered field from the slit cylinder of Fig. 6a where the FM is based on values of the scattered fields at its first four derivatives at ka = 2, 3, 4, 5 and 5.3. The frequencies of the resonances predicted by the FM are within a percent or so of those from the exact solution.

3.2 Waveform-Domain MBPE

Waveform domain MBPE is usually associated with modeling transient data [e.g., Poggio et al. (1978)]. Since numerous examples can be found in the literature, that particular application is not considered here. Instead, WD application to far-field data (radiation patterns) is demonstrated.

3.2.1 Use of MBPE for Radiation-Pattern Analysis and Synthesis--

The source integral from which a far field is obtained, when evaluated numerically as a phasor summation of incremental source samples while also taking their vector nature into account (a generic example is illustrated in Table I of RI as Model 4) is a candidate for WD MBPE, or Prony's Method An especially interesting possibility is that of developing an analytical representation of a sparsely-sampled far-field pattern as is illustrated in Fig. 9 [Roberts and McNamara (1994)]. They modeled a two-dimensional parabolic reflector using a FDIE, for which 190 field samples were used over a -1.5 to +1.5 radian angle interval to develop a continuous pattern plot over an unspecified number of subintervals in angle. A 1-radian portion of that pattern is shown below where a total of about 58 samples was used, or about 3 samples per lobe. For problems where the pattern samples require significant computation, the benefits of using such an approach can be significant. The authors also point out that number of pattern samples needed using their Prony model was less than the minimum of 237 derived by Bucci and Franceschetti (1987).

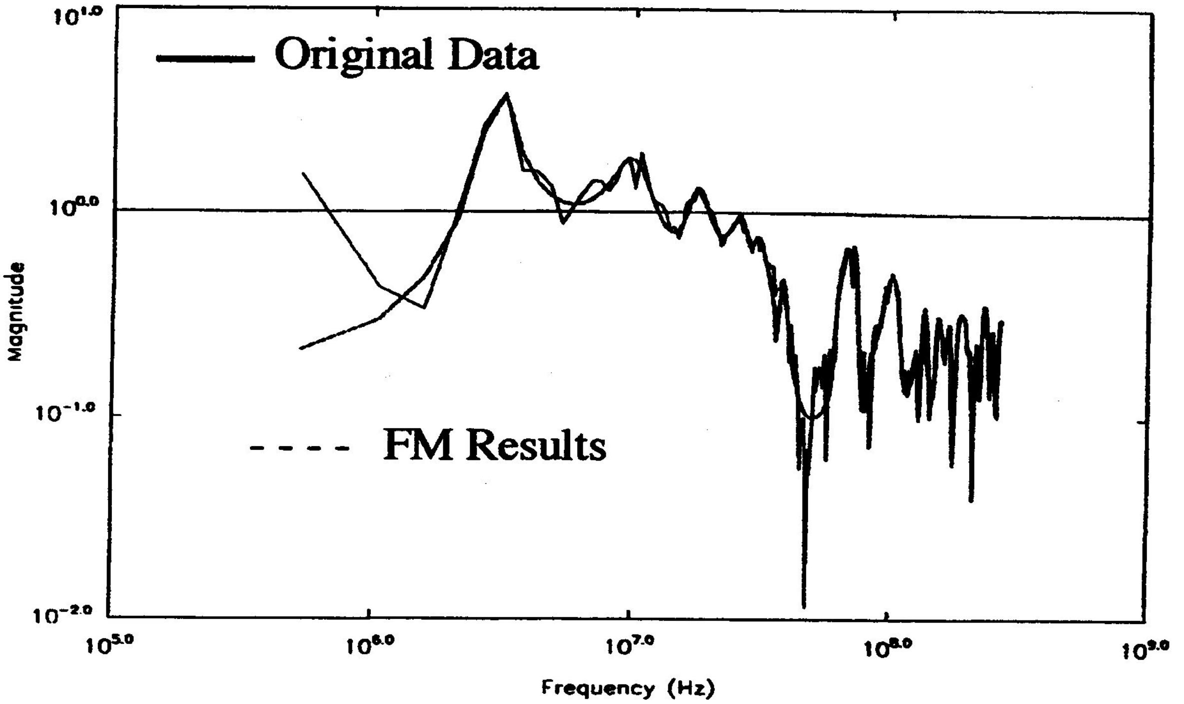


Figure 8. Smoothing of noisy spectral data achieved using a rational-function spectral filter (FM) [Fig. 34 from Lin(1991)]. The original measured data (the solid, more jagged line) has a 20 dB signal-to-noise ratio and 512 total samples of which 12 are randomly deleted. It is modeled using 4 rational-function FMs in sequence (the dashed, smoother curve) having 125 samples each with n = d = 12, 12, 10 and 12 respectively whose coefficients are computed using a least-squares solution.

Another pattern application is that of synthesis where the discrete source distribution required to produce a given far-field pattern is determined. The usual procedure is to specify the antenna geometry and to attempt the synthesis by controlling only the amplitude and phase of each source in the array. But a WD FM provides another way of accomplishing the synthesis in which the source locations, as well as their complex strengths, are both determined. An example of using MBPE for pattern (Prony) synthesis is illustrated in Figs. 10 and 11 where the Taylor pattern for a continuous aperture width A_W = 7 wavelengths is synthesized [Balanis (1982)]. The problem in this case is to develop the discrete array whose pattern, $P_{dis}(S;\theta)$, best matches the specified pattern, $P_{spec}(\theta)$, by varying the number, S, of discrete sources in the array. As S increases from a small value relative to A_W, the normalized mismatch error, $E_n(S;\theta) = |[P_{dis}(S;\theta) - P_{spec}(\theta)]/|P_{spec}(\theta)|$, is initially a poor match with $E_n(S;\theta) \sim 1$, but for $S > A_W$ it decreases exponentially to a minimum where $S \sim 2A_W$ as shown in Fig. 11.

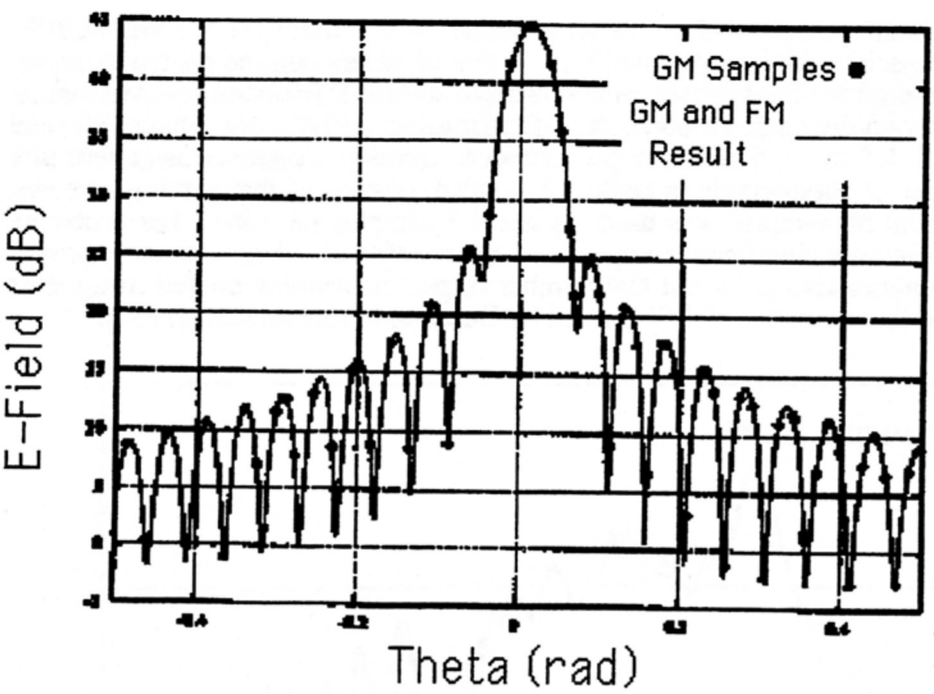
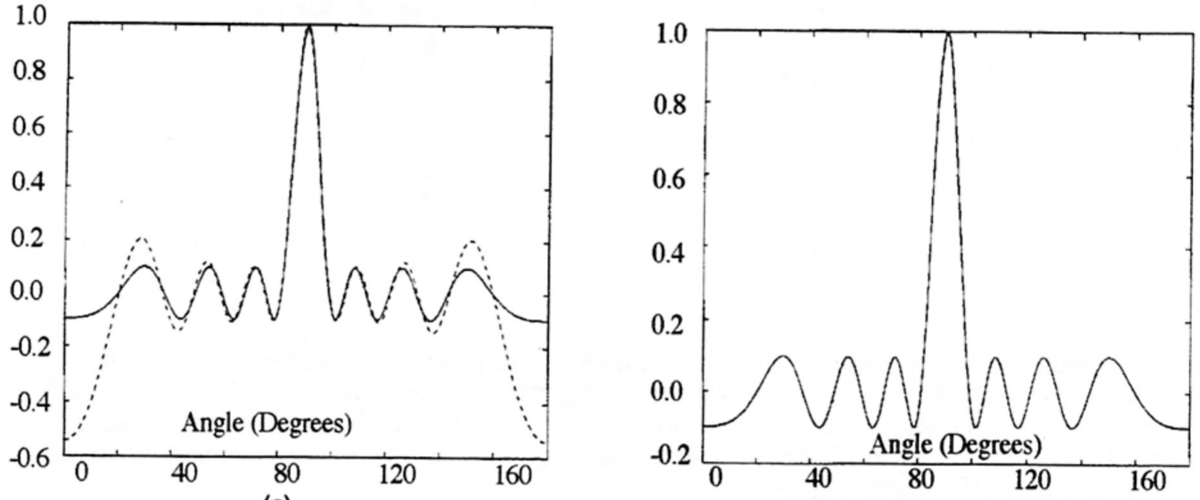


Figure 9. Comparison of finely-sampled GM (solid line) and FM (dashed line) patterns, which overlap and are graphically indistinguishable, where the latter is based on the data points shown by the open symbols [Roberts and McNamara (1994)]. A series of subintervals (width and order of FM unspecified) in angle was used to obtain these results, where it should also be noted that the pattern samples are spaced uniformly in sin(θ), rather than uniformly in θ, in order to retain the polynomial data form required.



(a)

(b)

Figure 10. Comparison of the pattern produced by a specified continuous Taylor source 7 wavelengths wide [Balanis (1982)] and the discrete Prony-synthesized pattern having S = 8 (a) and S = 12 elements (b) [Mathur (1995)]. In the range of S = 8 to S = 14 elements (see Fig. 11), the difference between the desired and synthesized patterns decreases monotonically.

3.3 Waveform-Domain MBPE for Inverse Scattering

When far-field scattered or radiated fields are sampled at a fixed position as the observation frequency is varied, still another kind of WD observable results, of the kind shown in Table I of RI as Model 2. In this case, a discrete set of point radiators or scatterers produces a superposition of observation phasors whose relative phase depends on source distance for a fixed frequency and on frequency for a fixed source. The separate fields of different sources add with phases that depend on frequency and position as a series of complex exponentials, thus becoming a candidate for WD Prony's method. This kind of data can be modeled using Prony's method for any given observation angle relative to a three-dimensional (3D) source distribution. However, in order to reconstruct the 3D spatial locations of the sources, various observation angles must be used, requiring either that the changed relative positions of a given source be identifiable from the different reconstructions, or that simultaneous solutions of observations made from multiple viewing angles be obtained, a problem that the basic Prony method is not able to handle [Miller (1991)]. However, by resorting to a least-squares numerical solution, the WD Prony model can be employed [Hurst and Mittra (1987), Sacchini (1992), Gupta (1994)] to image a distribution of scattering sources in the observation plane when various viewing angles in that plane are available. If different viewing planes can also be used, then true three-dimensional image reconstruction can be feasible.

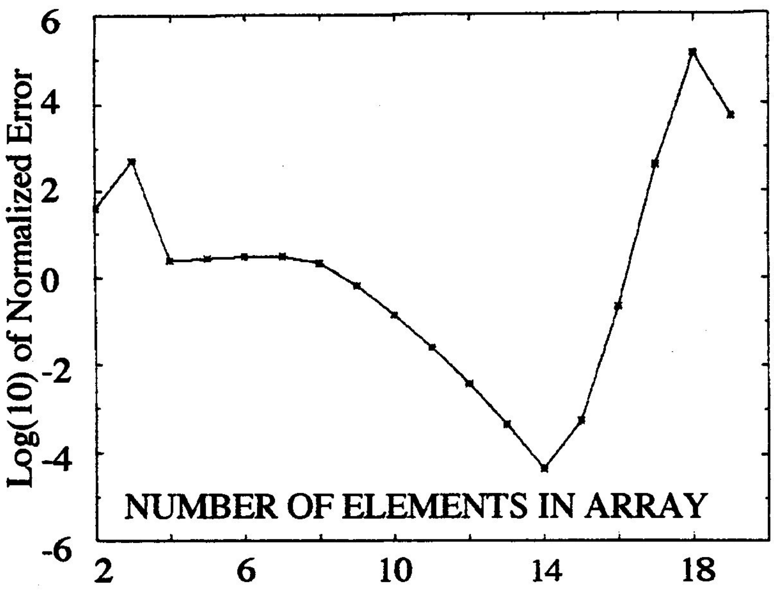


Figure 11. The mean-square between a specified continuous Taylor pattern 7 wavelengths wide and that provided by a discrete Prony-synthesized array have a variable number of elements [Mathur (1995)]. As the number of elements approaches twice the aperture width, the mismatch error becomes a minimum.

An especially simple, but still relevant problem of this kind is plane-wave reflection from a layered half-space where, interestingly, both the impulse response and the swept-frequency reflection coefficients can be expressed in WD forms. Thus, a WD FM can be used for the transient response, or a pole series for the SD FM, where the poles are inversely related to the electrical thickness of the individual layers [Lytle and Lager (1976)]. Alternatively, a WD FM can be used for the swept-frequency response, which also has a pole series SD FM but where now the poles are proportional to the layer electrical thicknesses [Miller and Lager (1982)], an observation previously made by Tai (1978) in connection with a transmission line having sections of different characteristic impedance.

4.0 ADAPTING AND OPTIMIZING SAMPLING OF THE GM

A major advantage of MBPE, and a prime motivating factor for its use, is its potential for minimizing the operation count needed for computing various EM (and other wave-equation phenomena) responses. This is especially the case concerning the time-frequency domain transform pair, where there is more flexibility with respect to sample placement and model order in frequency than in time. A polynomial arises in implementing both the exponential- and pole series FMs, requiring uniformly spaced data in the TD but not in the FD. Actually, this requirement is not inconsistent with how most time-domain computations are performed, where equal time steps are most-often used throughout the time interval for which the model is run. However, it also means that if subsequent evaluation of the time response shows that it was undersampled, it's not very practical to add new samples to the original result; instead, the model computation must be entirely repeated with a new time step. This is not the case for all WD models, however, as is demonstrated by sampling the far fields of a source distribution (model 4 in Table I of RI), where new observation angles can be added to an existing set without repeating any previous computation. This advantage is always true in the FD, where adding one, or several, new function or derivative samples to an existing set can be done while fully retaining the benefit of whatever samples have already been obtained.

Recall that a major goal of using MBPE is minimizing the measurement or computational cost of acquiring and representing observables to a desired accuracy or uncertainty over some specified range of an observation variable. Ideally, this would involve choosing sample locations and derivative orders such that the new information provided by each new sample is the maximum that can be provided over the range of interest relative to the cost of obtaining that sample. If this goal were to be realized for each of the samples ultimately needed for computing the FM parameters while satisfying whatever error criterion is specified, then the overall cost would clearly be a minimum for the chosen error measure. This idea is illustrated conceptually in Fig. 12 below.

There seems to be no obvious or unique approach for achieving this goal, since n and d, the number of samples D and the frequency range they span, are all free parameters in developing a FM. This means that some computer experimentation will usually be required to determine suitable numerical values for them. A few of the several sampling strategies that seem plausible and worth considering are considered immediately below, after which error measures, something that is required by all adaptive procedures, are then considered.

4.1 Adaptive Sampling Strategies

1) A strategy similar to one found useful for adaptive numerical quadrature based on Romberg's method (RM) [Miller (1970)] might be adapted to the spectral-estimation problem. That adaptive procedure involves choosing a starting subinterval over which five successive uniformly spaced samples of an integrand are computed upon which Romberg's method is applied to the three trapezoidal-rule quadrature values that are obtained (samples 1 and 5, 1,3 and 5, and all five samples). An error estimate provided by RM indicates whether new samples are required anywhere in this original subinterval. If that is the case, then two new subintervals are formed from each half of the original subinterval and two trapezoidal-rule values are formed from each (using samples 1 and 3 and 1,2,3 in the first half, and samples 3 and 5 and 3,4,5 in the second). If the RM error estimates show either of these new subintervals to require additional samples, then new samples are added where indicated half way between the original ones and the process is successively repeated. On the other hand, if the initial error is smaller than specified, the process is repeated while doubling the subinterval size. This kind of adaption has been found to work extremely well for numerically integrating sharply peaked integrands, yielding sample spacings that can vary by a factor of 10^6.

2) The first two samples could be taken at the endpoints of the variable range with additional samples subsequently developed by evenly subdividing this range into subintervals until the error criterion has been satisfied over all subintervals that are thus formed.

3) If an error measure is available as a continuous function of the independent variable over the range of interest, then placing a new sample wherever that measure is a maximum seems to be an obvious choice as a way to achieve the greatest amount of additional information from a single additional sample.

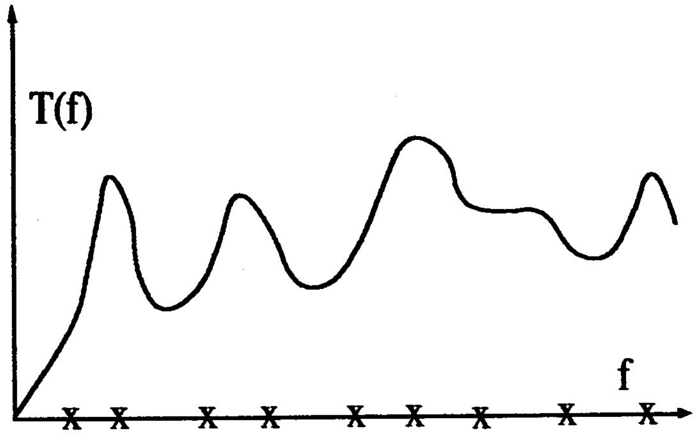


Figure 12. Conceptual diagram to illustrate optimal placement of frequency samples in developing a FM representation of a transfer function T(f). Since there is no computational penalty in doing so, we can expect that the samples would generally be non-uniformly spaced as a means of maximally reducing the uncertainty in the FM representation of T(f) with each added sample.

4.2 Estimating FM Error or Uncertainty

An adaptive process can be only as effective as the error measure used for estimating the degree to which the FM (or its equivalent) differs from the GM (or whatever process whose results the FM is to approximate). This observation is a general one that applies to all manner of numerical processes having the goal to minimize the number of accurate samples that are needed as a means of reducing the cost of developing a sampled representation of some process over a specified range of independent variable(s). For an SD application, it appears desirable to use lower-order FM's over subintervals of the spectral range to be covered to avoid possible ill-conditioning. It then follows that two or more FM's will be needed to span the spectral range of interest, leading to the situation illustrated in Fig. 13. By using overlapping FM's which share common data, their differences, or mismatch errors, can then be used to estimate FM uncertainty as a function of frequency. The minimum match (maximum, or mismatch, error), $\Delta MM_{i,j}(f) = \max\{[|M_i(f) - M_j(f)|]/[|M_i(f)| + |M_j(f)|]\}$ is then computed for each pair of overlapping models as a function of frequency. Subsequent sample placement and type would then be chosen to maximize the information acquired from each sample by adding each new sample at the frequency where the minimum match, ME_i, for all FMs occurs. Sampling of the GM would be concluded when the specified error criterion is satisfied. Also note that, alternatively, an exact error measure results from comparing a FM result with a GM sample $G(f_k)$, using the measure $\Delta GM_{i,k} = [|G(f_i) - M_k(f_i)|]/[|G(f_i) + M_k(f_i)|]$. However, doing this potentially would require more GM samples with a consequent increased computer time, while providing, in addition, only a pointwise error measure in f. Thus, $\Delta MM_{i,j}(f)$ requires less computation and yields a global , but approximate, error measure while $\Delta GM_{i,k}$ requires more computation and yields a pointwise, but exact, error measure.

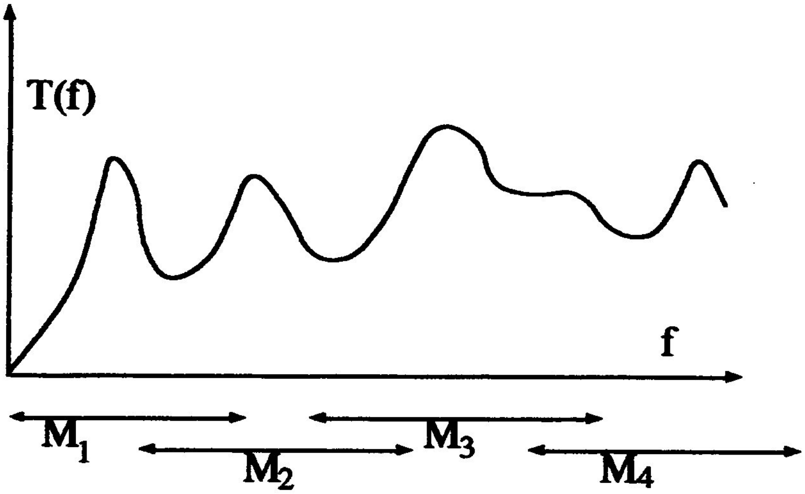


Figure 13 The possibility of developing a FM-representation of a transfer function over a wide frequency interval by employing a number of subinterval, lower-order Fitting Models, M_i, is illustrated here. Each FM represents the response over a frequency interval $F_i = F_{i,u} - F_{i,l}$ where the adjacent FM's share some frequency samples and the difference between them, $\Delta MM_{i,j}(f) = [|M_i(f) - M_j(f)|]/[|M_i(f)| + |M_j(f)|]$ provides a normalized, mutual-error estimate between FM's i and j. By evaluating $\Delta MM_{i,j}(f)$ as a function of frequency, new samples, either function or derivative, can be placed where $\Delta MM_{i,j}(f)$ exhibits values that exceed a specified amount and where, therefore, the corresponding FM results are most uncertain.

There at least three kinds of errors that the FM might produce relative to GM results:

1) Non-physical results are produced, e.g., negative conductance or resistance, as illustrated in Fig. 14;
2) Amplitude shifts in transfer functions;

and

3) Resonance shifts between transfer functions;

with the latter two occurring either between two (or more) FM's or between a FM and the GM result, and for which different sampling decisions might be made. For non-physical errors, an additional GM sample at the peak in negative conductance would seem most appropriate. For baseline-shift errors, an additional sample could be placed at the location of the maximum error if it exceeds the specified error criterion. For resonance-shift errors, an additional sample could be put between the response peaks, again if the shift exceeds the specified error criterion.

To summarize, for a FM having numerator and denominator polynomials of order n and d, respectively, n + d + 1 samples of the GM are needed, which can range, on the one hand, from using n + d + 1 different frequencies to, on the other hand, using one function sample and n + d derivatives at a single frequency. The "best" approach would be that which minimizes the GM operation count required to achieve some specified accuracy or uncertainty criterion appropriate to the transfer function being estimated, sampling adaptively while the most appropriate mix of function and derivative samples. Further improvement might be realized if better ways to handle the effects of non-pole contributions and poles that lie outside the frequency interval of interest could be found. Finally, use of other FM's is worth exploring as well as considering other signal-processing approaches.

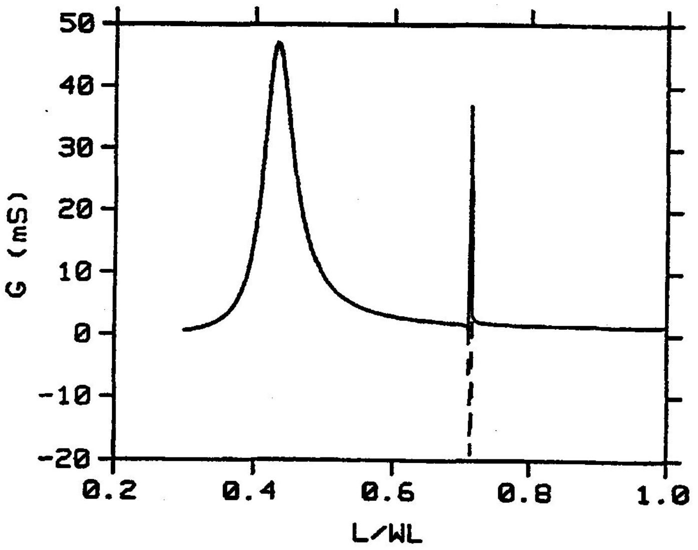


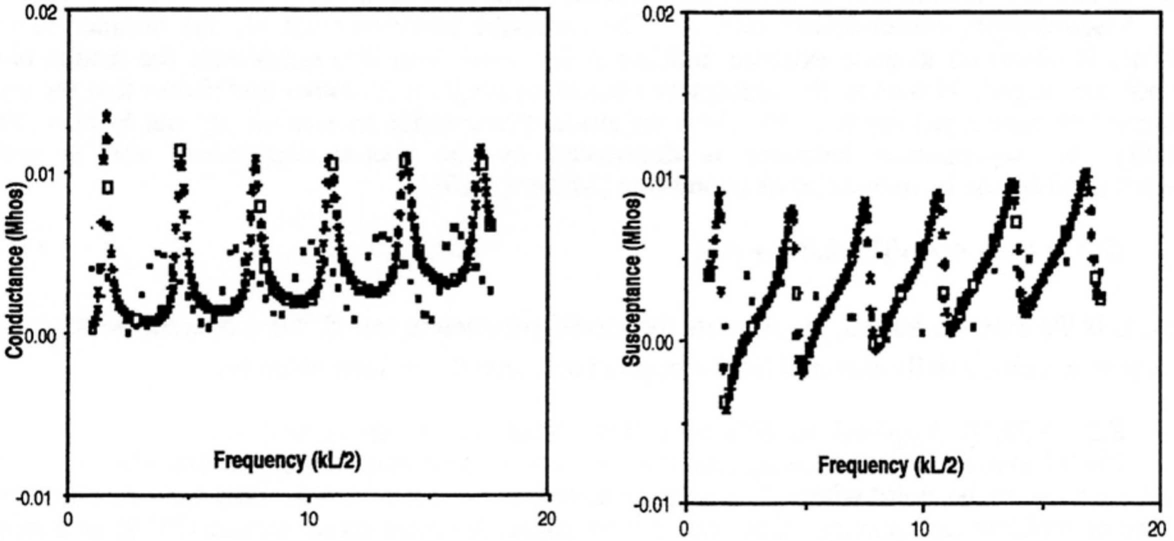
Figure 14. Example of an MBPE FM providing a nonphysical result, in this case negative conductance for an antenna [Miller and Burke (1991)]. Clearly, the best place to place one additional GM sample would be at the maximum value of negative conductance.

4.3 Adaptive Sampling of Antenna Admittance

A implementation of adaptive sampling is demonstrated here for the simple transfer function represented by the frequency-dependence of the admittance of a center-fed dipole antenna. The approach employed is the one illustrated in Fig. 13 with the amplitude difference between overlapping FMs being used to determine when and at what frequency another GM sample is needed, i.e., when $\max|\Delta MM_{i,j}(f_k)| > \varepsilon$, with $\varepsilon = 0.01$ (the mismatch error), another GM sample is obtained at f_k. Results based on this approach are presented in Fig. 15 obtained using as the GM an analytical approximation to the input admittance of a center-fed dipole antenna [Miller (1968)]. The twelve initial GM samples, spaced at 1.5 intervals over the 1-17.5 kL/2 range covered by the calculations, were used with four overlapping rational-function FMs. Two FMs (numbers 1 and 4) extended from GM samples 1-6 and 7-12 (using d = 3, n = 2) and the other two (numbers 2 and 3) extended over the 8 GM samples from 1-8 and 5-12 (d = 4, n = 3, respectively. This resulted in a minimum of 2 FMs overlapping at the ends of the frequency range and three overlapping in the center.

Ten subsequent GM samples were successively added, determined by the maximum difference between the overlapping FMs (in units of kL/2), at 9.1, 2.8, 7.9, 12.1, 4.6, 1.6, 10.9, 17.2, 8.2 and 13.9 at which point the convergence criterion had been satisfied at all remaining FM sample frequencies, which were spaced at 0.3 intervals in kL/2. At this point the four FMs had added 5, 7, 7 and 4 additional GM samples respectively, where the sum is less than 10 because each additional GM sample is shared by two or more FMs. The FMs were changed with each new GM sample by alternately increasing first n, and then d, to maintain a maximum difference of one between the orders of the numerator and denominator polynomials. Note that the new GM samples are mostly located at extrema of the admittance frequency variation, indicating that the FMs are evidently most sensitive to regions of rapid change in the process being sampled. It's also important to note that differences between the average FM values and additional GM samples used as checks were found to be in similar to the differences between the FM themselves, another indication that FM differences seem to be an appropriate way to establish areas of greatest uncertainty in the FM representation of the GM.

It should be observed that if the number of samples used for a FM in a fixed frequency interval is increased monotonically, the condition number of the FM matrix can increase beyond some acceptable threshold. Consequently, as an alternative to simply increasing the number of GM samples per FM until the mismatch error falls below a specified value, it might be more appropriate, or even necessary, to divide a too-large FM into two smaller ones. Another way to handle the ill-conditioning would be to employ singular-value decomposition as a means of handling a poorly conditioned FM matrix.



(a) (b)

Figure 15. Input conductance (a) and susceptance (b) as obtained from an analytical approximation for a center-fed, dipole antenna and modeled using four overlapping FMs. The final FM results (the crosses) are based on the 22 GM samples shown by the locations of the open squares and agree on average to within 0.1% of the actual GM results (the x's). The initial FM estimates (the solid squares) are based on 12 GM samples located at 1.5 intervals in kL/2 (the solid circles). Additional GM samples were added one at a time at the frequency where the maximum difference was found between the overlapping FMs until the specified agreement of at least 1% was obtained between them. Note that the additional GM samples are generally placed at or near maxima in the conductance or susceptance, showing that FM differences provide a good measure of extrema in the GM results and where the greatest uncertainty in the FM result might be expected. See Miller (1996) for further discussion.

5.0 EXAMPLES OF OTHER EM FITTING MODELS

Examples of MBPE applications in physics and engineering are bountiful. Perhaps the first encountered by most engineering students is that of estimating physical parameters from laboratory measurements. These can include determining the characteristics of various power components such as transformers and generators by measuring their inputs under varying loads, and estimating the effective permittivity of materials from reflection and transmission measurements. All such applications involve use of formulas for the anticipated behavior in which one or more parameters are to be numerically quantified from appropriate measurements.

5.1 Antenna Source Modeling Using MBPE

Examples of MBPE more specific to computational electromagnetics (CEM) can be found. It is known that the input admittance of an infinite, circular conducting cylinder excited by a z-directed electric field applied across a finite gap of width δ exhibits a susceptance that goes to infinity as $\delta \longrightarrow 0$ [Miller (1967)]. Physically, this behavior occurs because the feed region behaves as a circular capacitor whose susceptance is approximately $i\omega C \sim i\omega\pi a^2\varepsilon_0/\delta$, where a is the radius of the cylinder and ω is the radian frequency. This effect also extends to antennas whose feed regions are large compared with a, as is the case of a wire antenna modeled using subsectional basis and testing functions with the applied field point-sampled on (or integrated over) the driven segment.

If the number of segments used for the moment-method model is systematically increased to test convergence while continuing to use a single segment as the source, then the effects of model convergence and the variable source model can interact, producing results such as shown in Figure 16 for a 2-wavelength, center-driven dipole. The reactance variation with N, the number of unknowns, is observed to quite extreme, indicating that even with 200 unknowns the results have still not converged. However, the susceptance behavior is much smoother and shows that the conductance has converged for $N \leq 10$ while the susceptance varies monotonically out to $N = 200$. Actually, the susceptance behavior is dominated by the source capacitance and is well-approximated by the infinite-antenna expression [Miller (1967)]

$$B(X_S) \approx A_1 + A_2/[\mathrm{Ln}(L/N) + A_3] \tag{11}$$

where L is the antenna length, the A_i's are the model parameters and $(L/N) = \delta$ is the width of the gap across which a axially-directed field is applied to excite the infinite antenna.

5.2 MBPE Applied to STEM (STatistical ElectroMagnetics)

Use of statistics in electromagnetics becomes more important when problem size and complexity increase to the point where deterministic answers, even if available, may not be very useful because of problem complexity. Consider, for example, the radar cross section (RCS) of a target such as a B-52 aircraft at a frequency of 10 GHz where the target size measured in wavelength exceeds 1,000 wavelengths in linear dimension. The aspect-angle variation in the RCS of such a target is extremely "spiky," with changes of 10's of dB possible for incidence-angle changes of a few tenths of a degree. It's reasonable to ask whether, even were an exact, deterministic solution available for this problem, how such a solution might be used? Of course, in reality the aircraft-to-aircraft variation will be such that an answer for one specific aircraft may not be relevant to another, besides which in-flight measurements are affected by a multitude of additional variations that contribute further uncertainty to what the "correct" answer might be. Thus, at least two reasons for using statistics can be cited, problem complexity and problem uncertainty, where the latter is the usual reason why statistics is used.

As an alternative to deterministic electromagnetics, STatistical ElectroMagnetics (STEM) needs to be considered, wherein various statistical measures of relevant EM observables are used. However, a significant drawback of using statistics arises whenever a probability density function (PDF) and other statistical descriptions of a process are not available from analysis and must instead be inferred from fitting various distribution functions to data. The problem is much simplified if the PDF can be determined analytically instead, which also results in needing substantially less data to numerically quantify whatever parameters are contained in the PDF. This possibility is illustrated in Fig. 17 where experimental data has been fit to an analytically derived PDF by computing numerical values for the parameters of the normal distribution [Lehman (1993)].

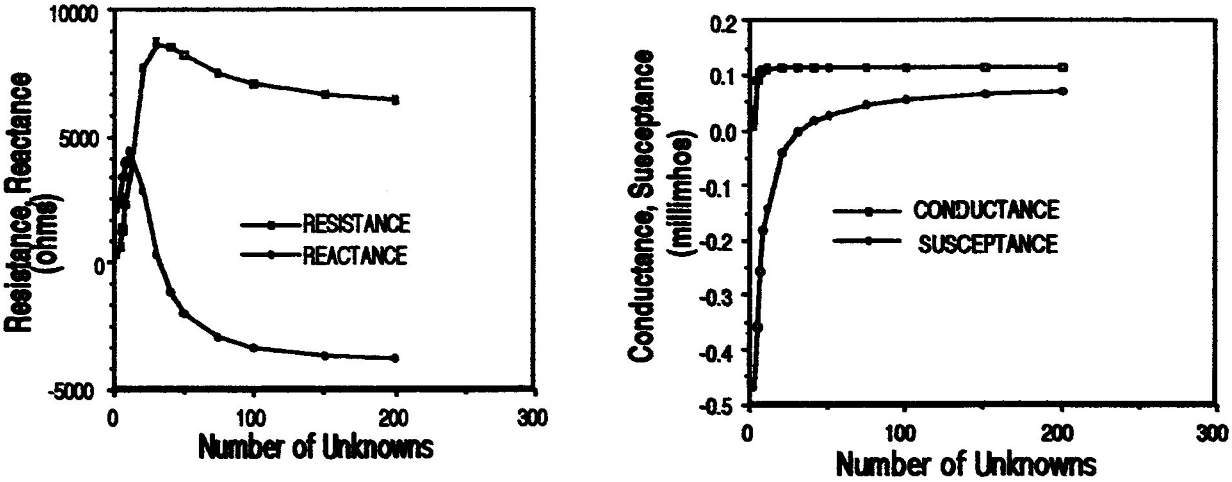


Figure 16. Results from a NEC GM for the input impedance (left plot) and input admittance (right plot) as a function of the number of unknowns,N, used in the model for a center-fed, two-wavelength dipole. The impedance has not satisfactorily converged over the N range shown which the admittance results demonstrate is due to a susceptance variation. In this case, the exciting source was a tangential field applied to the center segment of the antenna, whose decreasing length simulates a changing antenna source gap [Eq. (11)]. The susceptance curve exhibits the kind of variation expected from changing the gap size. In order to avoid this problem, the number of excited segments would have to increase in proportion to N to maintain a constant gap width.

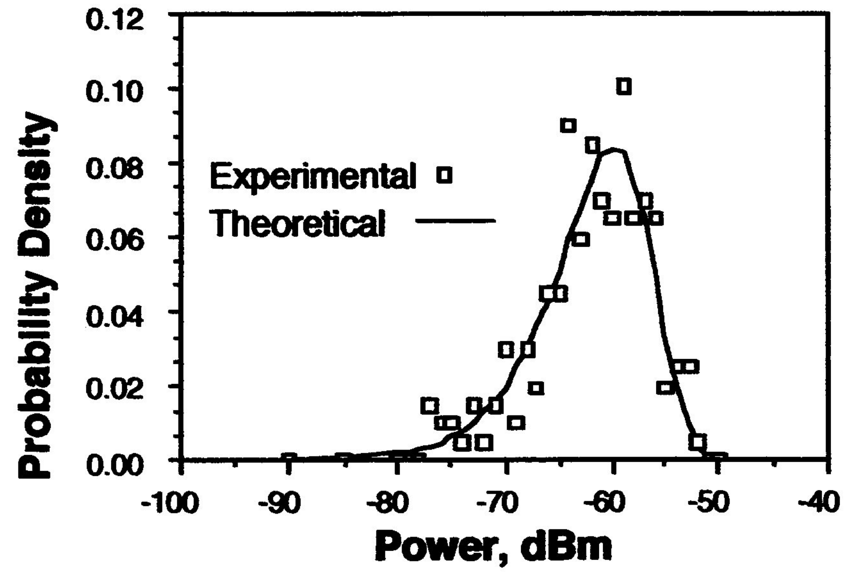


Figure 17. Probability densities and cumulative distributions for the power coupled to a shielded cable in a mode-stirred chamber measured by Kaman Sciences [Smith (1990)] compared with Lehman's theory. This result is typical of the comparisons that Lehman's theory has produced with experimental data obtained in such experiments. Note that the only "floating" parameter needed to complete this comparison is knowledge of the experimental power density. [After Lehman (1993)].

6.0 CONCLUDING COMMENTS CONCERNING APPLICATION OF MBPE TO ELECTROMAGNETIC OBSERVABLES

This discussion has considered the rationale and illustrated the application of model-based parameter estimation (MBPE) to achieve reduced-order representations of electromagnetic observables via fitting models (FMs), the "model-based" part of MBPE, that derive from the physics of EM fields. The "parameter-estimation" part of MBPE is the process of obtaining numerical values for the coefficients of the FM by matching or fitting it to sampled values of the EM observable of interest. Although a wider range of FMs are feasible, attention here is focused on what are termed waveform-domain models, comprised of exponential series, and spectral-domain models, comprised of pole series. These kinds of FMs are shown to provide natural "basis functions" for many kinds of EM observables, whether these observables are based on experimental measurement or numerical computation.

The role of models in science and engineering is crucial both to demonstrate correct understanding of the applicable physics that the models are intended to represent and to exploit this understanding in developing practical application based on that physical understanding. The models employed can be "first principles" or generating models (GMs) such as Maxwell's equations which can, in principle, provide a numerical solution of arbitrary accuracy to whatever problem is of interest so long as the problem itself can be described to sufficient accuracy. They can also be scale or "real-life" physical models where measurements yield an "experimental solution." In practice, of course, computer resources and other limitations constrain both the accuracy of the numerical solution obtained for the numerical model and the fidelity to which that model replicates the physical problem it is intended to represent. Similar kinds of observations can be made about experimental measurement.

Problem complexity, deriving from the information needed to adequately define its geometrical and electrical properties, and from the information needed to describe its electromagnetic response, further limits what can be done with GM solutions or experimental measurement. Thus, even if there were no limitations to solving first-principles models or conducting measurements, the utility of the results obtained may, paradoxically, be limited by their sheer complexity. Beyond that, practical considerations ensure that relying only on data from either source for design purposes will generally be unacceptable because the costs of that data will generally reduce the coverage of the parameter space that can be explored, leading to uncertainty about whether important behaviors have been missed and whether the performance synthesized numerically will be actually achieved.

Physically based FMs on the other hand complement the GMs on whose samples they are based by offering the possibility of accurately representing the physical observables produced by the GM while doing so with orders-of-magnitude reduced rank or complexity. These FMs, furthermore, provide an analytically continuous quantitative representation of the observable they model while revealing details that a coarsely sampled GM can easily miss. Thus, not only does an appropriate FM greatly decrease the amount of GM sampling required, but it leads to a more useful form for needed observables as analytically useful formulas rather than, for example, tables of numbers. Although a wide variety of FMs relevant to electromagnetic fields can be identified, the more useful seem to be the exponential and pole series to which most attention has been devoted here, since they form a natural basis for many kinds of electromagnetic observables.

As a final point, it is worth noting that a FM is well-suited to adaptive sampling of the observable it is intended to represent. This means that sampling can be algorithmically tailored to how a given observable changes with the relevant independent variable(s). The usual *ad hoc* sampling approach increases the cost of data acquisition when over-sampling occurs, or increases uncertainty about the actual behavior of an observable when under-sampling results. On the other hand, adaptive sampling naturally leads to a variable sampling density when the observable behavior permits this, and total number of samples is controlled by the observable behavior and the uncertainty acceptable in its FM representation.

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EDITORIAL

The Role of Computational Electromagnetics in Wireless Communications Part V: Chip Level Interference in Wireless Communications.

We keep "descending", from the structural point of view, on the study concerning the applicability of computational electromagnetics in wireless communications. In the last issue we addressed how computational electromagnetics can help in the design of printed circuit boards, multichip modules and most general board level design. In this section we will address how computational electromagnetics can help in the design of wireless communications products at the chip level.

The most predominant application of computational electromagnetics at the chip level design lies within the realm of interference scenarios in wireless communications systems. The objective is very simple: how can computational electromagnetics help predict noise level within chip design, especially for the case of mutual noise interference scenarios in wireless communications ? Consider the case of Figure 1 where an external noise source (e.g a nearby transmitter) is affecting the performance of a given network. The electrical network can be isolated by a metal enclosure, as shown in the figure, however electromagnetic radiation can still get through by apertures, imperfect seams,...etc. The electromagnetic radiation couples into the transmission lines and the induced noise current will affect the chips nominal voltages and currents. Figure 2 shows three scenarios where coupled noise can affect the performance of a NAND gate. The RF voltages induced are modeled by a Thevenin equivalent voltage source Vn with characteristic impedances Rn. Each of the three different cases in Figure 2 causes variable results in the behavior of IC chips. For example, RF signal present in the output terminal causes IC transient behavior at much lower RF level than noise present in input terminals.

Experimental work has been done in the past [1-3] that assess the noise immunity of CMOS chips. CMOS technology is very important for VLSI circuits. Attractive features of CMOS include very low standby power, large noise margins, straight forward circuit design, reliability and low cost. Faster CMOS circuits however, are susceptible to radio frequency interference. Data sheets published by IC manufacturers show static characteristics for noise, but do not show dynamic characteristics. Also noise immunity has been represented as a function of pulse width. However, this does not represent noise immunity characteristics for rapid rise time/fall time of the noise causing malfunction. Consider the case of Figure 3 which shows the experimental apparatus, input waveform (through a pulse generator) and output waveform reading (through a digital oscilloscope) for assessing the noise figure of IC chips. In Figure 4 the bias shown means high state input voltage and pulse voltage ascending from high state representing the noise waveform. When noise voltage increases, output voltage corresponding top noise increases. Noise margin δV, the input voltage amplitude in the case that output voltage amplitude exceeds the threshold voltage V_{iL} (about 2.5V) of the next stage IC, is defined as the index of noise immunity.

Modeling noise immunity is a much more difficult problem but proper modeling verified with the above experimental work can yield great advances in addressing chip level interference problems. Noise margin modeling requires the combined use of computational electromagnetics and SPICE level network analyzers. For a typical scenario as shown in Figure 1, computational electromagnetics can be used to model: a) the radiated energy from transmitter (if not known already), b) the energy coupled through apertures, and c) the coupled noise to transmission lines to obtain the induced noise current and voltages.

These three steps in the use of computational electromagnetics can become very complex and can easily consume the majority of the work and most likely require the use of hybrid methods. A Norton or Thevenin equivalent can then be modeled and used in a SPICE network analyzer to study the effects of such noise in IC chips. This will eventually lead to the calculation of noise margins.

Though we have simply stated the principles needed in modeling noise margins using computational electromagnetics and network analyzers, there are serious difficulties in implementing such an approach: a) several computational electromagnetic tools must often be used simultaneously (hybrid) or in sequence, b) coupling to transmission lines will often be in the near field which is highly difficult to model properly

c) coupling will occur at simultaneous locations within the electronic structure, and d) multiple noise sources will need to be modeled within SPICE. These challenges however, are an opening door for great opportunities to advance the state of the art in these areas and seems to promise research opportunities which would be highly relevant to wireless communications.

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Reinaldo Perez
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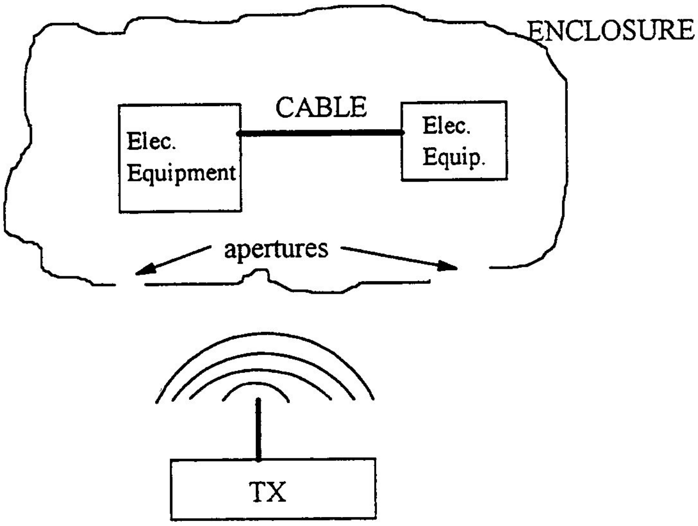

FIGURE 1. COUPLING OF ELECTROMAGNETIC FIELDS INTO ELECTRONICS

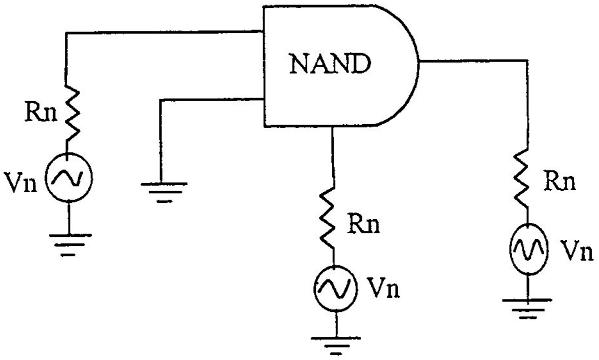

FIGURE 2. ILLUSTRATION OF RF SIGNAL COUPLING INTO IC CHIPS

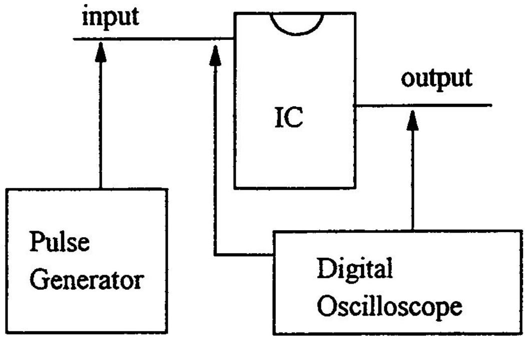

FIGURE 3. MEASURING RF NOISE SUSCEPTIBILITY IN ICs

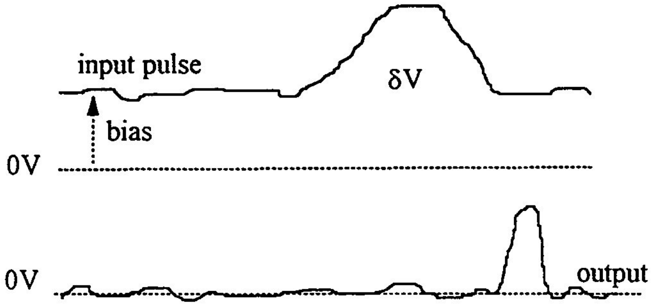

FIGURE 4. WAVEFORMS FOR INPUT AND OUTPUTS

Computational Electrodynamics: The Finite-Difference Time-Domain Method

by

Allen Taflove, Artech House, Boston, 1995, 599 pages

Reviewed by: James L. Drewniak, Electromagnetic Compatibility Laboratory, Department of Electrical Engineering, University of Missouri–Rolla, Rolla, MO 65401

Computational Electrodynamics: The Finite-Difference Time-Domain is written by a pioneer and leading contributor to the theory and application of this robust numerical method. In the preface to the book, Taflove briefly recounts with enthusiasm his discovery of Kane Yee's original paper, and the possibilities he envisioned for this numerical technique that has become known as the finite-difference time-domain method (FDTD). In the ensuing twenty plus years, Taflove's contributions to the development of FDTD for electromagnetic field interactions reflect this same enthusiasm and single-minded belief in the possibilities for wide application of the method. This well-written book retains that spirit of enthusiasm in laying out the fundamentals of FDTD and present "state of the art", while implicitly looking to future untapped applications of FDTD.

The advent of powerful and affordable desktop computers has led to numerous applications of FDTD in many diverse areas of electromagnetics since the late 1980's. A recent selective review of the FDTD literature by Schlager and Schneider [*IEEE Antennas and Prog. Mag.*, vol 37, pp. 39-57, Aug. 1995] containing over three-hundred references, indicates that the number of FDTD articles appearing in the literature grew from a mere handful in 1985 to over 200 articles published in 1994. FDTD is theoretically relatively straight-forward and remarkably robust, however, there are many details to master prior to successfully implementing the method for modeling complex problems. This book does a wonderful job of laying out the theory and practical implementation of FDTD in a clear and concise manner. It is an essential text for a newcomer learning FDTD, as well as a valuable reference for a more experienced practitioner. The book serves well as a teaching text for an upper level undergraduate and beginning graduate class, and includes end of chapter problems for all but one chapter. It is also a good text from which to learn for a professional pursing a self-study of FDTD.

The book has sixteen chapters, some relatively short, that is well organized into two sections, although there are no specific section designations. The first section comprising Chapters 1-7 details the fundamentals of FDTD, and begins building from very basic principles and concepts. The development begins simply with a scalar wave equation, continuing into the 3D Yee algorithm, stability, numerical dispersion, source implementation, and absorbing boundary conditions. The second section, Chapters 8-16, covers more specialized topics including, near-to-far-field transformation, dispersive and nonlinear materials, subcellular methods, unstructured grids, bodies of revolution, high-speed digital circuit modeling, antennas, RCS and complex wave scattering, and FDTD algorithms for vector and multiprocessor computers. Chapters 1-10 and 15 were written by Taflove, and the remaining chapters were contributed by several former students of Taflove, and other colleagues. Throughout the writing is well organized, clear, and concise.

The first section on FDTD fundamentals is sufficiently clear and complete that a student or professional new to the area could confidently write a 3D FDTD code after completing a study of these chapters without the aid of additional reading materials. Chapter 1 is an overview of the development of FDTD, and a perspective on where differential-equation based techniques, and in particular FDTD fit into the larger picture of computational electromagnetics. Several specific applications of FDTD are briefly discussed including RCS, antenna design, high-speed digital circuits, and optics. There are several pages of "flashy" color pictures showing FDTD simulation results for these applications that I liked because the simulations can provide unique physical insight with suitable post-processing.

Chapter 2 begins the development of the FDTD method with the one-dimensional scalar wave equation. Finite differences are discussed, and the second order accuracy of the discretized scalar wave equation with central differences is shown. The numerical dispersion relation for the 1D scalar wave equation is derived, and numerical phase velocity investigated. The chapter concludes with a development of numerical stability for the 1D algorithm. This short introductory chapter lays out in a simple manner the basic considerations in numerically pursuing a second-order accurate time-marching solution to the wave equation. The treatment of topics in Chapter 1 is very balanced between underlying theoretical details, and the operational mechanics of obtaining an update equation for the independent variable that can be immediately implemented in code. With only a few exceptions, this balance is achieved throughout the text.

The 3D FDTD algorithm on a rectangular grid, or Yee algorithm, is introduced in Chapter 3. A good qualitative description of the Yee algorithm is presented that provides the reader with some insight into the salient features of the method. The basic finite-difference equations for the six independent field components are developed from the source-free Maxwell's equations in differential form for a general medium, and the distribution of the components over the Yee cell discussed. It would have been helpful if the development at this stage had included impressed source terms. These details, however, are contained in a later section. A section interpreting FDTD in terms of the integral forms of Ampere's and Faraday's law is provided as well. This section appearing early in the book is very helpful for those learning FDTD because it relates the algorithm to the physics of Maxwell's equations contained in the circulation and flux integrals. This insight is essential, since the application of boundary conditions at material interfaces and many subcellular methods are developed from the contour integral interpretation. The divergenceless property of the Yee algorithm is shown, and a short discussion of exponential time-stepping for highly lossy media is given.

Chapters 4 and 5 are short chapters detailing numerical stability and dispersion, respectively, for the Yee algorithm. A rigorous treatment of stability is presented in two dimensions, and generalized to 3D. The author is careful to point out that while the basic algorithm is stable for appropriate choice of time-step, that perturbing the algorithm by introducing approximate absorbing boundary conditions, subcellular approximations (e.g. wires, slots, lumped elements), variable meshing, or boundary fitting approximations can potentially introduce instabilities. The reader is cautioned to always be vigilant in such cases. A good set of general references on stability are given at the end of the chapter. Chapter 5 develops the numerical dispersion relation for the Yee algorithm. Examples of the phase velocity for varying mesh dimensions and angle of wave propagation through the mesh are given. An example that lends insight into how fast phase errors can collect is given. Trade-offs between the second-order Yee algorithm and higher-order differencing are also briefly discussed.

Implementation of sources in free-space and waveguides is discussed in Chapter 6. The chapter focuses primarily on the total-field/scattered-field formulation for implementing a source. The computational domain is divided into a total- and scattered-field regions, and the source implemented via a connection scheme across the boundary. While the approach is general, it is most easily employed with plane-wave excitations. The algorithm is developed in careful detail in two dimensions and update equations are given. Extension is made to 3D, with the relevant time-marching equations provided. While the algorithm can get confusing, the text and figures provide good direction. The chapter concludes with a qualitative discussion of FDTD source modeling in waveguides. A broader discussion of sources and source modeling would have been helpful, e.g., impressed or soft sources, voltage and current sources, antenna source models, and sources for printed circuits.

Absorbing boundary conditions (ABCs) for truncating the computational domain in open region problems are treated in Chapter 7. The discussion proceeds roughly from a historical perspective beginning with the Bayliss-Turkel annihilators, followed by Enquist-Majda one-way wave equations. The mathematical details of the development are provided in both cases. The differential equations for the second-order approximation of the one-way wave equation at all six computational domain boundaries in a rectangular grid are given, and the finite-difference scheme for one is derived (resulting in the usual second-order Mur ABC). Higher-order ABCs are also discussed. Brief discussions of the Higdon operator, Liao ABCs, and Mei-Fang superabsorption are also given. The chapter concludes with a discussion of the Berrenger perfectly matched layer (PML) ABC in free-space and waveguides. The treatment follows that given by Berrenger in his original work, and retains the same notation. PML ABCs are compared to second-order Mur. The theory is well-developed, however, this is one of the few sections of the book that is lacking in implementation details. PMLs are an area of considerable current investigation, and several important papers have appeared in the literature since the publication of this book.

More specialized applications of FDTD are contained in Chapters 8-16. Chapter 8 details two near-to-far-field transformations for FDTD. The first approach is a frequency-domain method, and starts from first principles in two dimensions. Annotated FORTRAN code segments for performing a recursive DFT are provided for obtaining time-harmonic field quantities from the time-domain simulation. The 2D discussion is extended to 3D. A time-domain near-to-far-field algorithm is also presented for calculating the time-domain far-fields concurrently, and implementation details of the algorithm are provided.

Chapter 9 discusses FDTD modeling of dispersive, nonlinear, and gain materials. Two formulations of FDTD modeling of dispersive materials are presented, recursive convolution (RC) and auxiliary differential equation (ADE) methods. The RC method is treated for Debye and Lorentzian materials as well as for a linear gyrotropic medium. The necessary fundamentals are discussed, and explicit time-marching equations are given for both total and scattered field formulations. The ADE method is motivated with a simple 1D example, and the ADE's and associated time-marching equations are given for first- and second-order materials. Results are presented for second-order materials with single and multiple resonances. Overall the reader is left with some feeling for the tradeoffs between the two methods, the computational efficiency of the RC approach, and the robustness of the ADE method. Good discussions of the ADE method applied to nonlinear optics and gain media (lasing) are also presented.

Among the most attractive features of FDTD is the potential for modeling small features relative to the mesh dimension without meshing down to the small scale. Subcellular methods for modeling a limited class of slots, boundary fitting, thin wires, thin material sheets, and a dispersive surface impedance are discussed in Chapter 10. Methods for modeling voltage sources and lumped elements at the cell level are treated in a later chapter. The subcellular methods presented are based primarily on the contour path interpretation of the FDTD algorithm that is described in Chapter 3. An algorithm for thin slots with depth is presented, as well as thin wires, and conformal modeling of curved sheets. Sufficient details are provided for the underlying principles and approximations, as well as for readily implementing these algorithms. Good discussions of thin-material sheets and dispersive surface impedance boundary conditions are also given. The chapter concludes with a brief note of caution regarding stability when introducing subcellular algorithms. It is difficult to provide even a cursory treatment of the most significant work done in FDTD subcellular methods in the limited space of one chapter, and some significant developments were necessarily omitted. However, a good list of additional references are provided at the end of the chapter.

Chapter 11 on FDTD for nonorthogonal and unstructured grids was contributed by Gedney and Lansing. This chapter discusses tensor-based nonorthogonal FDTD and discrete surface integral (DSI) based FDTD methods. A brief discussion of FDTD on non-uniform orthogonal grids with examples is also given. Necessary tensor algebra is presented, the nonorthogonal FDTD method for a general curvilinear space and oblique space are given, and stability is discussed. The DSI-based FDTD algorithm is also discussed. This algorithm, while significantly more difficult to implement than the tensor-based algorithm, has the advantage that it is very general and suitable for unstructured meshes, and allows for a great deal of modeling flexibility. A fundamental challenge with this algorithm is that the edge vectors in the primary and secondary meshes ($\overline{\overline{\mathbf{E}}}$- and $\overline{\overline{\mathbf{H}}}$-field) are not orthogonal to the the face of its dual. As a result vector reconstruction and projection steps are necessary in the leapfrogging algorithm. Conceptually the problem is not difficult, but the details of implementing the algorithm are complex. While this section is well-written, implementing the DSI-based algorithm requires many details that could not be included in scope of the book. Several modeling examples and results are given, as is a picture of an unstructured mesh for a power divider that illustrates the modeling flexibility of this approach.

The body of revolution algorithm for FDTD, contributed Jergens and Saewert, is detailed in Chapter 12. The treatment is thorough and sufficient details given to readily implement this algorithm. Chapter 13 is contributed by Piket-May together with Taflove and focuses on modeling high-speed digital circuits. This chapter contains several FDTD topics applied to printed circuits including discussions on impedance and lumped element parameter extraction, signal processing and spectrum estimation techniques (Prony's method and autoregressive models). A good treatment of lumped element modeling is also presented for resistors, capacitors, inductors, voltage sources with source resistance, diodes and transistors. A short section showing that FDTD can be linked with SPICE is also provided, however, there are no details as to accomplishing this. This work is relatively recent, and, hopefully more details will appear soon in the literature.

Chapter 14, contributed by E. Thiele, presents applications of FDTD to antenna analysis. The chapter focuses primarily on two examples, a monopole over ground and a Vivaldi array. The chapter gives the reader an idea of the potential of FDTD for antenna analysis. Antenna applications of FDTD continue to be a challenging area of research. Among the difficulties are the widely varying scales of the problem between the feed geometry and the gross antenna conductors. Accurate input impedance calculations require the feed geometry to be modeled well. However, the number of unknowns in the problem can grow quickly. One example (far-field results) given for a single Vivaldi element employed 4.2 million unknowns and a Cray Y-MP for the solution. Chapter 15 discusses RCS, enclosure penetration and coupling, and biological applications of FDTD. Much of the chapter is from early work in FDTD. The final chapter contributed by Gedney and Barnard is on FDTD algorithms for vector and parallel computers. This chapter gives a brief overview of the essential elements of vector and parallel processing, and the implications for FDTD. Specific FDTD examples are used in both cases that provide the reader with good direction. A parallel algorithm for FDTD on an unstructured mesh is also considered, and several domain decomposition algorithms for parceling the computational load among processors are discussed.

Overall I felt this was an excellent book that is useful as a course text, or for self-study. The book is logically organized, well-written, and does a thorough job of presenting the fundamentals of FDTD from underlying theory to implementation details. The material throughout is well referenced. Many choices were made on the material to include in the applications chapters, and much of it was from the work of Taflove and his students. However, I felt that other important work was well treated, and overall the text was scholarly.

SOFTWARE REVIEW

"MININEC Professional for Windows"

EM Scientific, Inc.
J.W. Rockway and J.C. Logan (authors)
Reviewed by R. Perez

NOTE: Though we have titled this article "Software Review", this article pertains only to the description of software capabilities as described by the authors. No independent benchmark or evaluation studies have been performed in this case. Over the next several issues of the ACES Newsletter we will devote some time to let our readers become familiar with the capabilities of recent commercial electromagnetic tools that have appeared on the market.

If you would like to contribute to this column with a review of a recent tool you are presently using, please contact R. Perez.

The "MININEC Professional for Windows" is a computer program for the analysis of wire antennas in MS Windows environment (PC 486 or above is recommended, 4MB RAM, and sufficient hard disk space). The program is capable of analyzing antennas that are characterized by an arbitrary collection of thin wires in either free space or over a ground plane. The method of moments is the foundation of MININEC Professional. The Galerkin procedure is used in the electric field integral equation to solve for the wire currents. If you did not know by now MININEC is not a junior version of the well known NEC code. MININEC uses a different formulation for the integral equation for the current and fields from wires and different algorithms are also involved. The program uses both BASIC and FORTRAN. The formulation uses triangular basis function and for the ground plane Fresnel reflection coefficients are used.

The user interface to MININEC Professional is like spread sheet for data screens and is interfaced to Windows printer drivers. Some of the features are: 1) straight, helix, arc and circular wires, 2) node coordinate stepping, 3) frequency stepping, 4) lumped parameter loading, transmission lines, 5) Cartesian, cylindrical, and geographic coordinate systems (in meters, centimeters, feet or inches), 6) 3D geometric display with rotation/zoom/mouse support, 7) 3D current and charge displays, 8) linear, semilog and log-log plots of currents, coupling, near fields, impedance and admittance, and 9) linear and polar pattern plots. The general capabilities of MININEC Professional are: 1) current and charges on wires, 2) impedance and admittance, 3) near electric and magnetic fields, 4) far field patterns and electric fields, 5) effective height and current moments, 6) multi-port (antenna-to-antenna) coupling.

The program comes with four example problems (parallel dipoles, dual quad antennas, tee antenna, partial symmetry computation of tee antenna). The user is also provided with evaluation information to assess the technical limits of the code. The code is evaluated with respect to results reported in the professional literature and against NEC4 results and considerable amount of data is provided in this respect.

Some Theory: The three computational programs of MININEC professional are CURRENT, NEARFLD, and PATTERN. CURRENT solves for the currents of thin linear wires. NEARFLD uses these currents to solve for the near fields of the wires. PATTERN uses the current to calculate the radiation patterns of the wires. The computational program CURRENT is based on the numerical solution of the electric field integral equation [1]. As we all know leads to a very efficient matrix solution program. The theory is based on the derivation of Wilton [2]. The theory applies not only to straight wires but also to bent wires. In MININEC professional bent wires are treated in the same manner as the junction of multiple number of wires. A bend in an otherwise straight wire is treated as the junction between two straight wires. It has been generally accepted that the currents at junctions of thin wires must conform to Kirchoff's current law. Rather than explicitly enforcing this condition in this code, an overlapping segment scheme [3-4] is employed at junctions of two or more wires. MININEC Professional automatically determines, during geometry input, whether there is a connection on either end of a wire, and if so, to which wire and wire end it is connected. After solving for the current triangle amplitudes, MININEC Professional then computes the junction currents, if any, for each wire end. The method of images is used in the MININEC Professional algorithms to solve for currents on wires located over a perfectly conducting ground plane.

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The program comes with four example problems (parallel dipoles, dual quad antennas, tee antenna, partial symmetry computation of tee antenna). The user is also provided with evaluation information to assess the technical limits of the code. The code is evaluated with respect to results reported in the professional literature and against NEC4 results and considerable amount of data is provided in this respect.

Some Theory: The three computational programs of MININEC professional are CURRENT, NEARFLD, and PATTERN. CURRENT solves for the currents of thin linear wires. NEARFLD uses these currents to solve for the near fields of the wires. PATTERN uses the current to calculate the radiation patterns of the wires. The computational program CURRENT is based on the numerical solution of the electric field integral equation [1]. As we all know leads to a very efficient matrix solution program. The theory is based on the derivation of Wilton [2]. The theory applies not only to straight wires but also to bent wires. In MININEC professional bent wires are treated in the same manner as the junction of multiple number of wires. A bend in an otherwise straight wire is treated as the junction between two straight wires. It has been generally accepted that the currents at junctions of thin wires must conform to Kirchoff's current law. Rather than explicitly enforcing this condition in this code, an overlapping segment scheme [3-4] is employed at junctions of two or more wires. MININEC Professional automatically determines, during geometry input, whether there is a connection on either end of a wire, and if so, to which wire and wire end it is connected. After solving for the current triangle amplitudes, MININEC Professional then computes the junction currents, if any, for each wire end. The method of images is used in the MININEC Professional algorithms to solve for currents on wires located over a perfectly conducting ground plane.

For a wire attached to ground, a current pulse is automatically added to the wire end points connected to ground so that current continuity with its image is observed. If a lumped load (^{z}load$=R+jX$) is added to the structure so that its location coincides with that of one or more non zero current triangles functions (i.e. a lumped load is placed on the wire junction of two segments), then the load introduces an additional voltage drop equal to the product of the current triangle magnitude and ^{z}load. A specified impedance represented located on a wire coincident with a current triangle is simply added to the diagonal impedance. A distributed impedance such as wire conductivity can be treated in the same way by use of an equivalent, lumped-circuit, element-impedance relationship. The near electric and magnetic fields can be determined from the current distribution obtained in the solution of the integral equation. The near electric fields are computed by the method described by A.T. Adams et al. [5]. Once the current on the wires have been determined the radiation pattern are then computed. The power gain in the PATTERN program is evaluated with an approach similar to that of NEC. The PATTERN program includes an option to correct the far fields and gain for the effects of real grounds using Fresnel reflection coefficients and the method is similar to the one used by NEC. Finally, the problem of coupling between antennas are analyzed using the network Y parameters [6].

MININEC Professional has an option to correct the currents and far fields for real ground using a Fresnel reflection coefficient. This approach has been shown to be accurate for antennas elevated above real earth. Good results have been obtained for antennas as close as 0.1 wavelengths above the earth. The exact limit depends on the geometry and has not been fully explored.

You can obtain MININEC Professional for Windows by writing to: EM Scientific, Inc. 2533 N. Carson St. Suite 2107, Carson City, NV 89706, Phone (702) 888-9449; FAX: (702) 883-2384; Email:76111.3171@compuserve.com

References:

1. R.F. Harrington, "Field Computation by Moment Method". The Macmillan Company, New York, 1968.

2. D.R. Wilton, "Wire Problems", Lecture Notes for Short Course on Computational Methods in Electromagnetics, 1981.

3. J.C. Logan, "A comparison of techniques for treating radiation and scattering by bent wire configurations with junctions", Syracuse Univ. Technical Report, TR-73-10, National Science Foundation Grant GK-4227, August 1973.

4. H.H. Chao and B.J. Strait, "Computer programs for radiation and scattering by bent wire configurations with junctions", Scientific report No. 7, Contract F19628-68-0180, AFCRL-700374, September 1970.

5. A.T. Adams et al. "Near fields of wire antennas by matrix methods", IEEE Trans. on Antennas and Propagation, Vol. AP-21, No. 5, May 1973.

6. M.E. Van Valkenburg, "Modern Network Synthesis", John Wiley and Sons, New York 1960.

7. J.C. Logan and J.W. Rockway, "MININEC Professional for Windows", 1995.

1997 CALL FOR PAPERS 1997

The 13th Annual Review of Progress in Applied Computational Electromagnetics

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The Annual ACES Symposium is an ideal opportunity to participate in a large gathering of EM analysis enthusiasts. The purpose of the Symposium is to bring analysts together to share information and experience about the practical application of EM analysis using computational methods. The symposium offerings include technical presentations, demonstrations, vendor booths and short courses. All aspects of electromagnetic computational analysis are represented. Contact Eric Michielssen for details.

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THE APPLIED COMPUTATIONAL ELECTROMAGNETIC 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
    - radar imaging
    - shielding
    - EMP, EMI/EMC
    - dielectric & magnetic materials
    - microwave components
    - fiberoptics
    - communications systems
    - eddy currents
    - wave propagation
    - radar cross section
    - bioelectromagnetics
    - visualization
    - inverse scattering
    - MIMIC technology
    - remote sensing & geophysics
    - propagation through plasmas
    - non-destructive evaluation
- Partial list of techniques:
    - frequency-domain & time-domain techniques
    - integral equation & differential equation techniques
    - finite difference & finite element analysis
    - diffraction theories
    - modal expansions
    - hybrid methods
    - physical optics
    - perturbation methods
    - moment 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 26, 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 papers should not be more than 8 pages long including figures.

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. 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 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.

FINAL AGENDA

The Twelfth Annual Review of Progress in Applied Computational Electromagnetics

NAVAL POSTGRADUATE SCHOOL
18-22 MARCH 1996

Richard Gordon, Technical Program Chairman

Eric Michielssen, Conference Co-Chair

Jin-Fa Lee, Conference Co-Chair

Robert Lee, Short Course Chairman

W. Elliott Hutchcraft, Technical Assistant

Robert Bevensee, Assistant Conference Co-Chair

Richard W. Adler, Conference Facilitator

MONDAY MORNING 18 MARCH 1996

0745-0830	SHORT COURSE REGISTRATION	103 Glasgow Hall
0830-1200	SHORT COURSE (HALF-DAY) "An Application Oriented Introduction to the NEC-BSC Workbench" R.J. Marhefka & L.W. Henderson, The Ohio State University	
0830-1630	SHORT COURSE (FULL-DAY) "Wavelets: Theory, Algorithms, and Applications" A.K. Chan, Texas A&M	
0830-1630	SHORT COURSE (FULL-DAY) "Using Mathematical Software for Computational Electromagnetics" J. Lebaric, Naval Postgraduate School	
0830-1600	SHORT COURSE (FULL-DAY "Practical EMI/EMC Design and Modeling" T. Hubing, University of Missouri-Rolla	
0900-1200	REGISTRATION	103 Glasgow Hall

MONDAY AFTERNOON

1300-1630	SHORT COURSE (HALF-DAY) "Application of Modern Analytical and Hybrid Tools for Antenna Modeling and Synthesis" R. Rojas & P. Pathak, Ohio State University	
1630-1900	REGISTRATION	103 Glasgow Hall
1700-1915	AMATEUR RADIO DINNER	
SESSION 0:	AMATEUR RADIO SESSION Chair: W.P. Wheless, Jr.	
1930	"Ground-Plane Antennas with Elevated Radial Systems"	J.S. Belrose
1950	"Review of Characteristics for HF Dipole Antennas Including the Cases Where the Dipoles are Above and Parallel to the Surface of Real-World Grounds"	G.M. Royer
2010	"HF Multi-Frequency Antennas Using Coupled Resonators"	G.A. Breed
2030	"The Optimized Wideband Antenna (OWA) and its Application"	J.K. Breakall
2050	"The Quad-Rhomb Antenna - A New All Band Antenna for Amateur Radio Applications"	R. Anders
2110	BREAK	
2130	"SKY-WAVES-95"	R. Anders
2150	"Using Ham Radio CEM Codes to Gain Insight to VHF Ground Plane Antennas and to Mitigate 75 Meter Mars RFI at a Naval Receiving Site"	A. Hoffman & R.W. Adler
2210	"Development of Practical Landstorfer Antennas for Amateur Use"	M.C. Tarplee
2230	"Two-Port Network Specification of Baluns for NEC Analysis and Other Applications"	W.P. Wheless, Jr., & C.S. Wheless

TUESDAY MORNING 19 MARCH 1996

0700-0800	**REGISTRATION**		**103 Glasgow Hall**
0700-0745	**CONTINENTAL BREAKFAST**		**Glasgow Hallway**
0730	**ACES BUSINESS MEETING**	President Hal Sabbagh	**102 Glasgow Hall**
0745	**WELCOME**	Richard Gordon	**102 Glasgow Hall**

SESSION 1: HIGH FREQUENCY METHODS (Parallel with Sessions 2, 3, 4, & 5)

Chair: R.J. Burkholder

0800	"Physical Theory of Diffraction Analysis of Impedance Structures"	H.H. Syed & J.L. Volakis
0820	"Hybrid SBR/GTD Radio Propagation Model for Site-Specific Predictions in an Urban Environment"	J. Schuster & R. Luebbers
0840	"Analysis of Dielectric Structures Using the NEC-BSC"	R. Marhefka & L. Henderson
0900	"Hybrid MM-PO-Fock Analysis of Monopole Antennas Mounted on Curved Convex Bodies"	U. Jakobus & F.M. Landstorfer
0920	"Numerical Diffraction Coefficient for an Impedance Wedge with a Material Body Attached to its Edge"	M.F. Otero & R.G. Rojas
0940	"Reflection and Diffraction of Well-Focussed General Astigmatic EM Gaussian Beams"	G. Zogbi, H.T. Chou, P.H. Pathak, & R.J. Burkholder
1000	**BREAK**	
1020	"Polarized Scattered Light by a Semicylindrical Boss on a Conducting Flat Plane"	H.A. Yousif
1040	"Divergence of Rays in Modulated Atmospheric Ducts"	I.P. Zolotarev
1100	"Diffraction by a Weak Dielectric Wedge"	A.V. Popov
1120	"Far-field Diffraction Effects of EUV Fresnel Zone Plates"	Y.V. Kopylov, V.A.Baranov, A V.Popov, & A Vinogradov
1200	**LUNCH**	

SESSION 2: INVERSE SCATTERING (Parallel with Sessions 1, 3, 4, & 5)

Chairs: P.M. Goggans and L. Riggs

0800	"Radar Time and Frequency-Domain Received Signals for Realistic Antennas and Scatterers"	P.M. Goggans & J.D. Pursel
0820	"The Extraction of Scattering Mechanisms from Measured Data"	H.M. Chizever & K.M. Pasala
0840	"Using the E-pulse Technique and Hypothesis Testing to Perform Radar Target Identification"	L. Riggs, J. Mooney, & C. Smith
0900	"A Boundary-Integral Code for Electromagnetic Nondestructive Evaluation"	K. Murphy & H.A. Sabbagh
0920	"The Numerical Analysis of Planar Antennas Buried in Layered Media"	J. van Tonder, J. Cloete, & D. Davidson

SESSION 3: RCS ANALYSIS (Parallel with Sessions 1, 2, 4, & 5)

Chair: M. El-Shenawee

0940	"A Response Surface Methodology Study of Electromagnetic Data Compression and Reconstruction"	V.M. Floyd, Jr., A. Terzuoli, Jr., G.C. Gerace & P.F. Auclair
1000	**BREAK**	
1020	"Curvilinear, Isoparametric Modelling for RCS Prediction, Using Time Domain Integral Equations"	S.P. Walker, M.J. Bluck, M.D. Pocock, C.Y. Leung, & S.J. Dodson
1040	"Double Scatter Radar Cross Sections for Two Dimensional Random Rough Surfaces that Exhibit Backscatter Enhancement"	M. El-Shenawee & E. Bahar

SESSION 4: APPLICATIONS OF PARALLEL COMPUTING (Parallel with Sessions 1, 2, 3 & 5)

Chairs: L. Epp and K. Naishadham

1100	"Solution of Electromagnetic Eigenproblems on Multiprocessor Superscalar Computers"	M.P. Debicki, P. Jedrzejewski, J. Mielewski, P. Przybyszewski, & M. Mrozowski
1120	"Implementation of Hybrid FDTD/FVTD Conformal Algorithm on a Massively Parallel Computer"	J.S. Chen & A.A. Seidl
1140	"Parallel CARLOS-3D Code Development"	J.M. Putnam & J.D. Kotulski

SESSION 5: NEW DEVELOPMENTS IN TLM MODELING (Parallel with Sessions 1, 2, 3, & 4)

Chair: W.J.R. Hoefer

0800	"On the Advantages of ATLM Over Conventional TLM"	M. Krumpholz & P. Russer
0820	"Advanced Node Formulations in TLM - The Matched Symmetrical Condensed Node (MSCN)"	V. Trenkic, C. Christopoulos, & T.M. Benson
0840	"A General and Complete Two-Dimensional TLM Hybrid Node Formulation Based on Maxwell's Integral Equations"	N. Pena & M.M. Ney

TUESDAY MORNING 19 MARCH 1996

SESSION 5: NEW DEVELOPMENTS IN TLM MODELING (Parallel with Sessions 1, 2, 3, & 4) (cont)

0900	"A General Formulation of a Three-dimensional TLM Condensed Node with the Modeling of Electric and Magnetic Losses and Current Sources"	N. Pena, & M.M. Ney
0920	"A Numerical Comparison of Dispersion in Irregularly Graded TLM and FDTD Meshes"	F.J. German, J.A. Svigelj, & R. Mittra
0940	"Accuracy Considerations of a Class of Frequency-Domain TLM Nodes"	S. Chen & R. Vahldieck
	BREAK	
1020	"Distributed Simulation of Planar Circuits by TLM Method in a Parallel Computing" Environment"	B. Isele, J. Schmöller, & P. Russer
1040	"Modeling Gyromagnetic Media in Symmetrical Condensed Node TLM"	L. de Menezes & W.J.R. Hoefer
1100	"A Comparative Performance Study of Absorbing Boundary Conditions in TLM and FDTD"	C. Eswarappa & W.J.R. Hoefer
1120	"Modelling of Coplanar Waveguide Discontinuities Using the Alternating Transmission Line Matrix (ATLM) Method"	B. Bader & P. Russer
1140	"Quasi-Static Correction of a Knife Edge Corner in 2D TLM Algorithm"	L. Cascio, G. Tardioli, T. Rozzi, & W.J.R. Hoefer
1200	**LUNCH**	
1200	**BOARD OF DIRECTORS MEETING/LUNCHEON**	**Terrace Room, Herrmann Hall**

TUESDAY AFTERNOON

Ballroom, Herrmann Hall,

1400-1800	**VENDOR EXHIBITS AND STARTING AT 1600 -1800, WINE AND CHEESE BUFFET**	

SESSION 6: INTERACTIVE TECHNICAL SESSION,

1400-1800	"Electromagnetic Visualization Using Commercial Software"	H.A. Nott
	"Performance of Multiple, Thin Layers of Lossy Dielectrics as Broadband Attenuators"	G.W. Jarriel, Jr., M.E. Baginski, & L.S. Riggs
	"Research & Engineering Framework (REF) Data Dictionary Specification for Computational Electromagnetics"	J.A. Evans
	"Development of an Electromagnetic and Mechanical Simulation Tool for the Computer Modeling of the TACAMO LF/VLF Communication System"	M.C. Longtin, R.W. Sutton, K.J. Laskey, & P.J. Morrison
	"A New Look at Antenna Traps"	P.W. Leonard
	"Block Wavelet Transforms for Fast MOM Computations: An Application to Pocklington's Equation"	W.L. Golik
	"Imaging of Conductive and Ferromagnetic Materials Using a Magnetic Induction Technique"	J. Ferreira, F. Linhares, J. Velez, J. de Ribomar S. Oliveira, & A.R. Borges
	"Investigation of the Properties of Wavelet-Like Basis Functions in the Finite Element Analysis of Elliptic Problems"	L.A. Harrison & R.K. Gordon
	"Continuing Development of the Research and Engineering Framework (REF) for Computational Electromagnetics"	L.W. Woo, B. Hantman, K. Siarkiewicz, J. LaBelle, & R. Abrams
	"Numerical and Experimental Modelling of Liquid Dielectrics Using a Coaxial Cavity"	M. Bingle, D.B. Davidson, & J.H. Cloete
	"Hardware/Software Codesign Model for XPATCHF Optimization"	B.A. Kadrovach, T.S. Wailes, A.J. Terzuoli, Jr., & D.S. Gelosh
	"3D FDTD Simulation of EM Detection of Buried Waste"	D. Sullivan, B. Hansen & N. Skousen
	"Application of Digital Filters to the Construction of Wideband Dispersive Boundary Conditions"	M. Mrozowski, M. Niedźwiecki, & P. Suchomski
	"Note on Large Crane Coupling to Nearby AM Radio Stations"	P.W. Leonard & J.B. Hatfield
	"XPATCHF Software System Analysis and Profiling"	B.A. Kadrovach, T.S. Wailes, A.J. Terzuoli, Jr., & D.S. Gelosh
	"Theoretical Studies of Photonic Band Gap Materials"	M. Sigalas, R. Biswas, C. Chan, K. Ho, & C. Soukoulis
	"On the Use of Richardson Extrapolation in the Finite Element Analysis of Two-Dimensional Electrostatics Problems"	W.E. Hutchcraft & R.K. Gordon
	"Scattering from Chirally Coated Bodies"	R. Sharma & N. Balakrishnan

TUESDAY AFTERNOON 19 MARCH 1996

1400-1800	**VENDOR EXHIBITS AND STARTING AT 1600 -1800, WINE AND CHEESE BUFFET**	**Ballroom, Herrmann Hall**
SESSION 6:	**INTERACTIVE TECHNICAL SESSION, (cont)**	
	"A Mixed Formulation to Compute the Source Current Density in Inductors of Any Shape"	F. Robert, P. Dular, J.F. Remacle, M. Umé, & W. Legros
	"High Power Microwave Amplification for High-Intensity Relativistic Electron-Beam Storage-Rings"	R.A. Speciale
	"Real-Time Digital Signal Processor in Ionosphere Measurements"	A.L. Karpenko & V.V. Koltsov
	"High Frequency Electromagnetic Safety Analysis by Numerical and Empirical Methods on Mobile Platforms"	M.J. Packer, & R.C. Ferguson
	"Computational Modeling of Wave Plasma Interaction"	V.A. Eremenko & Y.Cherkashin
	"Attenuation of HF Radio Waves in a Forest: Results from Experiment"	I.P. Zolotarev. V.A.Popov & V.P. Romanuk
	"Statistical Reflection Properties of Electromagnetic Monopulse by Buried Object in Subsurface Random Ground Using FDTD"	Y. Miyazaki & Y. Jyonori
	"Running NEC4 on the Cray at NPS"	B. Neta
1730	**NO HOST BAR**	
1830	**AWARDS BANQUET**	**Ballroom, Herrmann Hall**

WEDNESDAY MORNING 20 MARCH 1996

0715	**CONTINENTAL BREAKFAST**	
SESSION 7:	**FDTD APPLICATIONS AND ENHANCEMENTS (Parallel with Sessions 8, 9, 10, 11 & 12)** Chair: J.H. Beggs	
0800	"UHF/VHF Propagation Model Characterization Over Irregular Terrain Using MOM/FDTD"	K.A. Lysiak, J.K. Breakall, & J. Zmyslo
0820	"Validation of FDTD Modeling of Ground-Penetrating Radar Antennas"	B.J. Zook
0840	"FDTD Analysis of Radiation from a Lens Terminated Conical TEM Antenna"	S.A. Blocher, E.A. Baca, & T.S. Bowen
0900	"FDTD Analysis of a Dipole Antenna Driven from Various Excitation Sources"	M.R. Zunoubi, N.H. Younan C.D. Taylor, & J.H. Beggs,
0920	"An Efficient Hybrid PEE-FDTD Field Modeling Technique in Cylindrical Coordinates"	M. Mrozowski, M. Okoniewski, & M.A. Stuchly
0940	"Absorbing Boundary Conditions for Optical Pulses in Dispersive, Nonlinear Materials"	P.M. Goorjian
1000	**BREAK**	
SESSION 8:	**FINITE ELEMENT AND FINITE VOLUME METHODS FOR ELECTROMAGNETIC FIELD SIMULATION** Chairs: R. D-Edlinger and R. Lee **(Parallel with Sessions 9, 10, 11 & 12,**	
1020	"Local Tetrahedron Modeling of Microelectronics Using the Finite-Volume Hybrid-Grid Technique"	D.J. Riley & C.D. Turner
1040	"Full Wave Vector Maxwell Equation Modeling of Self-Limiting Effects and Optical Nonlinear Vortices"	S.V. Polstyanko & J-F. Lee
1100	"A Hybrid FEM-FMM Technique for Electromagnetic Scattering"	S. Bindiganavale & J.L. Volakis
1120	"Finite Element Method Analysis of the Celestron-8 Telescope"	R.R. DeLyser & H. Pohle
1200	**LUNCH**	
SESSION 9:	**NUMERICAL ERROR ANALYSIS AND CONTROL I (Parallel with Sessions 7 8, 10, 11, & 12)** Chair: J.L. Volakis	
0800	"Error Analysis in the Adaptive Integral Method (AIM)"	E. Bleszynski, M. Bleszynski, & T. Jaroszewicz
0820	"Using Model-Based Parameter Estimation to Estimate the Accuracy of Numerical Models"	E.K. Miller
0840	"Guidelines for Using the Fast Multipole Method to Calculate the RCS of Large Objects"	S.S. Bindiganavale & J.L. Volakis
0900	"Developments in Error Estimation for Covolume and Staggered Mesh Approximations to Maxwell's Equations"	R.A. Nicolaides & D-Q. Wang
0920	"Adaptive Methods for the Numerical Solution of Reaction-Diffusion Problems"	D.J: Estep, M.G. Larsson & R.D. Williams
0940	"Error Estimates for Subgridded FDTD Schemes"	P. Monk
1000	**BREAK**	

WEDNESDAY MORNING 20 MARCH 1996

SESSION 10: NUMERICAL LINEAR ALGEBRA IN COMPUTATIONAL ELECTROMAGNETICS (Parallel with Sessions 7, 8, 9, 11, & 12)

Chair: A.S. Hodel

1020	"Applications of Numerical Linear Algebra in Electromagnetics"	G.K. Gothard, J.H. Henderson, & A.S. Hodel
1040	"Multilevel Preconditioning for the Time-Harmonic Maxwell Equations"	G. Starke
1100	"Iterative Solution Methods for ill-Posed Problems"	D. Calvetti, L. Reichel, & Q. Zhang
1120	"Methods for Large Sparse Eigenvalue Problems from Waveguide Analysis"	C. Peng & D. Boley
1140	"Iterative Solution of Field Problems in Space-Decoupled Configurations"	G. Bürger, & H. Singer
1200	**LUNCH**	

SESSION 11: NEC APPLICATIONS (Parallel with Sessions 7, 8, 9, 10, & 12)

Chairs: M. Ney and C. Christopoulos

0800	"Numerical Investigation of Antennas for Hand-Held Radiotelephones Using NEC Code"	A.A. Efanov, M.S. Leong, & P.S. Kooi
0820	"Evaluation of the Discrete Complex-Image Method for a NEC-Like Moment-Method Solution"	G.J. Burke
0840	"The Improvement of NEC-2's Out-of-Core Operation and the Analysis of UHF Monopole Antenna Mounted on a Car Model"	K. Natsuhara, T. Suda Y. Kazama, & K. Madono
0900	"MatNEC: A MATLAB Based Graphical Interface to SuperNEC"	R.M. Cooper
1000	**BREAK**	

SESSION 12: VALIDATION (Parallel with Sessions 7, 8, 9, 10, & 11)

Chair: D.R. Pflug

1020	"First and Second Generation Transformable Scale Aircraft-Like Models for Code Validation: Present Results and Future Plans"	D.R. Pflug, T.W. Blocher D.E. Warren, & D.O. Ross
1040	"Software for Modeling Helix Antennas with NEC and Validation by Measurement"	C.W. Trueman, N. Sultan, S.J. Kubina, & T. Pellerin
1100	"Evaluation of the Sensitivity of Scattering Predictions to Uncertainties in Material Characteristics"	G.A. Barnhart, A.J. Terzuoli, Jr., & G.C. Gerace
1120	"Validation of the PO-based RCS Code SIGMA by Using IEM and Experiments"	E. Kemptner, D. Klement, & V. Stein
1200	**LUNCH**	

WEDNESDAY AFTERNOON

SESSION 13: OPTIMIZATION (Parallel with Session 15 & 16),

Chair: E. Michielssen

1320	"Optimization of Broad-Band Loaded Wire Antennas in Real Environments Using Genetic Algorithms"	D.S. Weile, E. Michielssen, & A. Boag
1340	"Genetic Algorithms Based Pattern Synthesis Approach for Arbitrary Array Designs"	Y. Lu & K.K. Yan
1400	"Speeding Convergence of Genetic Algorithms for Optimizing Antennas Arrays"	R.L. Haupt
1420	"Order Recursive Method of Moments for Iterative Design Application"	K. Naishadham & P. Misra
1500	**BREAK**	

SESSION 14: MULTIPOLE TECHNIQUES

Chair: P. Leuchtmann

1520	"Discrete Sources Method for the Silicon Wafers Defect Discrimination"	Y. Eremin & N.V. Orlov
1540	"Iterative Scheme of Discrete Sources Amplitudes Determination Based on D-matrix Approach"	Y. Eremin
1600	"An Improving Technique for MMP Solutions Based on Ficticious Surface Sources"	M. Gnos & P. Leuchtmann

SESSION 15: ANTENNA ANALYSIS (Parallel with Sessions 13 & 16)

Chairs: A.W. Glisson and A.A. Kishk

1320	"Accurate Design of Shaped Beam Doubly Curved Reflector Antennas for Airborne Applications"	B.S. Shridhar & N. Balakrishnan
1340	"Rapid Parametric Study of Antennas Using Moment Method Codes"	G.P. Junker, A.A. Kishk, & A.W. Glisson
1400	"A Numerical and Experimental Investigation of a Shipboard DF Antenna Array"	J.B. Knorr
1420	"Radiation Patterns of Antennas Mounted on an Attack Helicopter"	O. Givati, A. Fourie, & J. Dresel
1440	"Modelling of a Discone Antenna Mounted on a Communication Van"	J.S. Seregelyi

WEDNESDAY AFTERNOON 20 MARCH 1996

SESSION 15: ANTENNA ANALYSIS (Parallel with Sessions 13 & 16) (cont)

1500	**BREAK**	
1520	"Dielectric Resonator Antenna Analysis and Design Using the FDTD Method"	K.P. Esselle
1540	"A Numerical and Experimental Investigation of a Semi-Loop Antenna on a Metal Box"	J.B. Knorr & D.C. Jenn

SESSION 16: EMI/EMC (Parallel with Sessions 13 & 15)

Chairs: T.H Hubing and J.L. Drewniak

1320	"On the Suitability of Simple Voltage Source Models for the Study of Mutual Coupling Effects"	G.P. Junker & A.W. Glisson, & A.A. Kishk
1340	"Susceptibility Modeling for PCBs with Long Wires Attached"	B. Archambeault & H.S. Berger
1400	"Computer Modeling Tools for EMC"	T.H. Hubing & J.L. Drewniak
1420	"Electromagnetic Induced Timing Defects in CMOS Chips"	R. Perez
1440	"Finite-Difference Time-Domain Analysis of Common Mode Cable Currents"	C-W. Lam
1500	**BREAK**	
1520	"Statistical Coupling of EM Fields to Cables in an Overmoded Cavity"	R. Holland & R. St. John
1540	"Power and Ground Plane Modeling and Decoupling in High Speed Printed Circuit Board and Multichip Modules"	F. Yuan, C-W. Lam, & L. Rubin

SESSION 17: ARRAYS

Chair: L. Epp

1600	"Synthesis of Phased Arrays Aperture Distributions"	R.A. Speciale
1620	"New Results in the Synthesis of Aperture-Field Distributions for Ultra-High-Gain Phased Arrays"	R.A. Speciale
1640	"Advanced Design of Phased Array Beam-Forming Networks"	R.A. Speciale
1730	**BOARD OF DIRECTORS DINNER**	

THURSDAY MORNING 21 MARCH 1996

0715	**CONTINENTAL BREAKFAST**

SESSION 18: FINITE ELEMENTS II (Parallel with Sessions 19, 20, & 21)

Chair: J.M. Jin

0800	"Adaptive Mesh Refinement Concepts for Electromagnetics"	Z. Chen & R. Lee
0820	"Analysis of Complete Basis Sets of DIvergencelessVector Expansion Functions for Finite Element Problems"	M.J. Walker
0840	"Multi-Mode S-Parameter Computation Using Finite Elements and Perfectly Matched Absorbers"	G.C. Lizalek, J.J. Ruehl, & J.R. Brauer
0900	"Characterization of MIMICs Packages Using a Parallelized 3D FEM Code"	J-G. Yook & L.P.B. Katehi
0920	"Combined PML and ABC for Finite Element Analysis of Scattering Problems"	J.M. Jin & W.C. Chew
0940	"Modeling Microstrip Patches Using the Finite Element Method"	D.B. Davidson, D.H. Malan, & C.B. Wilsen
1000	**BREAK**	
1020	"H_1(curl) Tangential Vector Finite Element Method with Additional Constraint Equation"	P. Bretchko, S.V. Polstyanko, & J-F. Lee
1040	"Extension of Higher-Order 3-D Vector Finite Elements to Curved Cells and Open-Region Problems"	J.S. Savage & A.F. Peterson
1100	"The Hybrid FEM/BEM Solution for EM Scattering from Arbitrary Cavity with Lossy and Anisotropic Material"	J. Xu, Y. Lu, & J.S. Fu
1200	**LUNCH**	

SESSION 19: FUTURE FIELDS FOR FDTD ANALYSIS (Parallel with Sessions 18, 20 & 21)

Chairs: D. Katz and M. Piket-May

0800	"FDTD Analysis of a Dielectric Leaky-Wave Antenna Using PML"	M. Chen, B. Houshmand, & T. Itoh
0820	"FDTD Analysis in Cylindrical Coordinates of a TEM Pyramidal Horn Antenna"	D. Menditto, P. Tognolatti, & F. Bardati
0840	"A Modified FDTD (2,4) Scheme for Modeling Electrically Large Structures with High Phase Accuracy"	M.F. Hadi & M. Piket-May, & E.T. Thiele
0900	"Application of the FDTD Method to Three-Dimensional Propagation in a Magnetized Ferrite"	J.W. Schuster, & R.J. Luebbers

THURSDAY MORNING 21 MARCH

SESSION 19: FUTURE FIELDS FOR FDTD ANALYSIS (Parallel with Sessions 18, 20 & 21) (cont)

0920	"Symmetry-Aided FDTD Analysis of Finite Phased Arrays"	D. Crouch
0940	"Conformal FVTD with a Rectangular Grid for PEC Scattering Objects"	K.S. Yee & J.S. Chen
1000	**BREAK**	
1020	"Application of Recent Advances in FDTD Modeling to the Problem of Acoustic Propagation in Shallow Water"	J.B. Schneider, F.D. Hastings. & C.J. Railton
1040	"FDTD Analysis of Small Loop Antennas for Partial Exposure of Rat Head at 837 MHz"	K.W. Chan, J.A. McDougall, & C.K. Chou
1100	"Scattering from Complex Geometries Using a Parallel FVTD Algorithm"	V. Ahuja & L.N. Long
1120	"FDTD Simulation of High Frequency Devices by Using Locally Refined Meshes"	P. Thoma & T. Weiland
1200	**LUNCH**	

SESSION 20: NUMERICAL ERROR ANALYSIS AND CONTROL II (Parallel with Sessions 18, 19, & 21)

Chair: J.L. Volakis

0800	"A WWW-Based Data Base for Code Validation"	C.W. Trueman & S.R. Mishra
0820	"Code Scaling"	M.J. Schuh & A.C. Woo
0840	"An Overview of Numerical Dispersion Error in PDE Methods for Electromagnetics"	R. Lee
0900	"Non-rigorous CEM Error Estimates and Their Limitations"	A.F. Peterson
0920	"Comparisons of Staggered and Non-Staggered Schemes for Maxwell's Equations"	D. Gottlieb & B. Yang
0940	"Minimizing the Number of Frequency Samples Needed to Represent a Transfer Function Using Adaptive Sampling"	E.K. Miller
1000	**BREAK**	

SESSION 21: MODELING TOOLS FOR VISUALIZATION: PRE- AND POST-PROCESSING (Parallel with Session 18, 19, & 20)

Chair: J. Karty

1020	"MATLAB NEC Toolbox: The Cross Platform GUI Pre-and Post-processing Tool for NEC Applications"	Y. Lu
1040	"Computation and Graphic Visualization of Plane-Wave K-Space Spectra and Far-Field Patterns with MATLAB 4.0"	R.A. Speciale
1100	"The Intelligent Computational Electromagnetics Expert System (ICEMES)"	A.L. Drozd, T.W. Blocher, V.K. Choo, & K.R. Siarkiewicz
1120	"NECSHELL - A New Graphical User Interface for the NEC Code"	M.Y. Mikhailov, V.O. Lomtev, & A.A. Efanov
1200	**LUNCH**	

THURSDAY AFTERNOON

SESSION 22: FINITE ELEMENT ANALYSIS (Parallel with Session 23 & 25)

Chair: J.R. Brauer

1320	"Finite Element Scattering and Radiation Analysis Using Prismatic Meshes and Artificial Absorbers for Conformal Domain Truncation"	M. Casciato, M. Numberger T. Özdemir, & J.L. Volakis
1340	"Application of Fast Multipole Method to Finite Element-Boundary Integral Solution of Scattering Problems"	N. Lu & J-M. Jin
1400	"Use of Perfectly-Matched Absorber Boundaries in Finite Element Analysis of Patch Antennas"	J.F. DeFord & G.C. Lizalek
1420	"A New Permanent-Magnet Synchronous Motor Design Configuration and Finite Element Analysis"	Q.K. Zhang, N. Ida, Y. Qiu, & Z.R. Jiang
1440	"Investigation of ABC Behavior in Axisymmetric Electrostatic Finite Element Analysis"	A. Konrad & L. Han
1500	**BREAK**	
1520	"An Efficient Scheme for Finite Element Analysis in the Frequency Domain"	M. Kuzuoglu, R. Mittra, J.R. Brauer, & G.C. Lizalek
1540	"Finite-Element Modelling of Head Coils for High-Frequency Magnetic Resonance Imaging Applications"	J.G. Harrison & J.T. Vaughan
1600	"H_1(curl) TVFEM in Conjunction with PML for Modeling 3D Waveguide Discontinuities"	S.G. Perepelitsa, R. Dyczij-Edlinger, & J-F. Lee

THURSDAY AFTERNOON 21 MARCH 1996

SESSION 23: METHOD OF MOMENTS APPLICATIONS (Parallel with Sessions 22 & 25)
Chair: A.F. Peterson

1320	"Global Fourier-Series Basis Functions for EM Scattering"	M.H. Smith & A.F. Peterson
1340	"A Numerically Stable Method of Moments Time Domain Model"	L.B. Gravelle & J-P. Estienne
1400	"Method of Moments Analysis of the Celestron-8 Telescope"	R.R. DeLyser, P. Ensaf, & P. McDaniel
1500	**BREAK**	

SESSION 24: FDTD ANALYSIS AND APPLICATIONS (Parallel with Session 26)
Chair: A. Elsherbeni

1520	"Dynamic Analysis of V Transmission Lines"	O.M. Ramahi, A.Z. Elsherbeni, & C.E. Smith
1540	"An Absorbing Boundary Condition for the FDTD Method Using Digital Filters Design Technique"	C-N. Kuo & T. Itoh
1600	"Application of the FDTD Method to the Electromagnetic Modeling of Patch Antenna Arrays"	M.F. Pasik, G. Aguirre, & A.C. Cangellaris

SESSION 25: MICROWAVE COMPONENTS (Parallel with Sessions 22 & 23)
Chairs: M.E. Baginski and M.M. Ney

1320	"Parallel Coupled Microstrip Patch Resonators on a Ferrimagnetic Layer"	J. de Ribamar S. Oliveira & A. Gomes d'Assunção
1340	"Fullwave Analysis of Circular Cylindrical Backed Slotlines"	L. Martins de Mendonça & A. Gomes d' Assunção
1400	"Properties of Tapered Microstrip Lines on Dielectric and Magnetized Ferrimagnetic Layers"	A. Gomes d' Assunção, F. de Lima, & M.R.M. Lins de Albuquerque
1420	"Frequency and Time Domain Computations of S-Parameters Using the Finite Integration Technique"	R. Schumann, M. Clemens, P. Thoma, & T. Weiland
1440	"Time Domain Analysis of Microwave Structures by MRTD"	M. Krumpholz, E. Tentzeris, R. Robertson, & L.P.B. Katehi
1500	**BREAK**	
1520	"A Parasite-Free Non-Orthogonal Finite-Difference Frequency-Domain Method for the Analysis of Inhomogeneous Lossy Waveguides"	L. Zhao & A.C. Cangellaris

SESSION 26: BIOMEDICAL ELECTROMAGNETICS (Parallel with Sessions 24)
Chairs: A.M. Morega and R.K. Gordon

1540	"A Spectral Approach to the Cardiography"	A.M. Morega, D. Mocanu, & M. Morega
1600	"Optimal Transcutaneous Pacing"	A.M. Morega, B. Ciocârlan, & M. Morega
	CLOSE	

FRIDAY MORNING 22 MARCH

0830-1200 **SHORT COURSE (HALF-DAY)**
"Using Model-Based Parameter Estimation to Increase the Efficiency and Effectiveness of Computational Electromagnetics"
E.K. Miller

0830-1600 **SHORT COURSE (FULL-DAY)**
"Conformal Time Domain Numerical Electromagnetics"
K. Yee, Lockheed

0830-1630 **SHORT COURSE (FULL-DAY)**
"Finite Element Methods for Electromagnetics"
J.L. Volakis, University of Michigan, and J. Brauer, Mac-Neal Schwendler Corporation.

FRIDAY AFTERNOON

1300-1630 **SHORT COURSE (HALF-DAY)**
"Antenna Properties in Linear and Nonlinear Environments"
R. Bevensee, BOMA Enterprises

SHORT COURSES AT THE 12TH ANNUAL REVIEW OF PROGRESS IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

The Applied Computational Electromagnetics Society (ACES) is pleased to announce nine Short Courses t be offered with its annual meeting of March 18-22, 1996. The Short Courses will be held on Monday and Friday. Short Course registration begins at 7;45 AM on Monday 18 March. PRE-REGISTRATION BY MAIL IS SUGGESTED! [Note: Tuesday through Thursday will be technical sessions and vendor exhibits]. ACES has the right to cancel a course at any time with full refund. For further information contact Robert Lee, Short Course Chairman: Ohio State University, EE Dept, 2015 Neil Avenue, Columbus, OH, 43210-1272, Phone (614) 292-1433, FAX (614) 292-7596, Email:lee@ee.eng.ohio.state.edu. Fees for half-day Short Courses are $90 and for full-day courses $140, if booked before Friday 1 March 1996. **NOTE: Short Course attendance is NOT covered by the Symposium Registration Fee!**

COURSE INFORMATION

1. **"An Application Oriented Introduction to the NEC-BSC Workbench"** 1/2 day course - Monday morning 18 March, by Ron J. Marhefka and Lee W. Henderson, The Ohio State University.

The Nec-BSC Workbench is a windows based graphical user interface for creating and manipulating input files for NEC-BSC. The NEC-BSC input commands are displayed in an edit window, and the actual geometry is displayed in separate wireframe views. The user can also accomplish dialog box editing of commands. This Short Course will demonstrate the use of the Workbench with practical applications, using realistic geometries. The course will emphasize how the interaction with the Workbench allows the user to easily employ the full capabilities of the NEC-BSC.

2. **"Wavelets: Theory, Algorithms, and Applications"**, Full-day course - Monday 18 March by Andrew K. Chan, Texas A&M.

Wavelet Analysis is one of the most exciting topics to emerge from mathematical research that has a wide range of engineering applications. Because of its flexible time-frequency window, the wavelet transform complements the shortcomings of Fourier-based techniques. In signal processing applications, wavelets are used in speech compression, echo-cancellation, music processing, etc. Their applications in electromagnetic problems are relatively new. In particular, they have been applied for processing data from electromagnetic scattering and for matrix compression in solving some integral equations. This course is aimed at providing an overview of wavelet analysis along with algorithms and applications. The first part of the course will begin with a brief review of Fourier analysis and short-time Fourier analysis. Construction of orthonormal and semi-orthogonal spline wavelets based on the multiresolution analysis will be discussed. The second part of the course is devoted fast algorithms and applications of wavelet analysis.

3. **"Using Mathematical Software for Computational Electromagnetics"**, Full-day course - Monday 18 March, by Jovan Lebaric, Naval Postgraduate School.

This "hands-on" course will introduce MATHCAD and MATLAB and show how they can be used for electromagnetic field calculation and visualization. MATHCAD will be used to implement Method of Moments (MOM) solutions of electrostatic, radiation, and scattering problems. MOM examples will include calculation of microstrip characteristic impedance and radiated/scattered far field of a simple wire antenna. MATLAB will be used for 1D and 2D finite-difference time-domain (FDTD) electromagnetic field calculations. Examples will include transients on a transmission line, and transient scattering by a metallic object of simple shape. The course will be held in a PC Lab with attendees working individually or in groups of two. Each attendee will receive course notes and a disk with MATHCAD and MATLAB sample programs.

4. **"Application of Modern Analytical and Hybrid Tools for Antenna Modeling and Synthesis"**, 1/2 day course, Monday afternoon, 18 March, by Roberto Rojas and Prabhakar Pathak, The Ohio State University.

This course will be a survey of modern analytical and hybrid tools for antenna analysis and synthesis. Gaussian beams will be introduced and their applications to the design and analysis of reflector antennas, phased arrays, radomes, etc., will be discussed. Several hybrid analytical/numerical techniques will also be introduced for the efficient analysis/design of microstrip patch and slot arrays as well as active integrated antennas. Finally, an efficient scheme to calculate the radiation pattern of antennas in complex environments will be discussed.

5. **"Practical EMI/EMC Design and Modeling"** full-day course - Monday 18 March, by Todd Hubing, University of Missouri-Rolla.

There are a large number of computer modeling codes available to assist circuits and system designers in solving or preventing electromagnetic compatibility problems. The intent of this course is to guide the student in selecting and using appropriate computer modeling tools for EMI/EMC applications. The student will learn about the sources of radiation and susceptibility problems, practical EMI/EMC design strategies, and how to develop simple models that represent the salient features of real products. The fundamentals of tools used to calculate radiated emissions will be discussed and the course will provide an overview of the various commercial and non-commercial computer modeling codes that are available.

6. **"Using Model-Based Parameter Estimation to Increase the Efficiency and Effectiveness of Computational Electromagnetics"**, 1/2 day course - Friday morning 22 March, by Ed Miller.

Hidden beneath the mathematical detail associated with most electromagnetic analysis is the possibility of representing physical observables in simpler ways using reduced-order models. Knowledge of such models can be helpful in ways ranging from reducing the computer cost of achieving desired solutions to developing more compact representations of observables. The basis approach is to estimate unknown parameters of the models from sampled data, a process called "mode-based parameter estimation" (MBPE). This lecture will survey some applications of MBPE in electromagnetic modeling and demonstrate some of the benefits that results, expanding on recent articles by the author in the ACES Journal and Newsletter.

7. **"Antenna Properties in Linear and Nonlinear Environments"**, 1/2 day course - Friday afternoon 22 March, by Robert Bevensee, BOMA Enterprises.

General theorems for an antenna as a transmitter and as a receiver-scatterer in an electromagnetically linear environment will be reviewed and illustrated. A hypothesis about the best gain-bandwidth behavior possible within a given electrical working volume will be developed. For an antenna operating in an electrically linear environment, relations among transmitted powers at various frequencies with nonlinear control port loads will be derived via the Manley-Rowe Relations.

The difficulty of developing an upperbound as opposed to a lowerbound to the bistatic scattered power of an N-port antenna will be discussed. The approximate nature of the Optical Theorem will be demonstrated. For an antenna operating as a receiver in an electrically linear environment, relations among collected (extinction), scattered, and load powers with a nonlinear load will be derived via the Manly-Rowe Relations

8. **"Finite Element Methods for Electromagnetics"**, Full-day course - Friday 22 March, by John Volakis, University of Michigan, and John Brauer, Mac-Neal-Schwendler Corporation.

The course will develop and apply two-dimensional and three-dimensional finite elements, both nodal-based and edge-based. Local and global mesh truncation techniques will be examined including the new perfectly matched layer method. Applications will include antennas, scattering, microwave circuits, nonlinear magnetic apparatus, electronic packaging, and electromagnetic compatibility.

9. **"Conformal Time Domain Numerical Electromagnetics"**, Full-day course - Friday, by Kane Yee, Lockheed.

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

MOTELS / HOTEL LIST FOR MARCH 1996 ACES SYMPOSIUM

18-22 MARCH 1996

**** (WITHIN WALKING DISTANCE OF NPS)**

FIRESIDE LODGE (**) (1 star)
1131 10th St. Monterey, CA 93940
(408) 373-4172
Govt. Rate $55 (Tax: see below)
Conference Rate: $69 + 10% tax.

STAGECOACH MOTEL (**) (1 Star)
1111 10th St. Monterey, CA 93940
(408) 373-3632
Govt. Rate $49 (tax: see below)
Conference rate: $49 S, $59D +10% tax

HYATT HOTEL & RESORT (**) (4 Star)
1 Old Golf Course Rd. Monterey, CA 93940
(408) 372-1234, Fax: (408) 375-3960
Govt. Rate: $74 S, $101.50 D (Tax: see below)
Conference Rate: $105 S, $127 D + 10% tax.
Book by 18 Feb. 1996
Cancellation: 48 hours

HOLIDAY INN (**) (3 Star)
1000 Aguajito Rd. Monterey, CA 93940
(408) 373-6141 Fax: (408) 375-2367
Govt. Rate $74 + Occupancy Tax
Conference Rate: $89 + 10% tax
Book room by 17 Feb. 1996. Cancellation by 12 March 1996.
Contact: Dawn Darling, Sales Manager

SUPER 8 MOTEL (2 Star)
2050 Fremont St. Monterey, CA. 93940
(408) 373-3081, Fax: (408) 372-6730
Govt. & Conf Rate: $39.60 Single + Tax
$43.20 Double + Tax
Book room by 2/26/96. Rooms must be booked with a Credit Card and 72 hour cancellation!
Motel Contact: Richard

EMBASSY SUITES, HOTEL & CONF. CENTER
1441 Canyon Del Rey, Seaside, CA 93955
(408) 393-1115, Fax: (408) 393-1113
Govt. Rate: $74 S, $94 D (tax: see below)
Conf. Rate: $129 S, $149 D + 10% tax
Book by 2/16/96 by Credit Card.
Cancellation: 48 hours

IMPORTANT INFORMATION FOR ACES ATTENDEES, PLEASE READ.

HOTEL ROOM TAX EXEMPTION REQUIRES ALL OF THE FOLLOWING DOCUMENTS: (1) TRAVEL ORDERS, (2) PAYMENT BY GOVERNMENT ISSUED AMEX CARD; (3) GOVT/MILITARY IDENTIFICATION. REGARDING GOVT. RATES: PREVAILING PERDIEM LODGING RATE AT TIME OF ARRIVAL WILL BE HONORED.

WHEN YOU BOOK A ROOM MENTION THAT YOU ARE ATTENDING THE "ACES" CONFERENCE, AND ASK FOR EITHER GOVERNMENT, OR CONFERENCE RATES.

THERE IS NO CONFERENCE PARKING AT THE NAVAL POSTGRADUATE SCHOOL OR NEARBY STREETS. WE RECOMMEND YOU BOOK A ROOM WITHIN WALKING DISTANCE, OR PLAN TO USE A TAXI.

THIRD STREET GATE IS THE CLOSEST GATE TO THE CONFERENCE REGISTRATION LOCATION. GATES OPEN AT 0600 (AM) AND CLOSE AT 1800 (6 PM) DAILY. AFTER 1800 HRS, MAIN GATE (BETWEEN NINTH AND TENTH STREET, IS THE ONLY GATE OPEN.

AIRLINE INFORMATION

THE FOLLOWING AIRLINES MAKE CONNECTIONS FROM LOS ANGELES AND SAN FRANCISCO, CA. TO MONTEREY, CALIFORNIA: AMERICAN, UNITED, DELTA/SKY WEST, US AIR.

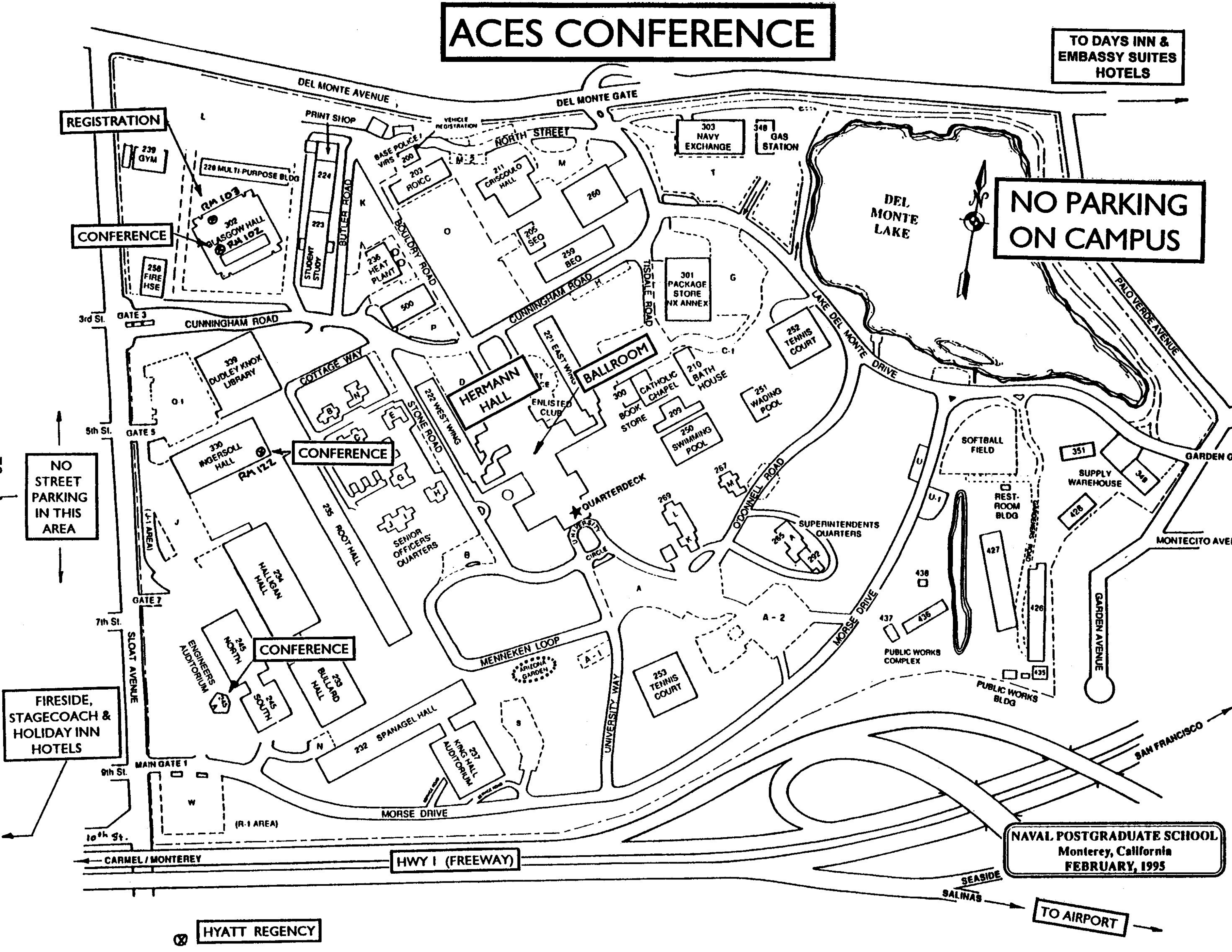
SIERRA EXPRESSWAY FLIES FROM OAKLAND, CA TO MONTEREY, CA.

THERE IS NO CONNECTION DIRECTLY FROM SAN JOSE, CA TO MONTEREY, CA. YOU CAN FLY TO SAN JOSE, BUT THEN GROUND TRANSPORTATION MUST BE USED. MONTEREY-SALINAS-AIRBUS SERVES SAN FRANCISCO INTERNATIONAL (SFO) AND SAN JOSE INTERNATIONAL (SJC). THERE ARE 6 DEPARTURES DAILY FROM MONTEREY AND SALINAS, ARRIVING AT BOTH SFO & SJC, APPX. (2-4) HOURS LATER. THERE IS ALSO THE SAME DEPARTURES FROM SFO AND SJC. FOR INFORMATION AND UPDATED SCHEDULE PHONE: (408) 442-2877 - (800) 291-2877.

THINGS TO DO AND SEE IN THE MONTEREY BAY AREA:

There are many activities for children and adults not attending the Conference. The Monterey Bay Aquarium, Maritime Museum of Monterey, Pacific Grove Museum of Natural History, and The Monterey Fisherman's Wharf are a few places to go and see. Other things to do include whale watching, sight-seeing historic Monterey and Carmel, bicycling, and roller blading. The Monterey Peninsula has 20 Golf Courses. Come and bring the whole family and have a memorable week. For more information, call the Monterey Peninsula Chamber of Commerce, Visitors and Convention Bureau at (408) 649-1770.

ACES CONFERENCE



THE APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY
12TH ANNUAL REVIEW OF PROGRESS IN APPLIED COMPUTATIONAL ELECTROMAGNETICS

March 18-22, 1996
Naval Postgraduate School
Monterey, CA

Registration Form

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NON-MEMBER	☐ $ 285	☐ $ 300	☐ $ 315
STUDENT * (no proceedings)	☐ $ 115	☐ $ 115	☐ $ 115
RETIRED/UNEMPLOYED	☐ $ 150 (includes proc.)	☐ $ 150	☐ $ 150
BANQUET ☐ Meat ☐ Fish	☐ $ 30	☐ $ 30	☐ $ 30

Short Courses

Course Fees do NOT include attendance at the symposium. Short courses can be taken without attendance at symposium.
Fees for a half-day and full-day course are: $90 or $140, before 3/1/96; $100 or $150, 3/1/96-3/11/96; $110 or $160 after 3/11/96

"AN APPLICATION ORIENTED INTRODUCTION TO THE NEC-BSC WORKBENCH" by R. Marhefka and L. Henderson, Half-day - Monday morning.	☐ $ 90	☐ $ 100	☐ $ 110
"USING MODEL-BASED PARAMETER ESTIMATION TO INCREASE THE EFFICIENCY & EFFECTIVENESS OF COMPUTATIONAL ELECTROMAGNETICS", by Ed Miller, Half-day - Friday morning.	☐ $ 90	☐ $ 100	☐ $ 110
"WAVELETS: THEORY, ALGORITHMS, AND APPLICATIONS", by A.K. Chan Full-day - Monday	☐ $ 140	☐ $ 150	☐ $ 160
"CONFORMAL TIME DOMAIN NUMERICAL ELECTROMAGNETICS", by K. Yee Full-day - Friday	☐ $ 140	☐ $ 150	☐ $ 160
"ANTENNA PROPERTIES IN LINEAR AND NONLINEAR ENVIRONMENTS", by R. Bevensee Half-day - Friday afternoon.	☐ $ 90	☐ $ 100	☐ $ 110
"USING MATHEMATICAL SOFTWARE FOR COMPUTATIONAL ELECTROMAGNETICS" by J. Lebaric, Full-day - Monday	☐ $ 140	☐ $ 150	☐ $ 160
"FINITE ELEMENT METHODS FOR ELECTROMAGNETICS", by J. Volakis and J. Brauer Full-day - Friday	☐ $ 140	☐ $ 150	☐ $ 160
"APPLICATION OF MODERN ANALYTICAL AND HYBRID TOOLS FOR ANTENNA MODELING AND SYNTHESIS", by R. Rojas and P. Pathak, Half-day - Monday afternoon	☐ $ 90	☐ $ 100	☐ $ 110
"PRACTICAL EMI/EMC DESIGN AND MODELING", by T. Hubing, Full-day - Monday	☐ $ 140	☐ $ 150	☐ $ 160

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January 1996

For information regarding ACES or to become a member in the Applied Computational Electromagnetics Society, contact Dr. Richard W. Adler. ECE Department, Code EC/AB, Naval Postgraduate School, 833 Dyer Rd, Rm. 437, Monterey, CA. 93943-5121, telephone (408) 646-1111, Fax: (408) 649-0300. E-mail: rwa@mcimail.com. You can subscribe to the Journal and become a member of ACES by completing and returning the form below.

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January 1996

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