The Applied Computational Electromagnetics

NEWSLETTER

Vol.1 No.2 November, 1986

The Applied Computational Electromagnetics

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Volume 1 Number 2 November, 1986

THE PRESIDENT'S CORNER

The primary purpose of ACES and the Newsletter is to foster information exchange among workers involved in developing and applying computer models in electromagnetics. A major component of this information exchange is collecting and collating user experience in a form that will have archival value as the data base grows in time.

In order to expedite this "feedback" process, we have designed the short-note format which follows, having two goals in mind. One is to encourage members of ACES to submit material to the Newsletter by providing a form that is easy to complete and less laborsome to prepare than might be the typical full-blown journal article. The other is to ensure some standards of consistency and uniformity for these short notes so that they will be most likely to contain the key information needed by someone else who is embarking upon a similar modeling problem and for whom the note(s) will provide knowledge of what worked in a similar application.

We emphasize that the ACES Newsletter is intended to include not only short notes, but longer articles, tutorials and regular columns. It is our expectation however, that the short notes could and should become the most valuable part of the Newsletter in that they will become an accumulation of modeling know how and experience that will guide the subsequent work of other modelers as well as to identify needed modeling developments and research.

We therefore present the format below for short-note (1-3 pages) submittals.

AUTHOR

Name______________________________

Affiliation______________________________

Address______________________________

____

____

Telephone______________________________

APPLICATION

Configuration (Whip antenna on tank; aircraft;...)
Excitation: As Antenna _____ As Scatterer _____
Purpose (Basic physics, design, validation, etc.)

PROBLEM DESCRIPTION

This could be a brief narrative or a fill-in-the-blank exercise to include information such as:

Object Geometry (Dipole, LP, Vehicle, Ship)
Object Size (Major Dimensions in feet or meters)
Frequency Range (in MHz and wavelengths)
Environment (Free space, Perfect Ground, Lossy Ground)
Other Details (Elaborate in written description as needed)

COMPUTER CODE USED

Name of Code (NEC, MININEC, TWTD, etc.)
Version (Name and/or date of release)
Originator (Name, Organization, Address)
Computer on which run (CRAY2, VAX750, etc.)
Formulation (Integral equation and type, or differential equation)
Domain (time, frequency)
Numerical treatment (bases and weight functions)
Special Features ____________________
Other Details (Elaborate in written description as needed)

MODEL DESCRIPTION

Number of unknowns ____________________
Type of unknowns (linear, surface, volumetric)
Physical approximations (wire mesh for surface, open gap for insulator, etc.)
Problem features omitted ____________________
Other Details (Elaborate in written description as needed)

RESULTS OBTAINED

Current Distribution ____________________
Input impedance ____________________
Far-field ____________________
Near-field ____________________
Other ____________________

HOW VALIDATED

Numerical ____ Analytical ____ Experimental ____

Estimated accuracy ____________________
Other Details (Elaborate in written description as needed)

COMMENTS

What went right ____________________
What could be improved ____________________
Overall value of the modeling exercise ____________________
Recommendations ____________________

We would appreciate your comments concerning this short-note format, and any suggestions that you may have for improving it. We should also mention that as one way of eventually organizing the short notes into a useful data base, we are considering using an "ikon-based" encoding scheme whereby problems of various types are keyed by a small diagram in the upper right-hand corner. The purpose of this procedure would be to make it easier to organize files of the notes into logical categories as well as to retrieve desired information from the files. As was noted earlier, we expect the ACES Newsletter to be different from most other publications in that it is intended for category archiving rather than chronological archiving, the idea being that collecting similar information together makes it easier to find and use.

As a concluding comment for this issue, it is necessary to "nag" the membership a little bit. The issue at hand is the paucity of Newsletter material that we're receiving. Without reader input, the Newsletter is not worth doing. As things stand, pretty much the only notes being submitted are those that have been solicited by one of the associate editors. While that's not necessarily inappropriate as one source of material, the Newsletter cannot survive let alone function as hoped for without the active, voluntary participation of workers in the field. Passing along application experience in using computer models for solving real-world problems is the primary purpose of the Newsletter. In order to achieve that goal, we absolutely must hear from the workers "in the trenches".

Please understand that we're not looking for IEEE Transactions articles. Short, to-the-point accounts of modeling experiences are what we primarily need. These can describe not only successes, but also failures. Anything learned by you from a modeling exercise is likely to be of value to someone else because they have encountered similar difficulties, are using the same computer code, are modeling similar problems for which your work will provide useful insight, etc. So let's please hear from YOU!!!

One final comment concerning the next ACES Annual Review. It will be held again at NPGS, Monterey, CA in March 1987. You will be receiving separate announcements about specific time, accommodations, and other details. I'm mentioning the Review at this time because we will require that presenters bring along with them final, camera-ready, copies of their papers. In this way, we will be able to turn around publication of the Proceedings in a more timely and less labor intensive way. Dick Adler did yeoman service in this regard last year in getting the Proceedings out as quickly as he did. But things would have been much less hectic for him had we imposed this requirement last year, while in addition the Proceedings might have been more complete as well. I hope to see you in Monterey for our Third Annual Review.

ACES NEWS

1. The 3rd Annual Review of Progress in Applied Computational Electromagnetics will be held in Monterey, CA at the Naval Postgraduate School during 24-26 March 1987. Attempts to locate the conference at other possible sites failed. If you attended in 1986 and can offer suggestions for (low-cost) improvements for the Conference, please direct them to:

Trish Adler
ACES Conference Coordinator
822 Devisadero St.
Monterey, CA 93940
(408) 649-1234

Flyers announcing the Conference will be mailed during the first week of December.

2. During the 1987 Review, we will have the pleasure of hearing from each of the ACES Committee Chairmen during a business session. The Committees & Chairmen are listed at the end of this Newsletter. (Committee Chairmen: PLEASE PREPARE YOUR REPORTS!!)

E.E. PUBLIC DOMAIN SOFTWARE LIBRARY

Ted Roach of Microcube Corporation, P.O. Box 488, Leesbury, VA 22075, has launched the AVAILABLE SOFTWARE section of the Newsletter with his contributions to this issue. He received information about an E.E. Public Domain Software Library, of which the "Statement of Policy" by Gerald S. Harrison, follows. In addition to being a potential source of computer codes of interest to ACES members, the Library may serve as a model of an ACES SOFTWARE LIBRARY to be discussed at the Third Annual Review of Applied Computational Electromagnetics at Monterey, CA in March of 1987. We want to hear your ideas for such a Library and we may draft a Constitutional Amendment to establish it at the Monterey Review.

THE NEEDS OF "NEEDS"

Jim Breakall has provided us with thought-provoking ideas concerning ways to improve the user-friendliness of EM codes in his letter, which we include here. During the 1987 March ACES Review, there will be a panel discussion/forum devoted to this subject. Please add your inputs to his ideas by attending the Review or by submitting a letter to this column.

--- Robert Bevensee
Editor

E.E. PUBLIC DOMAIN SOFTWARE LIBRARY

STATEMENT OF POLICY

1. All software in the library will be in the public domain.

2. The library will collect and distribute software covering all electrical engineering disciplines.

3. Programs will be distributed on 5 1/4 inch floppy disk in IBM PC format (360 k dsdd). Some programs will be available in CP/M format on 8 inch floppy disk in IBM format (240k sssd). Other formats may be available.

4. Programs will be accepted in the above formats and in other formats if the library can convert them to the above formats.

5. Contributors to the library will receive a limited number of programs free.

6. The library will impose a media and handling charge of $10 a disk. This will include the cost of reproduction and of mailing

7. Abstracts of programs in the library will be published periodically in R.F. DESIGN magazine.

8. Enhanced versions of programs in the library will be added to the library as they are received.

9. The library will be the sole judge as to whether a contribution to the library shall be distributed.

10. This library is providing a data distribution service. It does not review or evaluate the material it distributes.

11.WARRANTY

THE LIBRARY SHALL NOT BE RESPONSIBLE FOR ANY DAMAGES, INCLUDING BUT NOT LIMITED TO LOSS OF PROFIT, SPECIAL, INCIDENTAL, CONSEQUENTIAL, OR OTHER SIMILAR CLAIMS. THE LIBRARY SPECIFICALLY DISCLAIMS ALL WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO ANY DEFECTS IN THE DISKETTE, THE PROGRAMS CONTAINED THEREON OR IN THE DOCUMENTATION.

A PURCHASER'S SOLE REMEDY SHALL BE LIMITED TO THE REPLACEMENT OF MEDIA DAMAGED IN SHIPMENT BY THE LIBRARY.

E.E. PUBLIC DOMAIN LIBRARY
36 IRENE LANE EAST
PLAINVIEW, N.Y., 11803

The Needs of NEEDS*

J. K. Breakall
University of California
Lawrence Livermore National Laboratories, Livermore, CA

I would like to share some ideas and impressions I have on the soon-to-be completed workstation system called NEEDS, which you have all heard described over the past few years at the ACES conference and is being developed at the Lawrence Livermore National Laboratory. NEEDS stands for Numerical Electromagnetic Engineering Design Station and is a workstation based system that will run a host of EM codes and pre- and post-processing tools in a user-friendly environment. It is built around a system of pop-down menus and forms which allow data input and selection, much as is done on the Macintosh Computer. This NEEDS system will allow a new or inexperienced user to avoid being bogged down with all the details and guidelines in modeling in the EM world, and also, to use a host of pre- and post-processing tools with ease of learnability and application. At the same time, the NEEDS product will also address the many problems that the experienced user has had with modeling and communicating results.

The next-generation NEEDS workstation environment will have to incorporate more artificial intelligence and self-documentation. I will present some issues in this paper, but believe that the user-community, as a whole, will have to ultimately decide what its needs are. I suggest that a meeting to discuss any present and future ideas and wants preferably be held at the next ACES symposium in Monterey in the Spring of 1987.

Over the years, and probably more in the present, I have observed some needs of both experienced and inexperienced users, which I will try to communicate with some ideas of how they might be satisfied.

Geometry Manipulation.

One of the biggest problems with all EM codes, including NEC and GTD, is how to get the object one is modeling into the computer in a form that the code understands to execute calculations. Each and every code has different ways of representing this object, and almost universally, the code developer has used a system of description which corresponds in some way to the solution method which makes his life easier. In actuality, the user would simply like to get the object into the code and not be troubled with how the geometry is broken up into elementary geometry blocks or segments for computations. Most codes have clear guidelines and rules for this breakdown, and logical constructs can certainly be made (some may require more effort than others) to obtain the smallest and correct set of computational pieces of the original geometry.

The solution is clear. A universal geometry description or language must be formulated in a very precisely defined coordinate system for specifying objects by a finite number of basic geometrical shapes. After the object is described in terms of these basic geometrical

* Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

descriptors, it can be then further broken down into the appropriate geometrical blocks for each code by writing an intermediate translator that determines the computational geometry by following the code's guidelines and rules. This last step should be completely invisible to the user, and he might only have some control over it by specifying a degree of resolution in the solution desired (fine, medium, coarse, etc.). Some examples of basic shapes which could be used are:

(1) lines

(2) n-sides polygons

(3) circles

(4) cylinders

(5) boxes

Once the geometry is entered with the above shapes, it is then subdivided into its solution elements (segments, triangular or quadrilateral patches, cubes, wire grids, etc.) by adhering to modeling guideline rules.

EM Graphics Language and Package.

Every user uses different graphics packages for the basic plotting calls and then writes a custom package for plotting the specific EM output (patterns, contours, x-y plots, 3-d, etc.). Some packages are developed with commercial software (DISSPLA, very expensive) to lower cost (PLOT-10) or free software (NCAR or DIGLIB). The methods of putting together a particular EM plotting code can then be varied. Some put labels and titles from inside the code giving the user no interactivity while others prompt the user for this information. Some use fancy fonts and variable thickness lines while others produce plots that must be touched up by a series of cutting and pasting operations.

What is needed is to determine the minimum necessary fanciness and sophistication and come up with one package which will satisfy all EM users. In other words, a package specially tailored to EM graphics, with the ease of producing either simple graphics or journal-ready graphics, is needed which can be used by all. This implies that the inherent plotting package used must be inexpensive, and a lot of development time must be put in to enhance it towards customized EM fanciness. A universal data structure must be decided, and all EM codes should be modified or constructed so that they adhere to this specification. Separate subroutines (hi-level) should be written which can also be used in user-written programs to draw EM plots. Some examples of the types of plots and flexibility follows:

(1) Radiation Pattern, extremely flexible, scaling, multiple plots, titles, legends, splining, etc.

(2) Smith Chart

(3) Contour, near fields, current density, etc.

(4) XY, current, impedance, etc.

File Transfer.

There is some need to transfer files back and forth from the workstation to a host of different types of computers. Various users use different mainframe computers and operating systems for the actual crunching. This problem, I believe, is extremely important and maybe even critical for success. A generic data type and format (probably ASCII) should be developed which will be universally acceptable to a finite number of machines. File transfer codes and protocols need to be investigated, and maybe even commercial products will have to be purchased. This problem is not one unique to our situation, and I believe it will be one of the most important problems that will be worked on over the next few decades, with the need for computer mail and communication. Codes such as KERMIT and MODEM are possibilities which might work. The PC world may turn out to be an avenue of discovery for this investigation.

Digitizer.

This method of inputting geometry data is certainly one of important investigation. We need to find out what types of hardware are out there and what the range of costs are. The flexibility of the various units needs to be determined, especially when connecting and working with a Micro-Vax and other terminals. We need to investigate what software and algorithms are developed. CAD/CAM methods may equally apply to our problem or we may decide to use, and possibly enhance, the IGUANA approach. Image-to-computer transfer devices are really starting to emerge and the exploration of such devices is needed.

Mouse, Light-Pen, Cursor, etc.

The use of some extra hardware attachment such as a mouse, light-pen, etc. would be advantageous for manipulating menus and interacting with graphics input. Such features as segment-finding, inputting data, locating positions on output plots for titles and legends, and zooming could all use such a feature.

Miscellaneous.

Some other thoughts and ideas come to mind as well but need to have more details and expansion added.

(1) Output options, Tables, printout, sorting, etc.

(2) System commands, Execute from within NEEDS

(3) Database, The ability to keep track and sort through files is needed

(4) UNIX-like piping, Directing the output of one code to be the input directly of another code

A discussion and/or additional thoughts and criticisms are needed, as I see it, on these issues. This effort may be an unlimited sink for manpower and time, but if we can address some of the issues, with your own ideas and impressions, I think we will all be ahead. I suggest soliciting replies via correspondence to be published in the ACES Newsletter.

MODELING NOTES

The primary purpose of ACES and the Newsletter is to foster information exchange among workers involved in developing and applying computer codes to model electromagnetic problems.

This section will feature short articles about particular aspects of the more popular codes and short notes which summarize user experience with specific codes. To facilitate the submission of short notes in a standard form which can be easily referenced later, we present the ACES MODELING SHORT-NOTES form for 1-3 page submittals. This is the same form appearing in THE PRESIDENT'S CORNER.

Readers are encouraged to report their code experiences in these ACES MODELING SHORT-NOTE forms and send them to the ACES Secretary, whose address is listed in the FRONTISPIECE. Camera-ready SHORT-NOTE forms are preferred.

ACES MODELING SHORT-NOTE

AUTHOR	Name ______________________
	Affiliation ______________________
	Address ______________________
	______________________
	Telephone ______________________
APPLICATION	Configuration (Whip antenna on tank; aircraft....)
	Excitation: As Antenna _____ As Scatterer _____
	Purpose (Basic physics, design, validation, etc.)
PROBLEM DESCRIPTION	This could be a brief narrative or a fill-in-the-blank exercise to include information such as:
	Object Geometry (Dipole, LP, Vehicle, Ship)
	Object Size (Major Dimensions in fee or meters)
	Frequency Range (in MHz and wavelengths)
	Environment (Free space, Perfect ground, Lossy ground)
	Other Details (Elaborate in written description as needed)
COMPUTER CODE USED	Name of Code (NEC, MININEC, TWTD, etc.)
	Version (Name and or date of release)
	Originator (Name, Organization, Address)
	Computer on which run (CRAY2, VAX750, etc.)
	Formulation (Integral equation and type, differential equation)
	Domain (time, frequency)
	Numerical treatment (bases and weight functions)
	Special Features ______________________
	Other Details (Elaborate in written description as needed)
MODEL DESCRIPTION	Number of unknowns ______________
	Type of unknowns (linear, surface, volumetric)
	Physical approximations (wire mesh for surface,etc.)
	Problem features omitted ______________________
	Other Details (Elaborate in written description as needed)
RESULTS OBTAINED	Current Distribution ______________________
	Input impedance ______________________
	Far-field ______________________
	Near-field ______________________
	Other ______________________
HOW VALIDATED	Numerical ____ Analytical ____ Experimental ____
	Estimated accuracy ______________________
	Other Details (Elaborate in written description as needed)
COMMENTS	What went right ______________________
	What could be improved ______________________
	Overall value of the modeling exercise ______________________
	Recommendations ______________________

ACES MODELING SHORT-NOTE

AUTHOR

Name Jim Breakall

Affiliation Lawrence Livermore Nat'l Lab

Address L-156, P.O. Box 808
Livermore, CA 94550

Telephone (415) 422-8196

APPLICATION

Configuration 3- and 5-element YAGI (NBS)
Excitation: As Antenna X As Scatterer ______
Purpose Validation with Experimental Pattern Measurement

PROBLEM DESCRIPTION

This could be a brief narrative or a fill-in-the-blank exercise to include information such as:

Object Geometry YAGI
Object Size .25 X .4λ(3 EL), .25 X .8 λ (5EL)
Frequency Range 299.8-305 MHz
Environment FREE SPACE
Other Details E- and H- Plane Patterns and Gain

COMPUTER CODE USED

Name of Code NEC2, MININEC
Version ______________________
Originator Lawrence Livermore Nat'l Lab
Computer on which run VAX 11/780
Formulation Integral Equation
Domain Frequency
Numerical treatment 3 Term (NEC), Pulse (MININEC)
Special Features ______________________
Other Details Refer to article by J.K. Breakall, this issue.

MODEL DESCRIPTION

Number of unknowns 7-30 per element
Type of unknowns Linear
Physical approximations Thin Wire Approximation
Problem features omitted ______________________
Other Details Refer to article by J.K. Breakall, this issue.

RESULTS OBTAINED

Current Distribution Magnitude and Phase
Input impedance Real and Imaginary parts
Far-field Patterns and Gain
Near-field ______________________
Other ______________________

HOW VALIDATED

Numerical ____ Analytical ____ Experimental NBS Measurements
Estimated accuracy < 10% error in fields
Other Details Refer to article by J.K. Breakall, this issue.

COMMENTS

What went right NEC agreed well with measurements
What could be improved MININEC results are offset in frequency
Overall value of the modeling exercise Validation
Recommendations Look closer into MININEC formulation

PANDORA'S BOX

by Dawson Coblin

According to Greek mythology, Pandora opened her box only long enough for evil to escape and roam the world. By closing it, she trapped hope in the box. So man is doomed to live in an evil world without hope. In their less sanguine moments, code users feel the same way; lost, abandoned and despairing. It is intended that in this column Pandora's box can be opened again and hope allowed to escape.

The purpose of this column is to concentrate on unsuccessful applications of commonly used codes. The goal will be to determine areas where the application may have forced the code to break down and make suggestions for improving the results. The success of this approach depends on the responsiveness of the ACES members to share their less successful attempts and quandaries.

The membership is therefore solicited to send their problem cases to me for review. Please include the name of the code used (and version, if applicable), the specifics of the test case, examples of the output, a list of the problems and contradictions observed, and your name, address, and telephone number. Please respond to the following address:

R.D. Coblin
O/6242;B/130
Lockheed Missiles & Space Co.
P.O. Box 3504
Sunnyvale, CA 94088-3504.

COMPUTER CODE DESCRIPTIONS

This section of the Newsletter will feature succinct descriptions of codes similar to the accounts published in the COMPUTER CODE DESCRIPTION Section of the IEEE Transactions on Antennas and Propagation in the 1970's. Each description should include information such as code title, purpose, machine and language, author, availability, summary of capability, limitations, storage and timing, and an outline of a representative problem - preferably with a solution.

AVAILABLE SOFTWARE

In this Section, the Newsletter will foster the release of software from sponsoring organizations and individuals for use by ACES members. Most software will be in the public domain, but some will be restricted. The editors prefer that those persons or organizations willing to make software available do so by forwarding a copy of the ACES Software Form, reprinted here, to the Secretary, whose address is listed in the FRONTISPIECE. The Forms are preferred in camera-ready format. Contributors should refer to the paragraph on Software Material in the FRONTISPIECE.

Questions about contributions should be directed to editor Donn Campbell, whose address is in the FRONTISPIECE, and whose telephone number is (619) 592-3245.

Ted Roach of Microcube Corporation and Jim Logan of NOSC, have kindly furnished the software items in this issue.

ACES SOFTWARE FORM

Software Number: ____________________

Machine: ____________________

Directory Listing:

____________________ ________

____________________ ________

____________________ ________

Description:

____

____

____

a) Features:

1)____________________ 5)________

2)____________________ 6)________

3)____________________ 7)________

4)____________________ 8)________

b) Configuration:

____________________ ________

____________________ ________

____________________ ________

c) Software Language Required:

____________________ ________

____________________ ________

d) Formatted:

____________________ ________

____________________ ________

e) Available from:

____

____

____

____

f) Access:

____

____

g) Documentation:

____

____

____

____

h) Cost:

____

ACES SOFTWARE FORM

Software Number: #001 - MININEC2

Machine: IBM PC

Directory Listing:

Source Code:	MNEC2.BAS	15,671
Compiled:	MNEC2.EXE	49,408
Compiled for 8087:	87MNEC2.EXE	46,464
Documentation:	README.DOC	550

Description: Modified MININEC2 with optional 8087 capability.

a) Features:

1) Standard 10 wires
2) 50 Segments
3) Generates Impedance data
4) Generates Pattern data
5) Generates Current data
6) No disk file handling
7) Multiple loads allowed

b) Configuration:

128K RAM required
No graphics required
Optional PC-AT, XT, RT

Optional 8087 CoProcessor
Optional Printer (Serial or Parallel)

c) Software Language Required:

IBM BASICA or GWBASIC for interpreter
or none required for EXE files.

d) Formatted:
5 1/4" floppy 360k DSDD
DOS 2.0 or later

e) Available from:

Ted Roach
MicroCube Corporation
P.O. Box 488
Leesburg, VA 22075

f) Access:
Public domain software,
no access controls required

h) Cost:
$5.00 for materials, postage

g) Documentation:

NOSC-TD-516 for MININEC1
available from
NTIS
5285 Ft. Royal Rd.
Springfield, VA 22161

For MININEC2 (original code)
see "MICROCOMPUTER TOOLS FOR
COMMUNICATIONS ENGINEERING"
by S.T. Li, it al. CH.4
from ARTECH HOUSE (800) 225-9977

ACES SOFTWARE FORM

Software Number: #002 - MININEC2F

Machine: IBM PC

Directory Listing:

Source Code:	MNEC2F.BAS	18,884
Compiled:	MNEC2F.EXE	59,648
Compiled for 8087:	87MNEC2F.EXE	56,704
Documentation:	README.DOC	834

Description: MININEC2 with frequency sweep & file handling.

a) Features:

1) Standard 10 wires
2) 50 Segments
3) Frequency Sweep; Input Start, Stop, Step, up to 50 frequencies
4) Disk File handling
   a) Save Geometry
   b) Recall Geometry
   c) Modify Geometry
   d) Save Impedance to disk
   e) Recall Impedance
5) No printer output
6) No pattern or current outputs to disk file
7) No loads allowed

b) Configuration:

128K RAM required
No graphics required
Optional PC-AT, XT
Optional 8087 CoProcessor
Optional Printer (Serial or Parallel) with file handling

c) Software Language Required:

IBM BASICA or GWBASIC for interpreter or none required for EXE files.

d) Formatted:
5 1/4" floppy 360k DSDD
DOS 2.0 or later

e) Available from:

Ted Roach
MicroCube Corporation
P.O. Box 488
Leesburg, VA 22075

f) Access:

Public domain software, no access controls required

g) Documentation:

NOSC-TD-516 for MININEC1 available from
NTIS
5285 Ft. Royal Rd.
Springfield, VA 22161

For MININEC2 (original code) see "MICROCOMPUTER TOOLS FOR COMMUNICATIONS ENGINEERING" by S.T. Li, et al. CH.4 from ARTECH HOUSE (800) 225-9977

h) Cost:
$5.00 for materials, postage

ACES SOFTWARE FORM

Software Number: #003 Enhanced MININEC2 - double array size

Machine: IBM PC

Directory Listing:

MNEC2E1.BAS	72k	DL670CM.DAT	2.6k
MNEC2E2.BAS	15.3k	DL6220.DAT	2.4k
NBS42.DAT	2k	README	1k

Description: A larger version of MININEC2, with some of McNamara's enhancements.

a) Features:

1) 20 wires
2) 100 segments
3) Impedance data
4) Pattern data
5) Current data
6) Multiple loads
7) Geometry file handling
8) On-screen graphics but with some errors

b) Configuration:

512K RAM suggested
GRAPHICS suggested
8087 suggested

c) Software Language Required:

Professional Basic (to handle larger files than 64k)
(Better BASIC?)

d) Formatted:
5 1/4" floppy 360k DSDD
DOS 2.0

e) Available from:

Ted Roach
MicroCube Corporation
P.O. Box 488
Leesburg, VA 22075

f) Access:
Public domain software,
no access controls required

h) Cost:
$5.00 for materials, postage

g) Documentation:

NOSC-TD-516 for
MININEC1 available from
NTIS
5285 Ft. Royal Rd.
Springfield, VA 22161

For MININEC2 (original code)
see "MICROCOMPUTER TOOLS FOR
COMMUNICATIONS ENGINEERING"
by S.T. Li, et al. CH.4
from ARTECH HOUSE (800) 225-9977

ACES SOFTWARE FORM

Software Number: #004 Enhanced MININEC2

Machine: IBM PC

Directory Listing:

MININEC.BAS	74k	TEST.DAT	.5k
MININEC.EXE	103k	10MWHIP.ANT	.4k
MININEC1.EXE	101k		

Description: A version of MININEC2 with some of McNamara's enhancements.

a) Features:

1) 10 wires
2) 50 segments
3) Impedance data
4) Pattern data
5) Current data
6) Multiple loads
7) Geometry file handling
8) On-screen graphics but with some errors

b) Configuration:

256K RAM suggested
GRAPHICS suggested
8087 suggested

c) Software Language Required:

5 1/4" floppy 360k DSDD
DOS 2.0 or later

d) Formatted:
5 1/4" floppy DSDD 362k
DOS 2.0

e) Available from:

Ted Roach
MicroCube Corporation
P.O. Box 488
Leesburg, VA 22075

f) Access:
Public domain software,
no access controls required

h) Cost:
$5.00 for materials, postage

g) Documentation:

NOSC-TD-516 for
MININEC1 available from
NTIS
5285 Ft. Royal Rd.
Springfield, VA 22161

For MININEC2 (original code)
see MICROCOMPUTER TOOLS FOR
COMMUNICATIONS ENGINEERING"
by S.T. Li, et al. CH.4
from ARTECH HOUSE (800) 225-9977

ACES SOFTWARE FORM

Software Number: #005 THIN WIRE MININEC2

Machine: IBM PC

Directory Listing:

MNEC2G.BAS	14k	README	1k
MNEC2G.EXE	48k		
87MNEC2G.EXE	48k		

Description: MININEC2 modified by Todd Poston for very thin wires. Useful at VLF where very short segments occur.

a) Features:

1) 10 wires
2) 50 segments
3) Generates impedance data
4) Generates pattern data
5) Generates current data
6) Multiple loads
7) Printer output
8) Modified for 10^{-4} to 10^{-7} wavelength segments (good for VLF)

b) Configuration:

128K RAM
no GRAPHICS
optional 8087

c) Software Language Required:

IBM BASICA
or GWBASIC interpreter

none for .EXE files

d) Formatted:
5 1/4" floppy 360k DSDD
DOS 2.0

e) Available from:

Ted Roach
MicroCube Corporation
P.O. Box 488
Leesburg, VA 22075

f) Access:
no restrictions

g) Documentation:

NOSC-TD-516 for
MININEC1 available from
NTIS
5285 Ft. Royal Rd.
Springfield, VA 22161

For MININEC2 (original code)
see "MICROCOMPUTER TOOLS FOR COMMUNICATIONS ENGINEERING"
by S.T. Li, et al. CH.4
from ARTECH HOUSE (800) 225-9977

h) Cost:
$5.00 for materials, postage

ACES SOFTWARE FORM

Software Number: #006 - INTERACTIVE NEC, NEC2

Machine: DEC VAX

Directory Listing:

INEC2.DIR - Interactive NEC
NEC2D.DIR - NEC2 double precision
NEC2S.DIR - NEC2 single precision
README.NEC

Description: INEC2 is a subset of NEC2, useful for beginners and students. It prompts for inputs interactively.

a) Features:

1) 300 segments
2) Current and Impedance
3) Near and far fields
4) Loads and networks
5) Lossy ground
6) In Core calculations
7) Pattern Graphics with INEC2

b) Configuration:

VMS operating system
INEC2 - VT100 terminal
Device Independent Graphics

c) Software Language Required:

FORTRAN 77 (VAX VMS enhanced)

d) Formatted:
DEC backup tape
1600 BPI, 9 track

e) Available from:

J.K. Breakall, L-156
Lawrence Livermore Nat'l Lab
P.O.Box 5504
Livermore, CA 94550
(415) 422-8196

f) Access:
NEC2 - public domain

g) Documentation:

NOSC-TD-116 for NEC2
supplied with puchase.

h) Cost:
$850.00
(These codes are included if NEC3 is puchased as #007)

ACES SOFTWARE FORM

Software Number: #007 - NEC3, NECGS

Machine: DEC VAX

Directory Listing:

NEC3D.DIR - NEC3 double precision README.NEC 1k
NEC3S.DIR - NEC3 single precision
NECGS.DIR - special radials code

Description: The latest version of NEC featuring buried wires. NECGS treats monopole-like structures with radial wires in a very efficient manner.

a) Features:

1) 300 segments
2) Current and Impedance
3) Near and far fields
4) Loads and networks
5) Lossy ground
6) In Core calculations
7) Pattern Graphics with INEC2
8) Buried Objects

b) Configuration:

VMS operating system

c) Software Language Required:

FORTRAN 77 (VAX VMS enhanced)

d) Formatted:
DEC backup tape
1600 BPI, 9 track

e) Available from:

J.K. Breakall, L-156
Lawrence Livermore Nat'l Lab
P.O.Box 5504
Livermore, CA 94550
(415) 422-8196

f) Access:
NEC3, DOD Contractors,
Military critical,
Foreign request must go
through Diplomatic channels.

g) Documentation:

NOSC-TD-116 for NEC2 &
2 LLNL NEC3 reports (as additions to NEC2) provided with purchase.

h) Cost:
$850.00
(This cost includes INEC &
NEC2 of #006)

ACES SOFTWARE FORM

Software Number: #008 - MININEC3

Machine: IBM PC/XT or AT

Directory Listing:

MININEC3.BAS	MNPOST.BAS	README.NEC
MININEC3.EXE	MNPOST.EXE	
MNPRE.BAS	ACES.DOC	
MNPRE.EXE		

Description: Lastest version of MININEC from the authors. On-going updates will be available only via this NEWSLETTER. MNPRE converts NEC input geometry from IGUANA or other sources into MININEC3 format. MNPOST prepares MININEC3 output files for GRAPS plotting.

a) Features:

1) 50 pulses/ 50 wires
2) Impedances (Z or S-parameters
3) Currents
4) Ground conditions: FS, Perfect ground or reflection coefficient finite ground.
5) Extensive file saving
6) Output to printer or disk
7) Near E,H in freespace & over perfect ground only.
8) Patterns for FS, PG, multiple RC finite grounds with linear, circular boundaries/cliffs (similar to NEC)

b) Configuration:

256K RAM

c) Software Language Required:

IBM BASICA for .BAS but arrays must be reduced for 64K limit to 30 pulses/10 wires

d) Formatted:
5 1/4" floppy
DOS 2.1

e) Available from:

James C. Logan
NOSC, Code 822 (T)
271 Catalina Blvd.
San Diego, CA 92152

f) Access:
Foreign requests must go through diplomatic channels.

g) Documentation:

NOSC-TD-938 is in process, not yet available. Requests for it will be honored when it is available.

h) Cost:
Send 1 preformatted (DOS 2.1) floppy in self-addressed, stamped return mailer and include a request in writing.

ACES SOFTWARE FORM

Software Number: #009 - GRAPS

Machine: IBM PC/XT or AT

Directory Listing:

57 FILES 305k

Description: GRAphical Plotting System from NOSC displays and plots linear/log rectangular graphs plus Smith Charts and polar patterns. Designed for use with MININEC3 and IGUANA but can be used stand-alone.

a) Features:

1) Linear
2) Bi-linear
3) Log-linear H or V
4) Polar (dB)
5) Smith Chart
6) Sample plot data files
7) Menu driven screens
8) Plot, View, Print, Edit label functions

b) Configuration:

IBM PC-XT/256K RAM
HiResolution graphic card (CGA)
Parallel & Serial ports

Dot matrix IDS - or EPSON compatible printer
(optional) HP 7470, 7475, 7550, 7220 or 9872 plotter

c) Software Language Required:

IBM BASICA

d) Formatted:
5 1/4" floppy
DOS 2.1

e) Available from:

James C. Logan
NOSC, Code 822 (T)
271 Catalina Blvd.
San Diego, CA 92152

f) Access:
Public domain

g) Documentation:

NOSC-TD-820 will be sent with software.

h) Cost:
Send 1 preformatted (DOS 2.1) floppy in self-addressed, stamped return mailer and include a request in writing.

ACES SOFTWARE FORM

Software Number: #010 - IGUANA 4.0

Machine: IBM PC/XT or AT

Directory Listing:

160 FILES - Over 1M Bytes
.BAS & .EXE with auxiliary programs and sample data sets

Description: Interactive Graphics Utility for Army NEC Automation is a system to partially automate data entry and display processes for NEC/MININEC3.

a) Features:

1) Creation of 3-D models
2) Generation of NEC wire cards for (1)
3) User entry & maintenance of other required NEC input information
4) Translate & transmit data to a NEC host computer
5) Capture & Display of NEC output
6) MININEC3

b) Configuration:

IBM PC-XT/256K RAM
HiResolution graphic card (CGA) or compatible
Parallel & Serial ports

Dot matrix IDS - or EPSON compatible printer

(optional) HP 7470, 7475, 7550, 7220 or 9872 plotter

c) Software Language Required:

IBM BASICA

d) Formatted:
5 1/4" floppy
DOS 2.1

e) Available from:

James C. Logan
NOSC, Code 822 (T)
271 Catalina Blvd.
San Diego, CA 92152

f) Access:
Foreign requests must go through diplomatic channels.

g) Documentation:

Provided with software.

h) Cost:
Send 4 preformatted (DOS 2.1) floppies in self-addressed, stamped return mailer and include a request in writing.

ARTICLES

All members of ACES, and nonmembers as well, are invited to submit original, previously unpublished articles on various aspects of applied computational electromagnetics. The content and format of submissions are described in the FRONTISPIECE information. Articles should be succinct and preferably no longer than 10-12 printed pages. (Short submissions may be more appropriate for another section of the Newsletter.)

GAIN AND PATTERN MEASUREMENT EXAMPLES OF A LOW PROFILE HF ANTENNA ARRAY

By

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O. Niel Skousen

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Eyring Research Institute
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Provo, Utah 84601

ABSTRACT

Measurement data are presented for several configurations of the Eyring Low Profile Antenna (ELPA). The antenna can be classed as an arrayed, broadband antenna with a controlled ground interaction. Examples will demonstrate feedpoint matching, bandwidth, azimuth patterns, elevation patterns and site layout conditions. Eight-element arrays will be compared to typical broadband tactical antennas at several frequencies. The measurements were obtained by a helicopter-towed elementary dipole beacon.

The measurements were performed in the autumn of 1985 at the Eyring Research Institute test facility located at the Cedar Valley Airport, Cedar Valley, Utah.

INTRODUCTION

The Eyring Low Profile Antenna * (ELPA) family has a unique performance envelope that matches many modern military communications requirements. The ELPA is inherently a broadband device that typically displays more than three octaves of bandwidth within a demonstrated spectrum application range of 10 kilohertz to 88 megahertz (1,2). The antenna concepts employed in the design can be viewed as synergistically interacting with the ground environment. Ground coupling is controlled by the low profile geometry of the multiple radiating elements that make up the antenna. In general, the ELPA makes a favorable trade-off between radiation efficiency, wide bandwidth, uniform pattern gain, compact deployment area and lightweight survivable packaging style. The reduced efficiency limits the attainable overall pattern power gain, but the typical ELPA element and array structures offset this limitation by providing a significant directive gain along a bidirectional or unidirectional beam axis.

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*Patents Pending

The ELPA was developed empirically through full-scale HF (2- to 30-MHz) testing techniques over the last six years. The techniques evolved into a Broadband Antenna Test System known as BATS (3,4).

EXAMPLES

The following figures are presented to provide an introduction to some of the features of low profile ground interactive antennas. The mechanical descriptions and power gain pattern data for the ELPA are presented with collective detail sufficient to guide the expectations of modeling investigations for similar structures located near lossy earth. The databases represented here were developed either solely by Eyring Research or in joint sponsorship with Government agencies. Some measurements represented here were made in the autumn of 1985 in joint sponsorship with the Naval Electronics Systems Engineering Activity (NESEA), St. Inigoes, Maryland (5,6,7).

Basic Layout and Feedpoint Characteristics

Figure 1 represents the basic deployment configuration of a model 504, 4-element Man Pack series ELPA antenna (75/75 symmetric element, 150 feet total span). This layout can be modified by removing the 23-inch (58.5 cm) high stakes and laying the entire structure on the ground. The antenna element wire is a phosphor bronze conductor with a diameter of 0.062 inches (1.57 mm) covered by a black polyvinyl chloride dielectric jacket, nominally 0.015 inches (0.38 mm) thick. All interconnections between elements are made with RG-142 B/U teflon coaxial cable appropri-

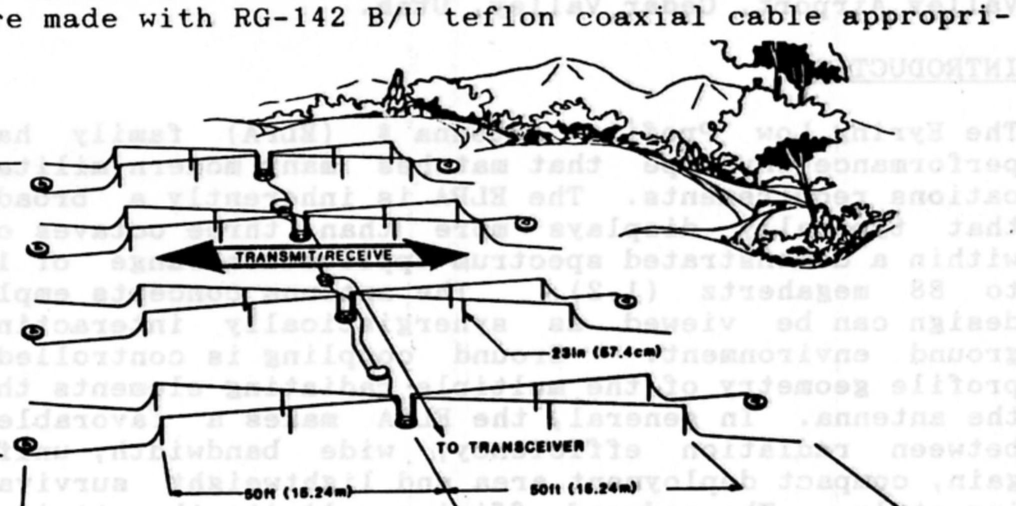

Figure 1. A 4-element Eyring Low Profile Antenna is shown with a V-element structure.

ate in length to the layout dimensions within one foot. The interconnections junction at power dividers (3 units for 4-elements), which match the 50-ohm coaxial cables and can be assumed to have a midrange insertion loss on the order of 0.05 dB. Each element is driven in phase through a matching network that contributes 1 dB of pattern asymmetry in the direction of the antenna's "phase arrows" marked on each element-matching network. For modeling purposes, the network can be assumed linear with an impedance matching ratio selected between 1:4 and 1:12. The exact ratio range is determined by application guided tradeoffs between element structure and anticipated ground conductivity and dielectric constant.

The element-to-element spacing shown in the figure and used for data throughout this paper is standardized at 20 feet (6 m). The spacing can be expanded to improve directive gain below 10 MHz. Similarly, increasing element length improves overall low angle directive gain as well as low frequency power gain, but ultimately creates a tradeoff between low angle and high angle pattern coverage. Similarly, asymmetric deployment of an element directly translates into controllable pattern changes. Deployment in terms of percent staked length versus ground contact length can be used in the context of length derived directivity (previously noted as directive gain) to create significant (10 to 15 dB) front-to-back ratios.In general, large asymmetries over "good" to "excellent" ground conditions create the best front-to-back ratios.

Figure 2 is a Smith chart display of the feedpoint reflection coefficients (S11) of a 4-element antenna deployed on stakes. The feedpoint is at the central power divider, which is depicted in Figure 1 at the junction with a cable labeled "To Transceiver."

These measurements were made with an HP3577A network analyzer and an S-parameter test set(8), and are typical for the ground parameters measured at the reference frequency indicated in this figure. The near surface ground condition measurement was made with a 30.5 cm inverted monopole probe and represents a surface weighted upper bound for the parameters of this region. The subsurface measurement was made on excavated material typical of a 50 to 100 cm depth where the soil is sandy, rocky, free of organic material, and typically quite dry. This subsurface measurement employed a capacitor technique that typically provides lower boundaries for soil parameters. It is therefore important to note that these plots are in the context of a two-layer dielectric problem where the thin, 10 cm thick surface lawn sod probably represents "good" ground conditions over the "poor" ground conditions measured for the subsurface sand below 50 cm.

Figure 3 is a plot of the magnitude of the feedpoint impedance. Note that the maximum value for these test conditions is 125 ohms (2.5:1 VSWR) at 2.425 MHz.

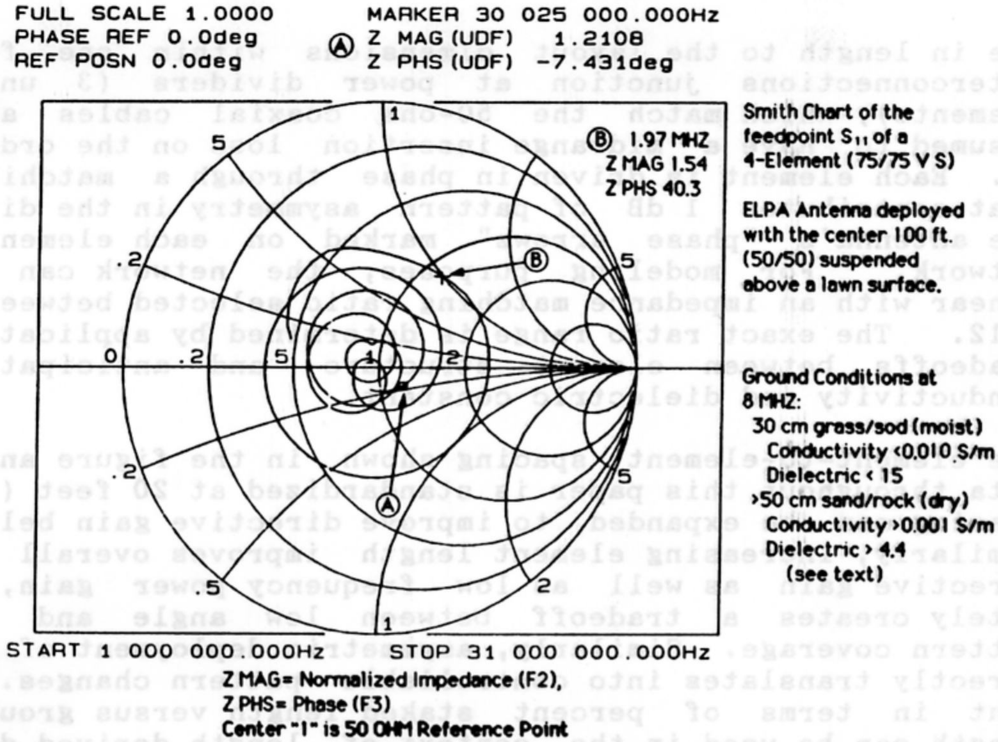

Figure 2. Feedpoint of a 4-element antenna on stakes.

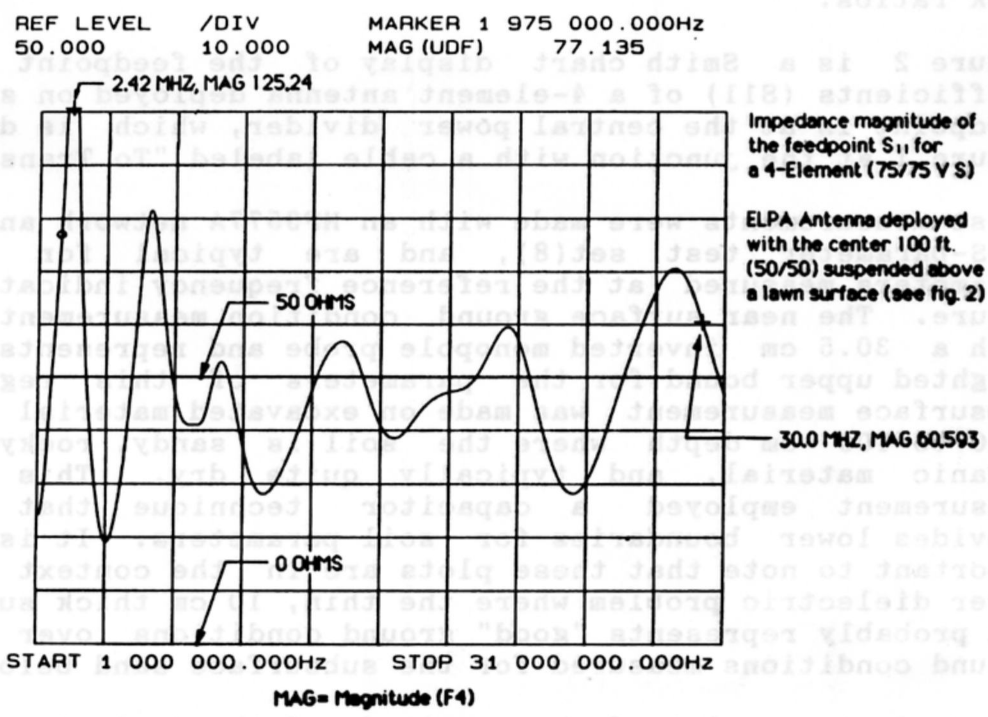

Figure 3. Impedance plot of figure 2.

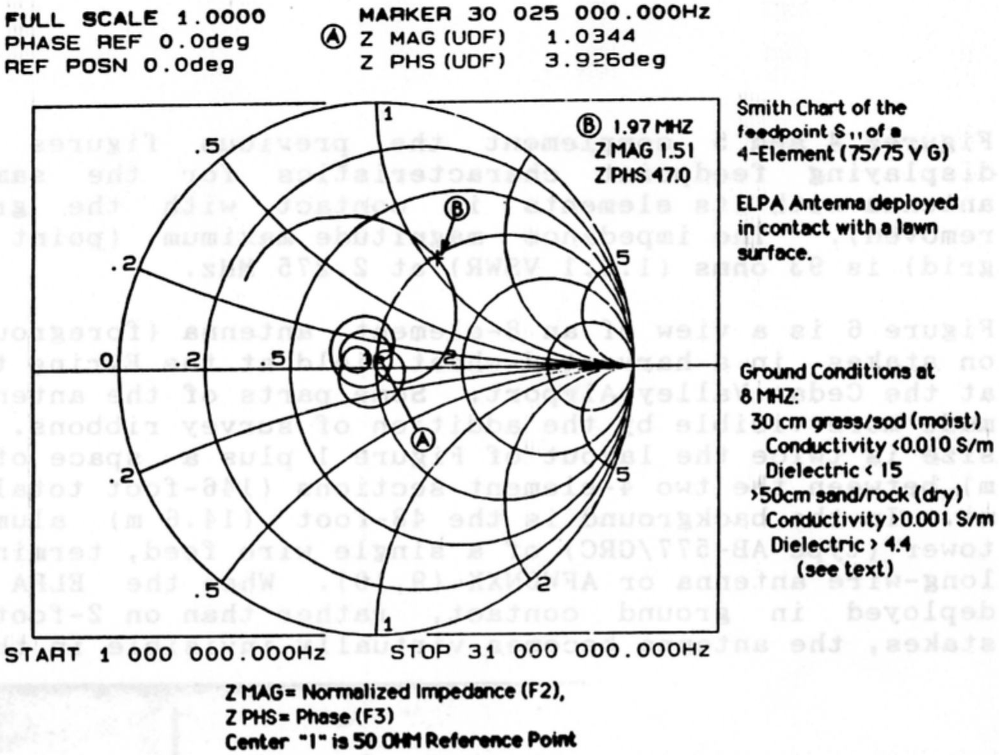

Figure 4. Feedpoint of a 4-element antenna deployed in full surface contact (0.0 height).

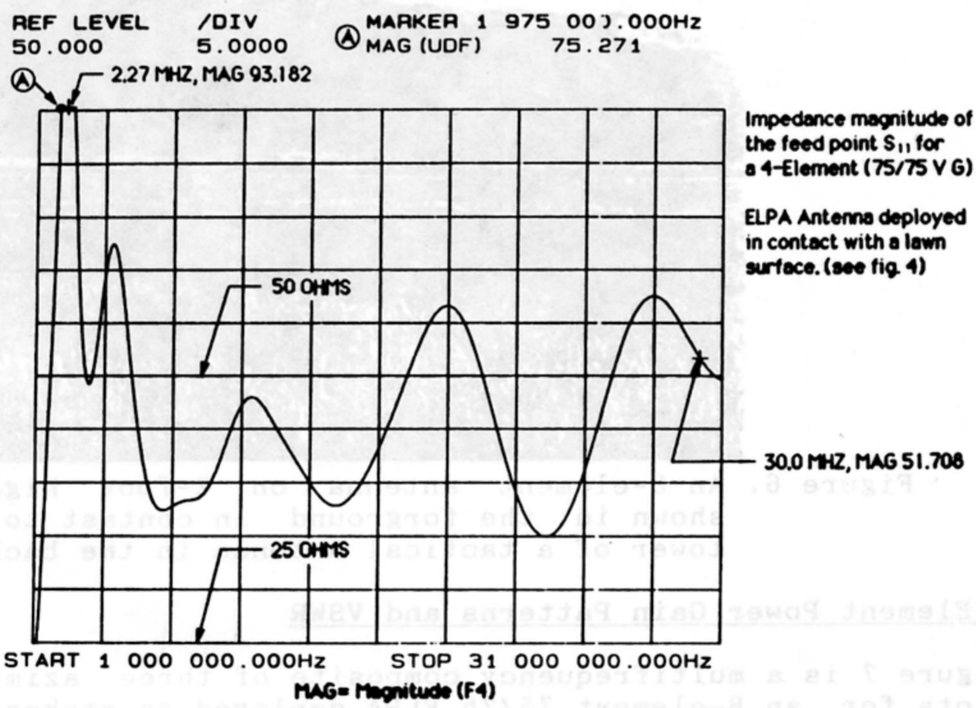

Figure 5. Impedance plot of figure 4.

Figures 4 and 5 complement the previous figures 2 and 3 by displaying feedpoint characteristics for the same 4-element antenna with its elements in contact with the ground (stakes removed). The impedance magnitude maximum (point off the plot grid) is 93 ohms (1.9:1 VSWR) at 2.275 MHz.

Figure 6 is a view of an 8-element antenna (foreground) deployed on stakes in a harvested wheat field at the Eyring test facility at the Cedar Valley Airport. Some parts of the antenna have been made more visible by the addition of survey ribbons. The antenna size is twice the layout of Figure 1 plus a space of 20 feet (6 m) between the two 4-element sections (146-foot total width, 44.5 m). In the background is the 48-foot (14.6 m) aluminum support tower (type AB-577/GRC) of a single wire feed, terminated sloping long-wire antenna or AFWONXX (9,10). When the ELPA elements are deployed in ground contact, rather than on 2-foot (.57m) high stakes, the antenna becomes virtually invisible in the field.

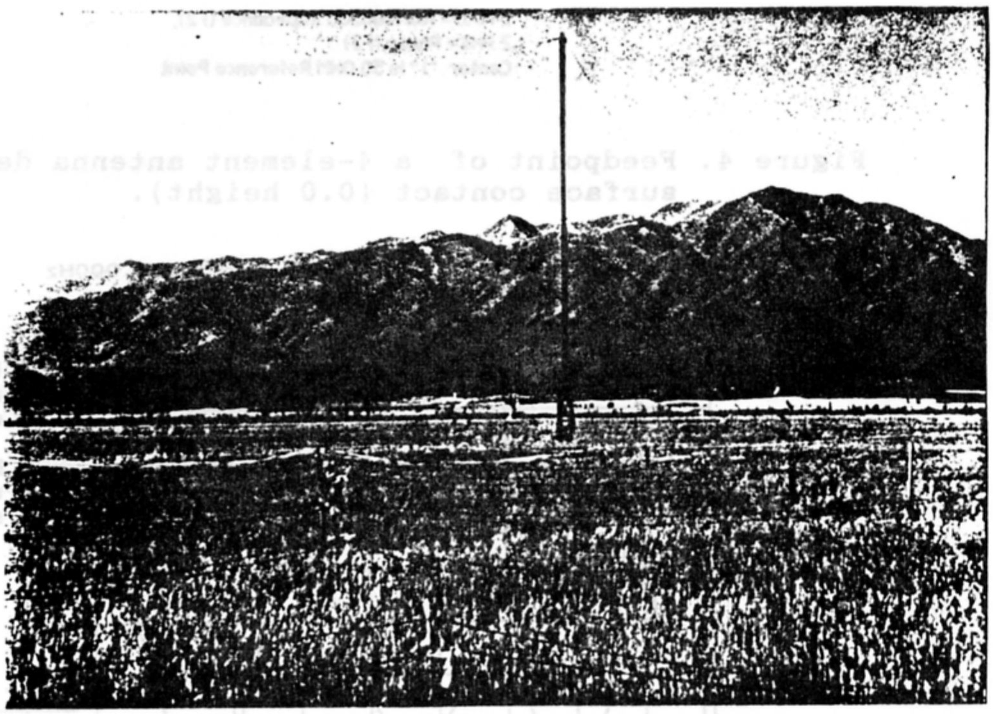

Figure 6. An 8-element antenna on 2-foot high stakes is shown in the forground in contast to the 48-foot tower of a tactical antenna in the background.

8-Element Power Gain Patterns and VSWR

Figure 7 is a multifrequency composite of three azimuth response plots for an 8-element 75/75 ELPA deployed on stakes. To obtain these plots, the ELPA is illuminated by a vertically polarized elementary dipole beacon towed 200 feet (61m) below a helicopter flown at a nominal range of 1.2 miles (2 Km) and an elevation angle of 20 degrees about the test site. Each power gain plot in this figure is fully corrected and scaled in terms of absolute dBi (3). By this processing, each plot in the figure is directly comparable to the others within the figure and to other plots in this test series. These plots can also be directly compared to other antenna patterns in the literature if they are presented in terms of power gain, scaled in dBi and include the effects of real ground conditions (e.g., calculations by codes such as NEC-3). The ground conductivity measured by the capacitor sample technique was classed as "average" and ranged from about 0.012 S/m at 22.9 MHz to less than 0.006 S/m at 8.0 MHz. The dielectric constant was typically 9 over the same frequency span for this antenna site. Subsurface samples from a 1 m depth were measured to be as much as 50% lower in value than the surface measurements of both constants. These values differ from Figure 2 in that they represent lower bounds for the true values and are for a different test site. The monopole method at this site suggests a relative dielectric of 9 with 0.010 S/m at 22.9 MHz and 12.5 with 0.007 S/m at 8.015 MHz.

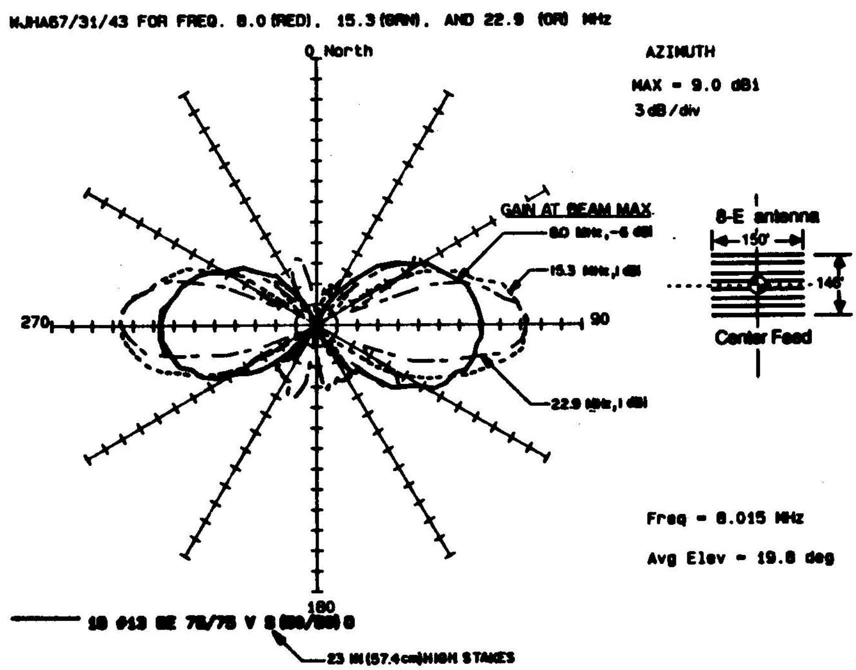

Figure 7. Azimuth response patterns of an 8-element ELPA deployed on stakes.

Figure 8 displays the vertically-polarized multifrequency response pattern of an 8-element 75/75 antenna adjacent to the antenna of Figure 7. This antenna was deployed directly on the ground without stakes. The directive gain pattern is similar to that of Figure 7, but with a change in efficiency ranging from -8 dB for 22.9 MHz to -1 dB for 8 MHz.

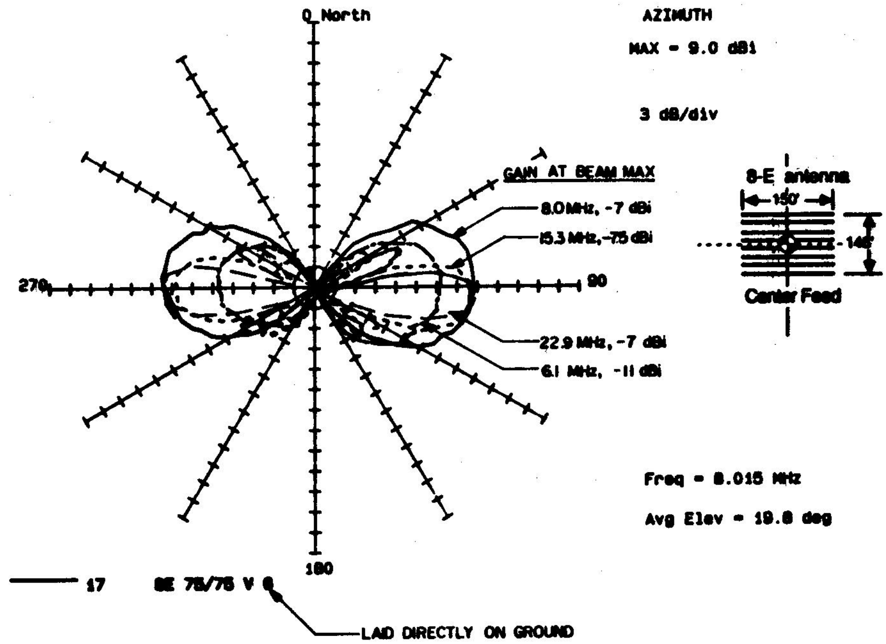

Figure 8. Azimuth response patterns of an 8-element ELPA deployed in ground contact.

Figure 9 portrays the return loss, which is -20 log (S11 reflection coefficient) measured at the feedpoint of a 75/37 antenna similar to that of Figure 7 but deployed asymmetrically. The main beam of the antenna projects from the forward, longest element. At the feed point, the forward element half is elevated to a height of 2 feet and then suspended on stakes for 50 feet. At the 50-foot point, the element is dropped to the ground and continues in ground contact for 25 feet. The rear element half is only deployed to a length of 37 feet and is completely in ground contact. The bottom half of the figure displays the corresponding VSWR. The VSWR peaks at 23 MHz and 27.5 MHz are typically suppressed by feed cable losses. All VSWR plots presented here are feedpoint measurements and represent a "worst case" maximum for the ground conditions noted. Better ground conditions will further reduce the VSWR.

Figure 10 shows a measurement of the return loss and VSWR for the 75/75 V G antenna of Figure 8.

Figure 11 displays the vertically polarized azimuth pattern of the Figure 9 antenna for three elevation angles. The antenna pattern front-to-back asymmetry (3 dB) is due to the element asymmetry (75 foot to front). Note that the ELPA main beam (180 degrees azimuth) varies only 2 dB over the 20-degree elevation span. This smooth pattern variation with elevation angle is a

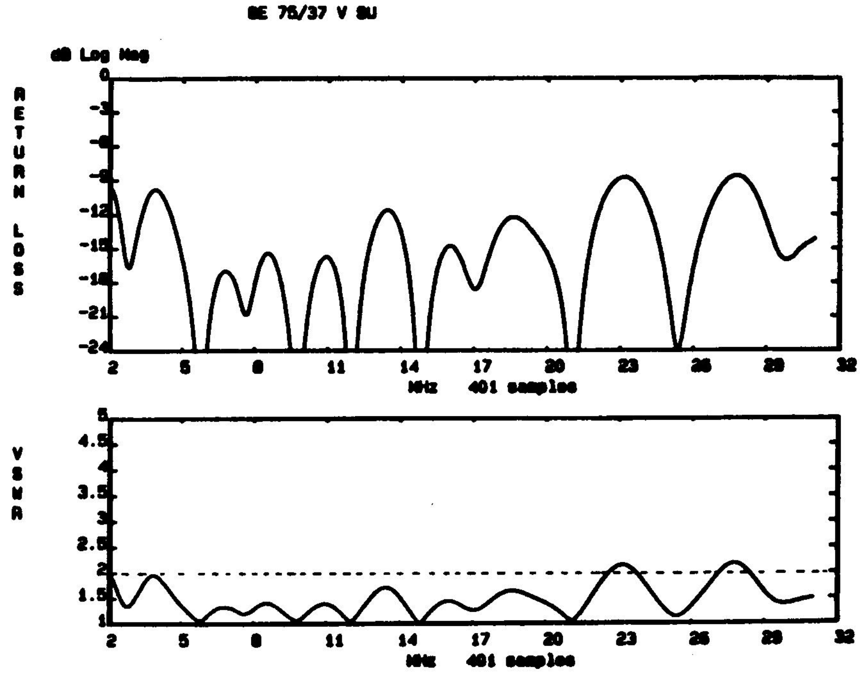

Figure 9. Feedpoint characteristic of an 8-element 75/37 V-element ELPA with 50 feet of the 75-foot elements deployed on stakes.

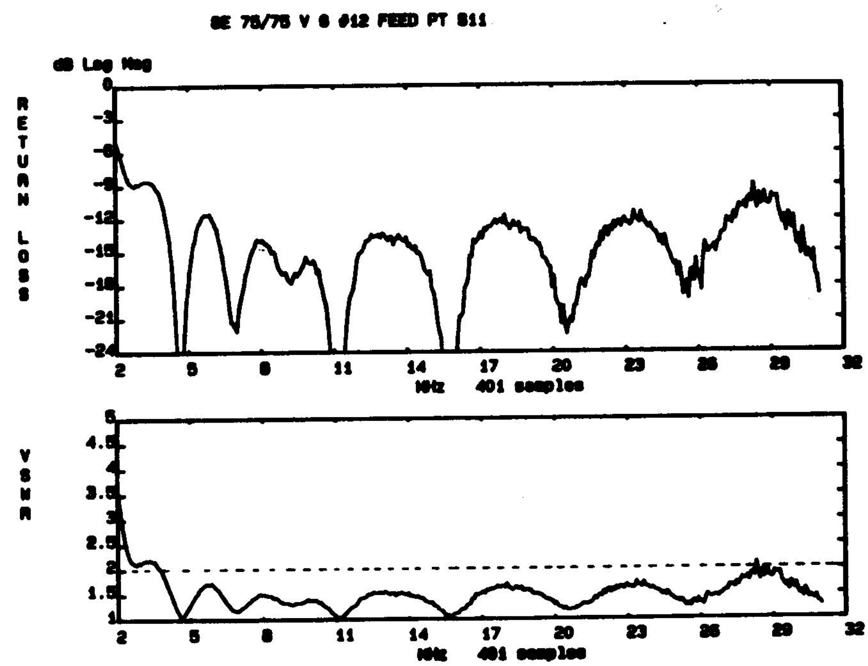

Figure 10. Feedpoint Characteristic of an 8-element 75/75, V-element antenna deployed in ground contact.

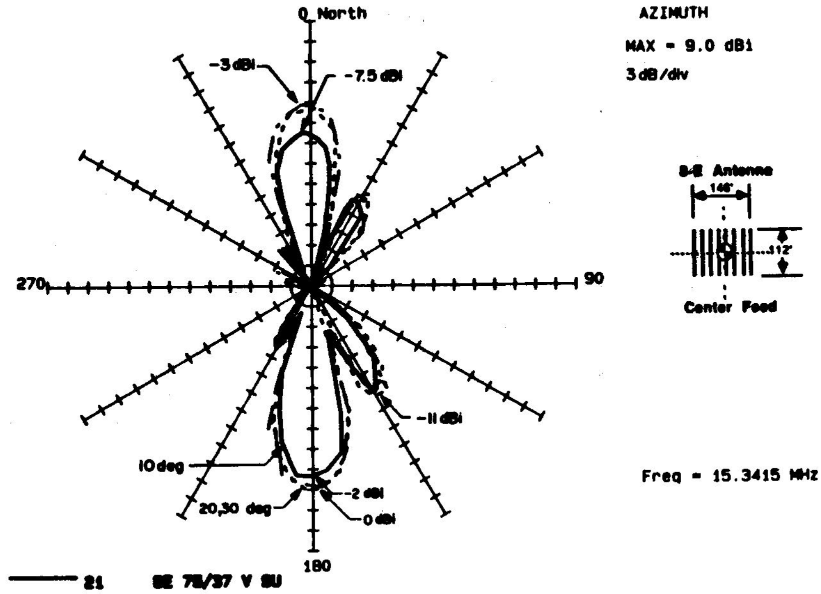

Figure 11. Composite azimuth response patterns at elevation angles of 10,20, and 30 degrees for an 8-element 75/37 antenna with the 75-foot element staked.

characteristic that the ELPA antenna shares with a vertical loop antenna and is, in general, a characteristic of a ground interactive antenna. The pattern is also smoothly varying as a function of frequency. The VSWR for this antenna is given in Figure 9.

The side lobes evident at 30 and 150 degrees are due to an intentionally casual deployment of the antenna elements. The layout principally differed from the Figure 1 diagram in that the element wires were typically touching the ground between the stakes and the element "V" structures were not uniform. The pattern at a 180-degree azimuth is directly comparable to that of Figure 7 at 15.3 MHz and 90 degrees. The penalty for this layout under these site conditions was on the order of only -1 dB in main beam power gain, the narrowing of beamwidth from 24 to 21 degrees, and the appearance of a -12 dBi side lobe. The ground interactive antenna is very forgiving to imperfections in layouts of this type.

Cross Comparisons

Figure 12 is supplied to contrast the elevation step profile of Figure 11. Here, a 500-foot span vertical half-rhombic antenna

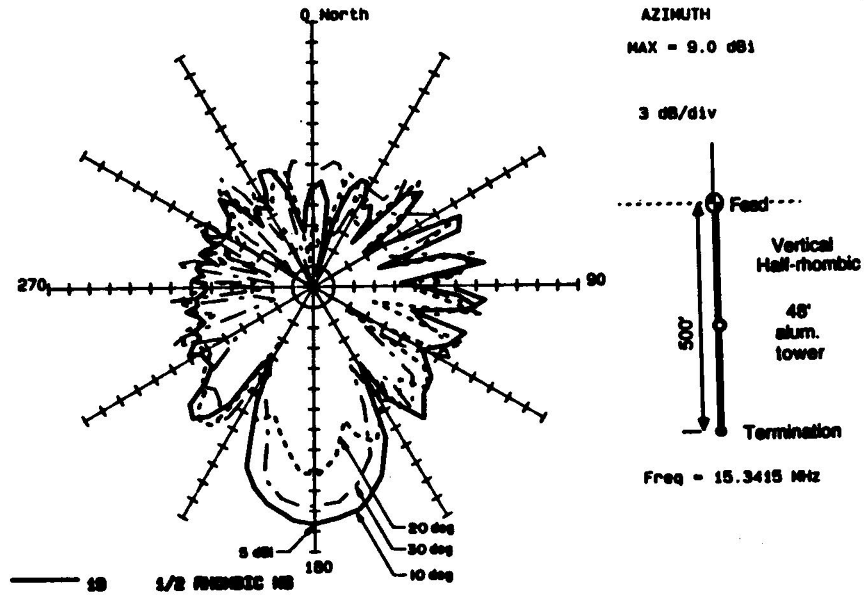

Figure 12. Composite azimuth response at elevation angles of 10,20, and 30 degrees for a 500-foot vertical half-rhombic antenna (see text for estimate of power gain accuracy).

(9) displays a 7-dB variation in gain over the same elevation angle range. This is typical of long-wire antennas, which display a lobe structure that varies as a function of frequency with deep (more than 6 dB) notches.

This antenna was configured with commonly available, military stock, tactical components, but may be as much as 3 dB lower in efficiency at this frequency than can be achieved. The low efficiency is due to the use of a 12:1 balun employing an internally grounded center-tap connection (10). A worst case efficiency correction of 3 dB added to the measured power gain of 5 dBi at 10 degrees would suggest an attainable gain of 8 dBi. This 8 dBi value exceeds a numerical simulator derived prediction of about 5 dBi (9) for an ideally configured vertical half-rhombic antenna (9).

Figure 13 overlays the physical deployment areas and profiles of three 8-element ELPA configurations in comparison to a 500-foot span vertical half-rhombic antenna and a tuned reference monopole antenna (3).

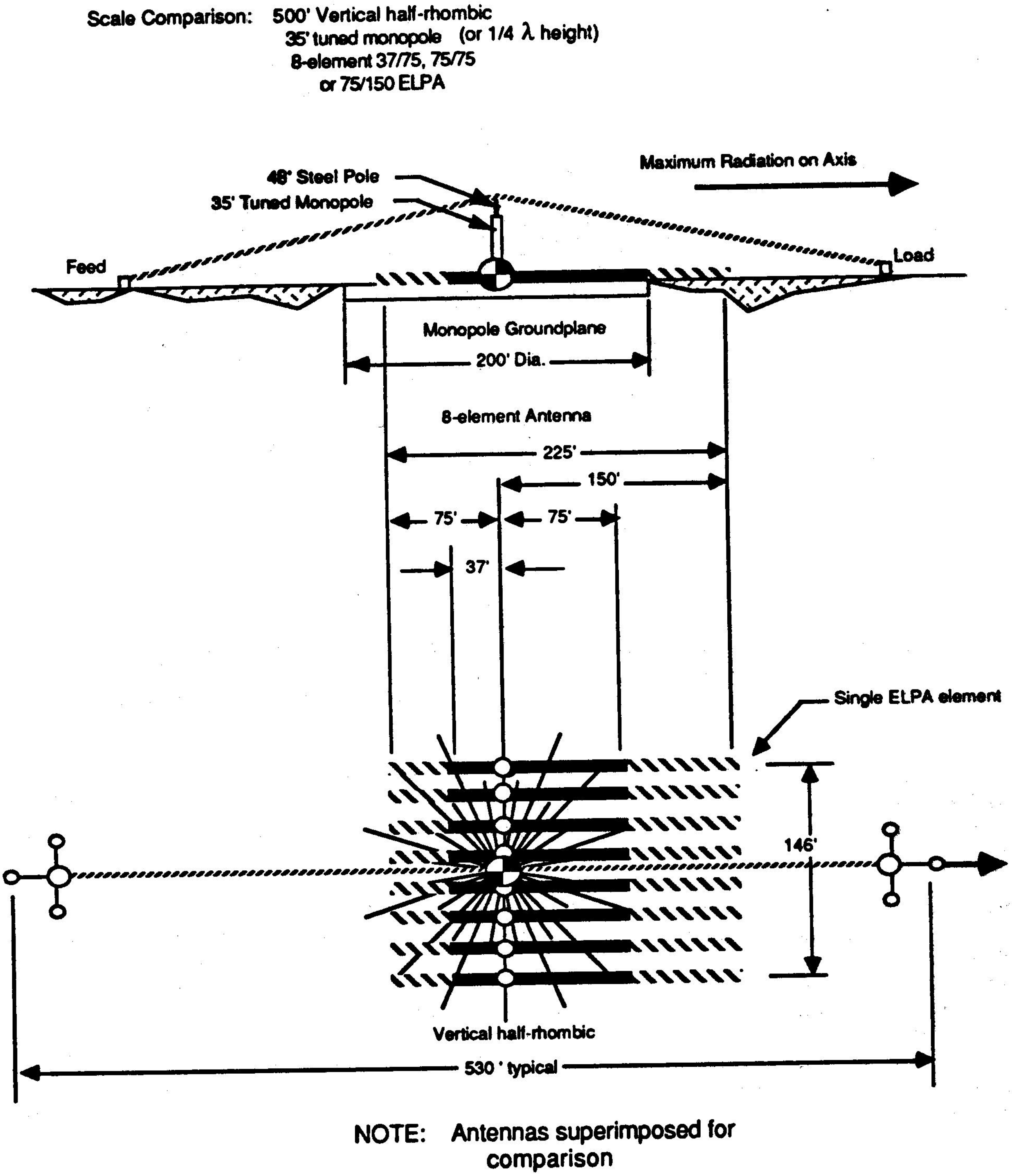

Figure 13. Scale comparison of profile and deployment area views for three antenna types.

Figure 14 provides a low-frequency performance comparison of the elevation patterns of two ELPA's, one broadbanded tactical sloping long wire antenna (AFWONXX) ** and one tuned reference monopole antenna. It is important to note that the 150/75 on antenna channel 21 closely matches the groundwave capability of the tuned 35-foot monopole. However, the 150/75 also has, on the same axis, a high-angle coverage pattern that suits it well for near-vertical incidence skywave communication paths. Channel 20 compares another, shorter ELPA (deployed on the ground) that also displays an overhead pattern. For this low frequency and for these ground conditions, the difference between the ELPA's is only about 4 dB even though there is a significant difference in deployment.

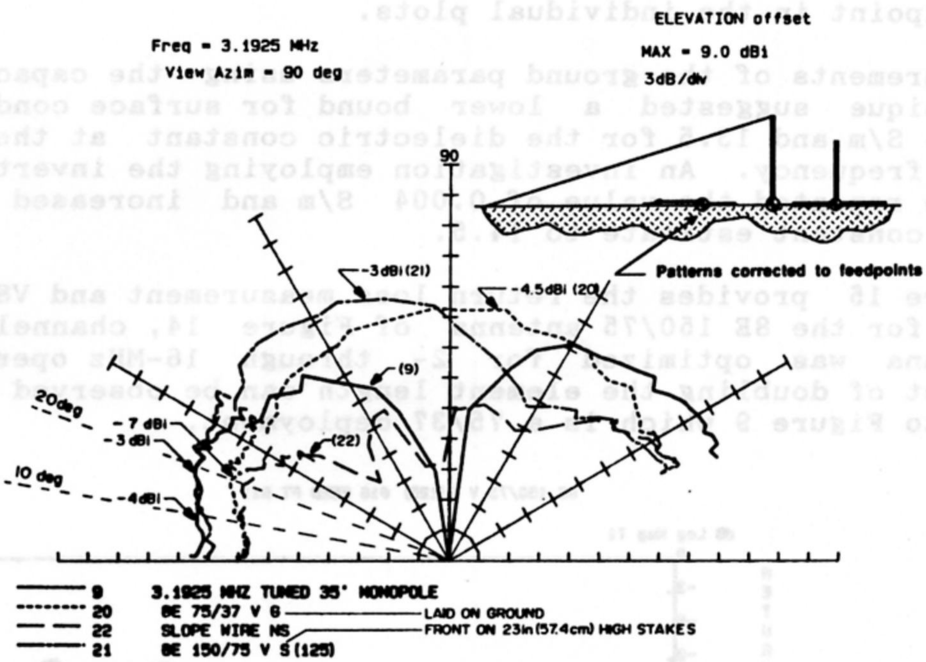

Figure 14. Elevation pattern comparisons of four antennas. The power gain plot of channel 22 (slope wire) may be as much as 5 dB below optimum (see text).

**This sloping long wire antenna is a non-optimal configuration of an AFWONXX antenna (9) that employed a 600 ohm balun with a grounded internal center-tap connection similar to the one feeding the vertical half-rhombic of Figure 12. At this frequency, the worst case efficiency loss could be 6 dB. The actual effect is estimated to be about 5 dB and would cause the sloping wire channel 22 plot to essentially overlay the 35 ft tuned monopole plot of channel 9.(10)

It should be noted that below about 5 degrees, the elevation patterns are a composite of antenna response to skywave illumination (as previous plots) plus an additional groundwave response. This makes this elevation span of the plot useful only for relative comparisons (multiple measurement ranges can separate responses). In this test protocol, the beacon is positioned at a range of 1 Km from the optical tracking site, which places these antennas under test about 0.85 Km from the beacon at ground level. The helicopter literally places the beacon on the ground and then lifts it vertically to in excess of a 45-degree elevation angle relative to the antennas. The remainder of the pattern is derived from a flyover path 1 Km above the test site. The patterns overlap after geometrically derived corrections are applied. The overlap (+/- 1dB) can be seen at a 35-degree breakpoint in the individual plots.

Measurements of the ground parameters using the capacitor sample technique suggested a lower bound for surface conductivity of 0.004 S/m and 13.5 for the dielectric constant at the 3.1925-MHz test frequency. An investigation employing the inverted monopole probe repeated the value of 0.004 S/m and increased the dielectric constant estimate to 14.5.

Figure 15 provides the return loss measurement and VSWR calculation for the 8E 150/75 antenna of Figure 14, channel 21. This antenna was optimized for 2- through 16-MHz operation. The effect of doubling the element length can be observed by comparison to Figure 9 which is a 75/37 deployment.

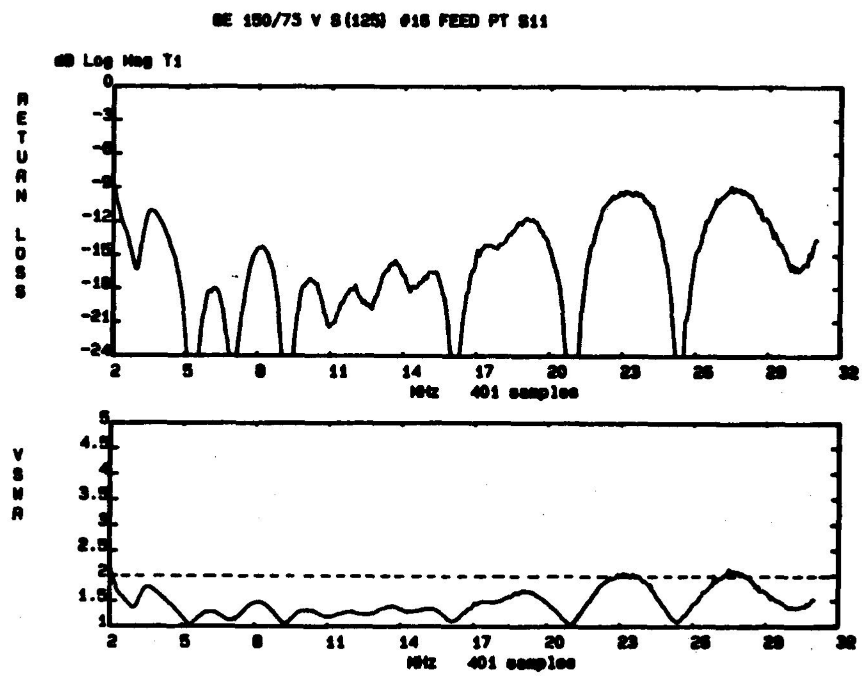

Figure 15. Feedpoint characteristics of an 8-element 150/75, V-element antenna with 125 feet of the 150-foot elements staked 2-foot high.

SUMMARY

The preceding figures should suggest that a ground interactive antenna can demonstrate power gain, directive gain, pattern, and matching characteristics that class it as a viable concept in the context of existing antenna designs.

Ground interactive, or interface antennas similar to the ELPA, present difficult modeling and simulation problems for current analysis tools. Hopefully, the observations presented in this paper will motivate continued refinement of codes such as NEC-3 (11) to successfully and economically predict the characteristics of complex ground interface structures.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the significant efforts of both Government and Eyring personnel that enabled these measurements. In addition, we would like to recognize the original theoretical and design contributions of Ferril Losee which laid groundwork for the current ELPA designs.

REFERENCES

1. "Eyring Low Profile Antenna Specification Sheet," Preliminary, December 1985, Eyring Document No. 500-0051.

2. "Eyring Low Profile Antenna Operator's Manual," December 1985, Eyring Document No. 300-0054-01.

3. D. L. Faust and M. B. King, "Full-Scale HF Antenna Test Approaches Applicable to Numerical Model Validation," presented at the 2nd Annual Review of Progress in Applied Computational Electromagnetics, at the Naval Postgraduate School, Monterey, California, March 18-20, 1986. The paper was updated September 1986 and is available as Eyring document No. 900-008 and may be published in the Applied Computational Electromagnetics Newsletter in 1987.

4. D. L. Faust and M. B. King, "Broadband HF Antenna Testing," Proceedings of RF Technology Expo '86, Anaheim, California, pp. 625-631, January 30, 1986. Note: Figure 9 antenna pattern plot could be lower than optimum by as much as 3 dB due to a feed configuration employing a grounded center-tap balun.

5. Final Report for Test Evaluation and Analysis for the Eyring Low Profile Antenna, prepared for Bendix Field Engineering Corp., St. Inigoes, Maryland, January 17,

1986, Eyring Document No. 800-0760. Note: This report is the cover document for a database with over 2,000 pages of reduced pattern plots and 13 disks of magnetic media containing raw data files for pattern and feed point measurements.

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11. G. J. Burke, "Numerical Electromagnetics Code-User's Guide Supplement for NEC-3 for Modeling Buried Wires," Lawrence Livermore Laboratory, Livermore, California, Rept. UCID-19918, October 1983.
Note: A current developmental adaptation of NEC-3 has demonstrated reasonable ability to model low profile and buried antenna elements. NEC-3I (insulated wire adaptation) has demonstrated correlation with full scale test data from elementary 1-element antennas. Power gain estimates window within +6 to -3 dB, feed point impedance magnitude and phase appear accurate to within 25%, and pattern shapes follow the general trends of most measured patterns. These preliminary observations suggest real added capability over NEC-3 which did not possess buried or near interface insulated wire modeling capability. It is a significant improvement over previous codes such as NEC-2 which were not structured to accurately address ground interaction problems.

A NEC TOPSIDE ANTENNA CASE STUDY
WITH DIDEC AND SPECTRUM:
MODEL GENERATION AND CURRENT DISPLAY CODES

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Introduction

Some of the compromises in ships' topside antenna design are discussed in the book by Preston E. Law[1]. For UHF communication antennas he mentions the mounting of dipoles on the ends of yardarms. This paper describes an approach to the dilemma faced by a project engineer who must approve the location of UHF antennas mounted on a yardarm near a sizeable tubular mast structure that supports other antenna systems and devices. Without quantitative data, say from brass scale model measurements, he needs computations of pattern data in order to establish the extent of the perturbations which will occur. The example of this paper occurred recently on a ship modernization project. Some detail of the installation is shown in Figure 1.

The use of NEC at UHF frequencies for a structure of this size implies a large number of wire segments and costly execution times. This consideration led to the modelling of the mast alone rather than the complete modelling of the nearby environment including the less dominant structures. This approach was thought to be sufficient to determine the order of magnitude of the perturbation that would be produced in the inherent omnidirectional azimuth pattern of the UHF dipole antennas. The corresponding GTD model was a box-like structure formed from a set of four intersecting plates placed at the periphery of the mast shown in Fig. 2. The plate model approximates the blockage and reflection effects of the structure while the joining edges provide the diffraction effects

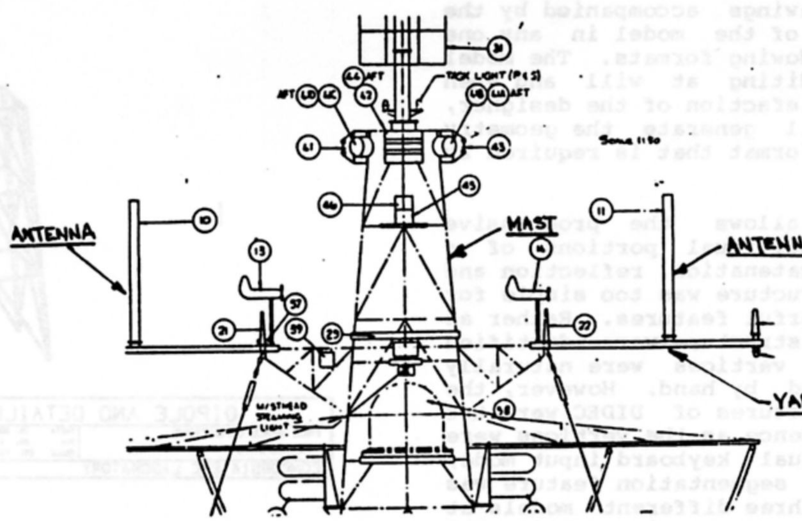


Figure 1 - Topside Detail - Rear View

The first impression in viewing Fig. 1 is the clutter of detail of other systems in addition to the two UHF antennas on the end of the yardarm and the main mast structure. The first question then is, what should be modelled and what can be modelled, and by what techniques? In the absence of measurement data, it was prudent if not essential to have some results from two different techniques for comparison or validation purposes. The techniques available were either NEC[2] or MININEC[3] for a Moment Method analysis and the Basic Scattering Code[4] for a Geometric Theory of Diffraction analysis.

from the corners of the structure. In principle, this is the inverse of the wire-grid modelling process for surfaces.

The next three sections describe the Method-of-Moments modelling process and display the results that were obtained using DIDEC[5] and a new program called SPECTRUM[6] to display the current distributions computed by NEC.

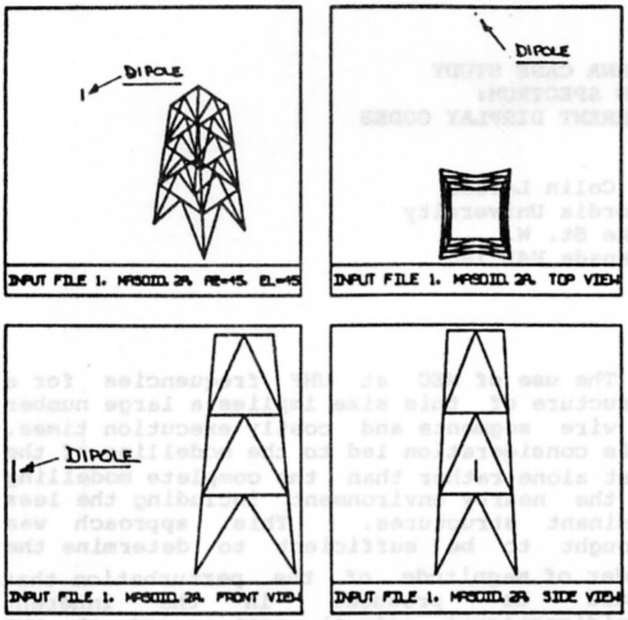


Figure 2 - DIDEC Display - Dipole and Mast

NEC Model Development

The acronym DIDEC is derived from Digitize, Display, Edit and Convert, the basic processes of this computer-aided model generation code. Models are created by the error-free digitization of drawings accompanied by the instantaneous display of the model in any one of a variety of windowing formats. The model can be changed by editing at will and when completed to the satisfaction of the designer, a 'NEC' command will generate the geometry input file in the format that is required by NEC.

Athough DIDEC allows the progressive development of individual portions of a structure, their concatenation, reflection and translation, this structure was too simple for the use of these powerful features. Rather as the details of the structure were identified in the drawing, the vertices were naturally scaled and tabulated by hand. However, the file manipulation features of DIDEC were too useful to ignore. Hence as the vertices were entered using the manual keyboard input mode, the automatic wire segmentation feature was used to derive the three different models at the three specified frequencies of 230, 297 and 395 MHz.

Figure 2 shows the four-ported DIDEC display of the dipole and mast. Figure 3 is intended to show the colour-coding of the diameters that were selected to represent the structural members, except that in this black and white copy of the colour print, the colours appear as shades of gray. Figure 4 shows the structure with the actual radii and segmentations that were used at 297 MHz. The segment lengths were chosen to be less than 0.2λ and the radii were the estimated radii of the tubular members. The 685 segments of the 395 MHz frequency model represent a sizeable matrix size for NEC execution on the university CYBER 835.

For purposes of this study free-space calculations were sufficient to represent the perturbing effects of the mast, hence ground plane calculations were considered but deferred. Precise limits for pattern distortion are difficult to set in complex cases such as this. The project engineer would be concerned, however, by 3dB pattern distortions occurring over a sizeable sector in azimuth.

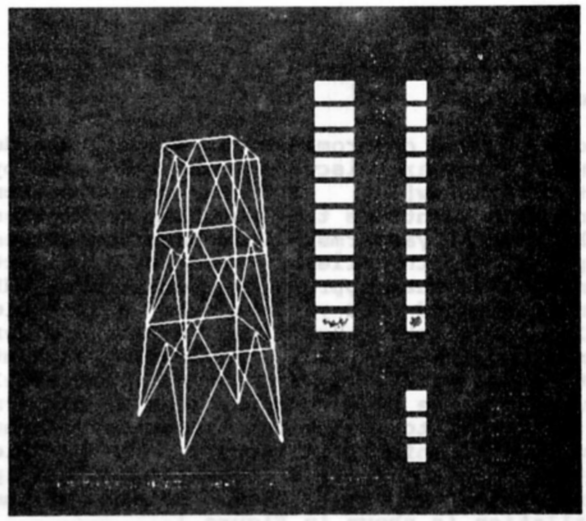


Figure 3 - Colour Coding of Diameter

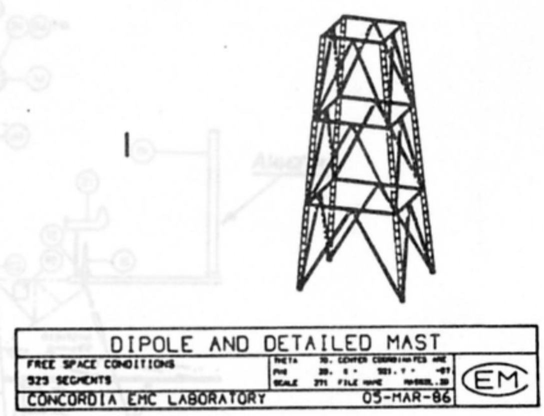


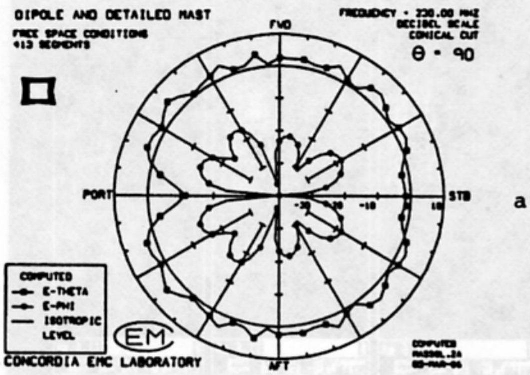
Figure 4 - Model Segmentation at 297 MHz

NEC Radiation Pattern Calculations

The results for the three frequencies are presented in Figures 5-7. The dominant features are the scalloping of the dipole patterns and the generation of a sizeable cross-polarized component. The null directly to port ranges from 8-14dB and the 3dB perturbation limits are exceeded over angular sectors ranging from 10 to 20 degrees. The three-dimensional displays show the extent of the disturbances in the elevation plane. Note that in these displays the scale is linear.

Azimuth Patterns

3-D Pattern Displays



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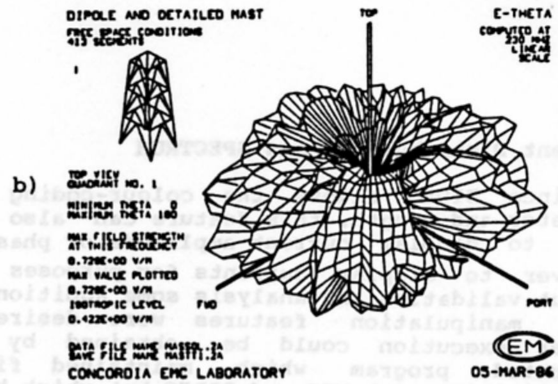
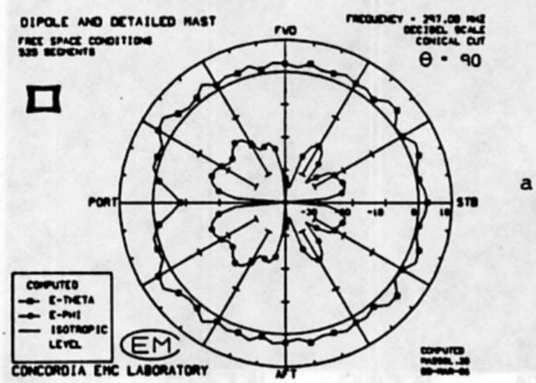


b)

Figure 5 - Radiation Patterns, 230 MHz



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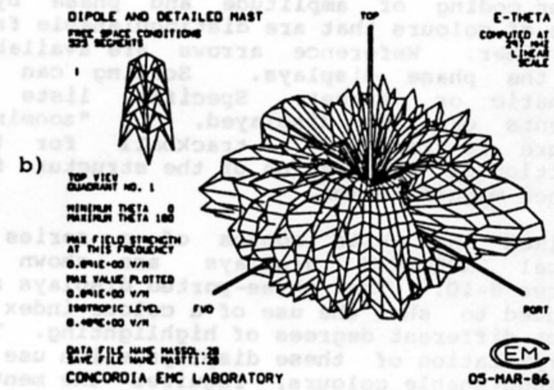
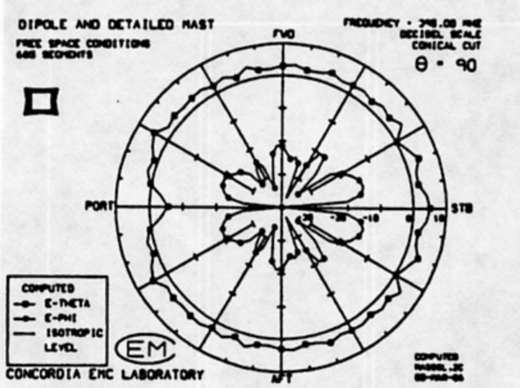


b)

Figure 6 - Radiation Patterns, 297 MHz



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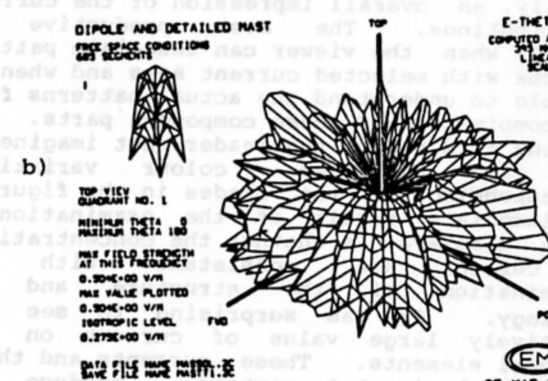


b)

Figure 7 - Radiation Patterns, 395 MHz

Are these results credible? Before attempting to formulate an answer, the computed current distributions are examined for self-consistency in a series of SPECTRUM displays.

Current Distributions and SPECTRUM

Since DIDEC allows the colour-coding of diameter and length, this feature can also be used to display current amplitude or phase. However to display currents for purposes of output validation and analysis some additional file manipulation features were desired. Faster execution could be obtained by a dedicated program which maintained file compatibility with NEC and DIDEC but which had specific additional commands to manipulate the current displays at will. For this purpose SPECTRUM was created.

SPECTRUM accepts a reduced NEC output file which contains the model geometry data and the currents on the wire segments. It allows the colour coding of amplitude and phase by a range of colours that are distinguishable from each other. Reference arrows are available for the phase displays. Scaling can be automatic or preset. Specific lists of segments can be displayed. A "zooming" feature is tied to a trackball for the selection of any portion of the structure for further magnification.

Black and white copies of a series of typical SPECTRUM displays are shown in Figures 8-10. The three-ported displays are intended to show the use of a colour index to select different degrees of highlighting. The interpretation of these displays,which use 90 distinguishable colours, requires the mental association of magnitude with colour and subsequently the appreciation of the associated phase of these currents. The advantage of the colour-coded displays is the ability to produce a display with minimum clutter and at the same time, to create more readily, an overall impression of the current distributions. The most productive use results when the viewer can associate pattern effects with selected current sets and when he is able to understand the actual patterns from the combination of these component parts. In reading this paper, the reader must imagine as best as he can, colour variations corresponding to the shades in the figures. An immediate result of the examination of these displays is whether the concentrations of current are consistent with the illumination of the structure and its topology. It was surprising to see the relatively large value of current on the diagonal elements. These currents and those on the horizontal members produce the sizeable cross-polarized component of the patterns. The preset scale feature of SPECTRUM is used in Fig. 10 to produce a very effective comparison of the variation of induced current versus frequency that then has its consequences in the radiation patterns of Figs. 5 through 7.

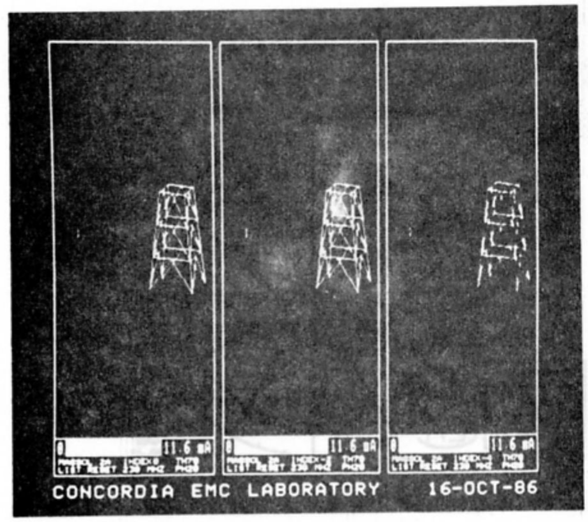


Figure 8 - Spectrum Displays - 230 MHz

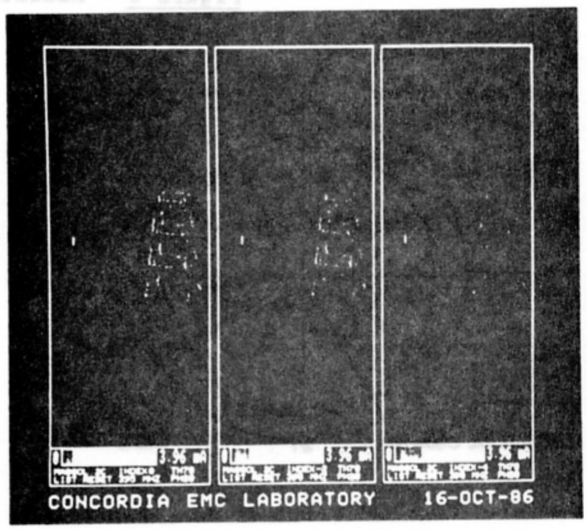


Figure 9 - Spectrum Displays - 395 MHz

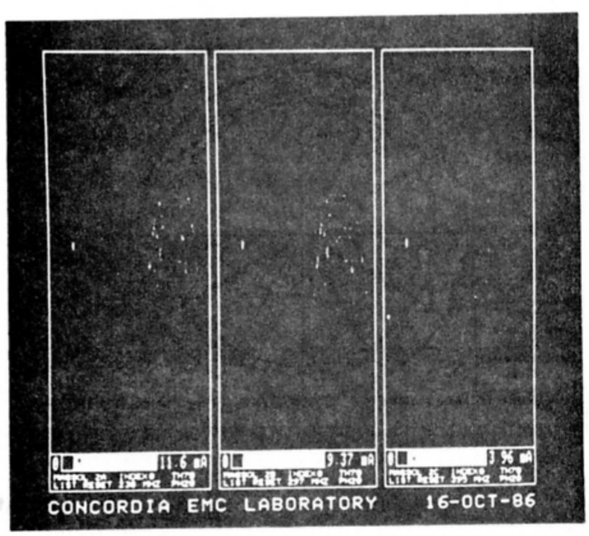
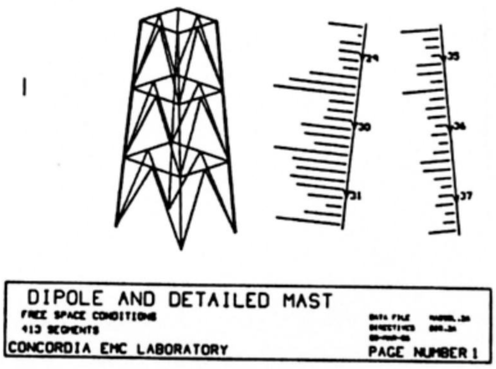
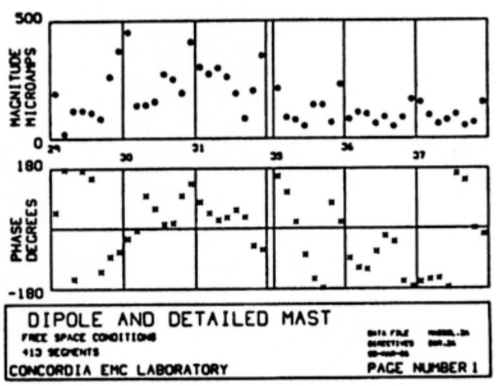


Figure 10 - Spectrum Displays - Frequency Comparisons

The correlation of these colour displays with more conventional displays of amplitude and phase helps to train the analyst's eye in the appropriate interpretation of these results. An illustration of this is shown in Fig. 11. The first part of this figure shows the amplitude differences on the front and rear legs of the tower at 230 MHz. Often it is meaningful to plot the amplitude and phase of the current versus segment number as shown in the lower portion of the figure. This is particularly useful in cases where it is important to identify resonant paths.



a) Amplitude - Front, Rear Legs



b) Amplitude/Phase vs. Segment Number

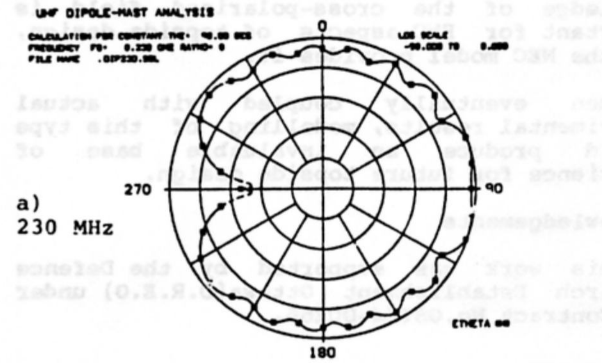
Figure 11 - Alternate Current Displays

The examination of the radiation patterns and the subsequent analysis of the current distributions for an appreciation of their specific correlation in terms of current location, amplitude and phase, produces a basic level of confidence in the modelling and serves as an appropriate base for the comparison with GTD results.

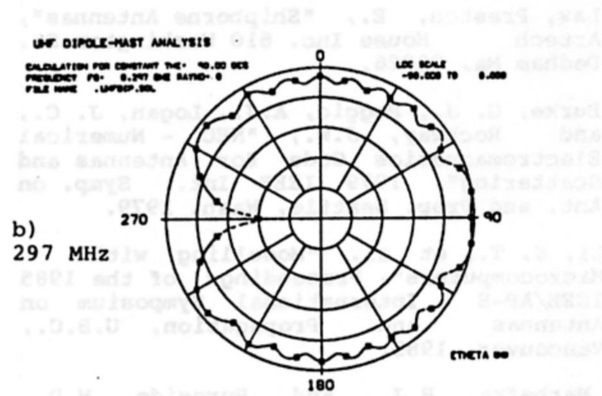
Results of GTD Modelling

The results from the Basic Scattering Code using the simplified box-like model is shown in Fig. 12. It can be seen that except for the sharper nulls, the patterns are in good general agreement with the NEC calculations. As expected, there is considerable similarity between these patterns and the patterns of the canonical dipole/plate reflector or dipole/mast geometry[7]. This latter geometry has been the subject of many measurements in the past which show agreement with the referenced results. Note that the cross-polarized component is zero in the GTD model.

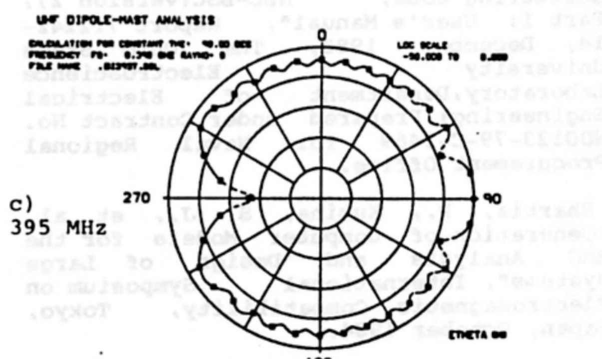
The GTD computations are relatively inexpensive by comparison with those for the wire-grid model. In this regard, they are more suitable for the exploration of the distortion effects at finer frequency increments over the UHF range.



a)
230 MHz



b)
297 MHz



c)
395 MHz

Figure 12 - GTD Results

Conclusions

NEC can be used to model ships' UHF antennas and nearby structures when an estimate of their pattern characteristics is required. The patterns can be corroborated by simplified GTD calculations for these configurations.

The model creation by means of DIDEC and the analysis of the results by SPECTRUM assure an error-free model generation process and a meaningful and interesting examination of the results. The nature of the user's interaction with the displays heightens his intellectual appreciation of the electromagnetic aspects of the modelling and its relationship to the actual topside configuration. Intuitively, once the basic corroboration is established, the results from the NEC model, because of its detail, can be expected to more closely represent the patterns for the actual ship's structure. Knowledge of the cross-polarized field is important for EMC aspects of topside design, and the NEC model provides it.

When eventually coupled with actual experimental results, modelling of this type should produce an invaluable base of experience for future topside design.

Acknowledgements

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MODELING A RECEIVING MF-HF PHASED ANTENNA ARRAY: NUMERICAL COMPUTATIONS VS FIELD MEASUREMENTS

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ABSTRACT

A moment method model utilizing the Numerical Electromagnetics Code (NEC version 3) is employed to compute the current vector at the inputs of fourteen active vertical monopoles. The identical antennas are arranged in an "L" (135 m max. aperture). seven to a leg, and non-uniformly spaced. Suspended transmission cables and grounding wires penetrating an imperfect substrate are also modeled. At 0.5 to 5.0 MHz, the cables were found to differentially alter the phase-of-arrival of a polarized arbitrary wave at the antenna inputs.

The phase differences of antenna pairs as computed by NEC and measured in situ are compared for several MF fixed transmitters. Problems of extending the model to shorter wavelengths are also examined.

I. INTRODUCTION

In receiving adaptive arrays, the phase-of-arrival of an incoming wave at the antenna inputs must be accurately known because the inputs are combined with complex weights to optimize signal processing [1]. Much of the literature on adaptive arrays is at VHF and above where typically a small array size backed by a realizable highly conducting ground plane lends itself to physical modeling and verification under controlled conditions. Below VHF, the opposite is often true and an array is much larger, operates within a fraction of a wavelength above an imperfect ground, and is installed with limited testing because of high monentary cost. The purposes of this paper are to show how the input signals in such a situation can be assessed by numerically modeling the array and its milieu, and to present some preliminary comparisons with field measurements.

II. THE ARRAY AND ITS ENVIRONMENT

The L-shaped array consists of 14 identical antennas located on flat coastal sandy soil of fairly high conductivity because of brackish water infiltration from the Chesapeake Bay [Fig. 1]. The antennas and attached cables have rotational symmetry; i.e. the N-S leg is formed by rotating the E-W leg clockwise 90 degs. Each antenna consists of an short vertical whip and an active unit whose housing is grounded to a stake [Fig. 1, inset]. The monopole is connected to a receiver by a phase-stabilized coaxial cable 259 m long. The cables are suspended in bundles 3 m above ground and their sheaths grounded at the receiver building.

III. MODELING WITH THE NEC CODE

During the past 15 years, numerical methods applied to EM problems have become an attractive alternative to costlier experimental procedures, particularly in the early stages of system installation. The Numerical Electromagnetic Code, NEC, a well-tested representative, replaces the classic integral equations for the electric field of a current distribution within a volume (for thin bodies) and the magnetic field of a current distribution on a solid area (for smooth surfaces) with the following moment method approximation:

$$L\ f = e, \tag{1}$$

where f and e are unknown and known responses, respectively; and L is a general linear integral operator. The unknown f is expanded in a sum of basis or expansion functions having coefficients which are in turn determined by weighting functions involving the known response e. Numerical methods differ in the choice of basis and weighting functions. The array and its EM environs <u>sans</u> ground are satisfactorily modeled with wires only. In this situation, NEC expands a sine-cosine function along a wire segment and centers a delta weighting function on each segment [2].

A wire segment's dimensions are critical because current and charge must be relatively smooth and continuous across end connections in order to satisfy fundamental relationships such as Kirchoff's current law. An increase in the number of segments will produce better results <u>sensu lato</u>; however, the size of the interaction matrix for generating the coefficients in (1) increases geometrically. This in turn puts additional demands on computer CPU time and file storage.

NEC-2's ability to model wires less than 0.2 wavelengths above an imperfect ground is very useful for low frequency antenna design. This asset, derived by a numerical calculation of Sommerfeld integrals, is extended by NEC-3 to encompass wires penetrating and embedded within a dielectric half-space [3]. All of these features have been included in the array simulation.

IV. RESULTS OF THE LOW HF NEC MODEL

In the receiving mode, NEC finds the current vector at an antenna input (suitably loaded) for an incident wave directed at the origin of the spherical coordinates specifying the geometry of the array. Therefore, the geometrical position of the input must be deleted in order to single out the effect of the antenna's environment. Typical results for current phase are depicted in Fig. 2. Note that although only one antenna is considered, this is a complete simulation of 300 segments including coupling with 13 antennas and interaction with cables and ground. The solid line at zero phase indicates no environmental interaction, the desired ideal.

At low HF, the proximity and number of cable bundles, and the antenna's position within an array leg appear most influential. At 315 deg. azimuth [Fig. 3], where one would expect minimal cable effect, X4 and Y4, representatives of antennas embedded in the array legs, are least affected; whereas X7, the outlier of the double-bundle leg, deviates most.

In the worst case of 180 deg. azimuth (not depicted), wherein a vertically polarized wave travels along the length of a bundle before reaching the origin, X7 is confirmed to be the poorest followed by X1. The single-bundle E-W leg is least touched.

V. COMPARISONS WITH MF FIELD DATA

The phase-difference-of-arrival from eight AM broadcast stations for four runs were simultaneously collected by five antennas of the E-W leg during daylight hours when a vertically polarized surface wave will predominate over sky waves [4]. Fig. 4 is a bar graph of the 8 x 4 = 32 occurrences classed accordingly to phase difference from the arbitrarily chosen reference antenna Y2. Also in the figure is an example of a typical run for one station. NEC and the field measurements differed by two degrees or less in the majority of occurrences.

IV. SUMMARY AND FUTURE WORK

Numerical calculations for a computer model of an existing MF-HF receiving adaptive antenna array are valuable in evaluating the phase difference-of-arrival performance of individual antennas. Transmission cables, ground connections, and other possible sources of disturbance can also be examined quantitatively. Although provisional, the comparison with field measurements is encouraging in that disagreement is in the order of a few degrees.

Additional surface wave comparisons are planned in the low HF band with the eventual inclusion of sky wave measurements. Extending NEC above 10 MHz will require more wire segments and longer CPU runs, but time-consuming Sommerfeld calculations can be avoided because of diminishing ground effects.

ACKNOWLEDGMENTS

The author wishes to thank Mr. George Joyner for implementing NEC on IBM 3081 and 3084 computers, and Mr. Matthew Taylor for obtaining the field measurements.

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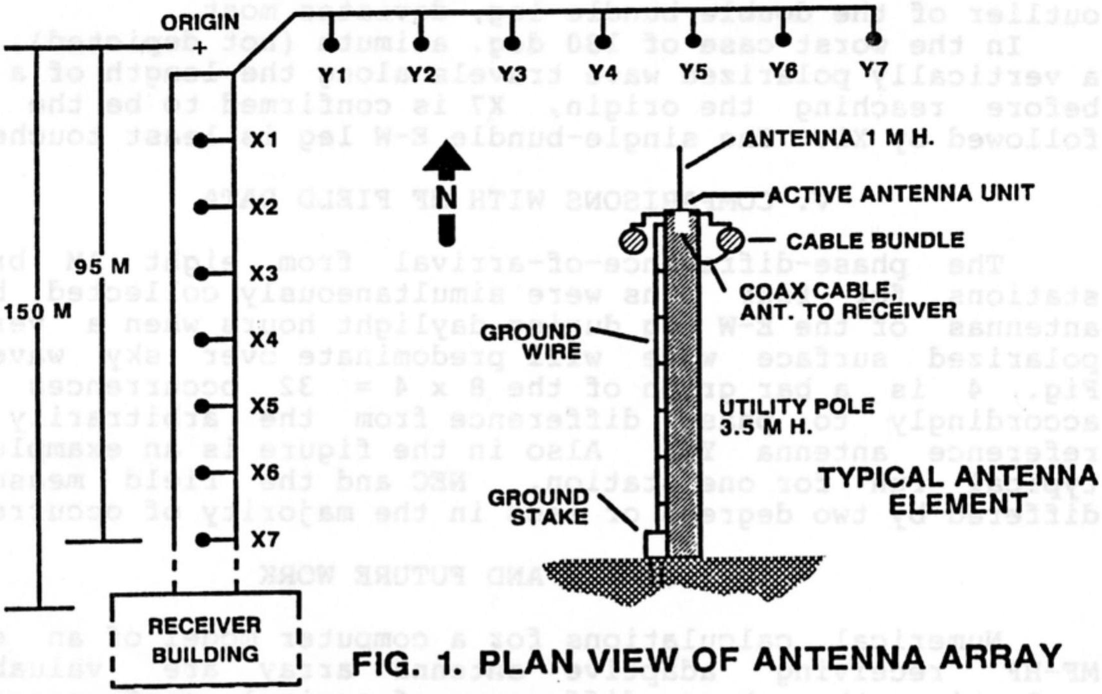

FIG. 1. PLAN VIEW OF ANTENNA ARRAY

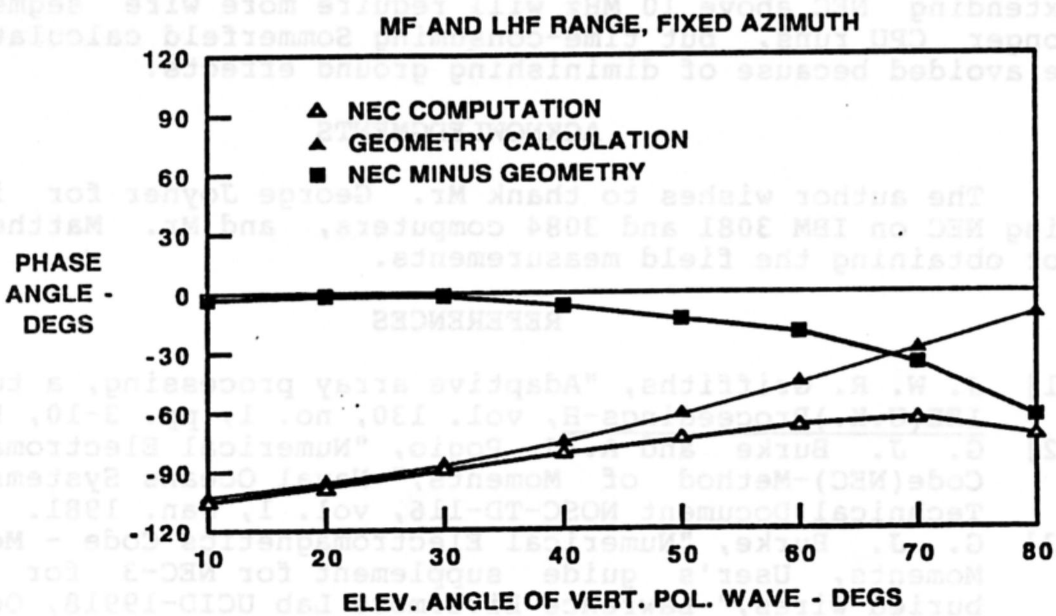

FIG. 2. COMPLETE ARRAY SIMULATION: TYPICAL ANTENNA

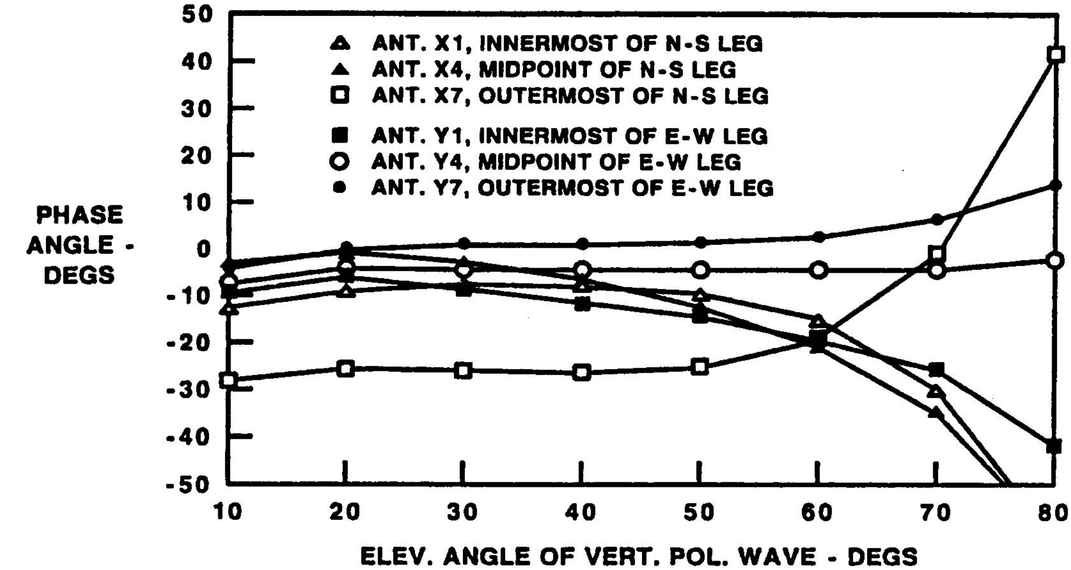

FIG. 3. COMPLETE ARRAY SIMULATION: 2 MHz, AZIMUTH 315 DEGS

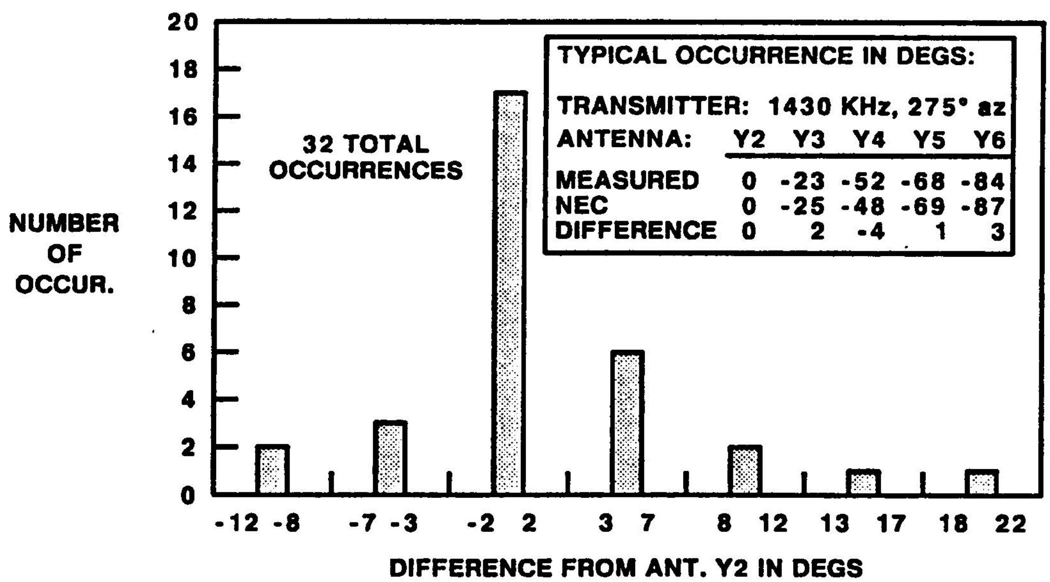

FIG. 4. COMPARISON OF MEASURED & NEC DATA

A Validative Comparison of NEC and MININEC using NBS Experimental Yagi Antenna Results*

J. K. Breakall

University of California

Lawrence Livermore National Laboratories, Livermore, CA

I have performed a comparison several years ago of measurements made at the National Bureau of Standards (NBS) [1] on various Yagi antennas and results from models of these same antennas using the Numerical Electromagnetic Code (NEC) [2]. This was done to see how closely the two different techniques (experimental versus computer) would agree. If no agreement would have been obtained, then one would have been left to make the conclusion that either the measurements were in error or the computer code does not give the correct results. Well, fortunately the results agreed remarkably well down to every little inflection point in the various patterns. The NBS should be commended for their painstaking detail in making such accurate measurements and the authors of NEC should feel equally complimented to achieve such excellent agreement. I believe many more such comparisons of this type are needed for a host of types of antennas and antenna - ground interaction studies for further validation of the code. These NBS results were performed many years ago and similar experiments should be able to be executed today with better accuracy and ease with the advent of better network analyzers and data taking computers.

Results are shown from this comparison for the 3 and 5 element Yagi antennas in figures 1 and 2 and dimensions are shown for the various Yagi antennas in Table 1. I have included

* Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

the NEC model data for these antennas which is shown in Table 2. As can be seen from the antenna pattern data the results are excellent except for a little asymmetry of the pattern for the NBS measurements which can be caused by slight current unbalance in the feed system, feed coax radiation, and objects in the measurement field causing unwanted reflections. This asymmetry indicates the level of one error source of the experimental results. Other error sources in such measurements are, to mention a few, actual errors of the measurements of physical lengths and spacings of the various Yagi elements, frequency stability and error of the excitation source, mechanical stability of the test antennas, etc. Errors in the computer model can mainly be caused by not obtaining convergence of the solution (not enough segments), violation of the thin - wire approximation, errors in the theoretical formulation of the integral equations, etc. With all of these various possibilities of introducing errors in both methods of antenna analysis it is remarkable that such excellent agreement is obtained. Of course it should be mentioned that the computer modeling is much easier to execute and takes a much shorter time to achieve results. The NBS study took some 15 years to complete. This is a big advantage that computer modeling has over experimental modeling if one believes the results. This accepting of the results can only take place more comfortably with further validation results of this type.

I have also run the same 3 and 5 element Yagis using the code MININEC [3] which is a smaller version of NEC running on Personal Computers (PC's). MININEC is a similar method of moments formulation but uses different basis functions (pulse) and solution techniques. It is therefore interesting to compare the results with the much larger code NEC. Results are shown from this comparison for the 3 and 5 element Yagi antennas in figures 3 and 4. I have also included the MININEC model data for these antennas which is shown in Table 3. The agreement for the 3 element Yagi is fairly close, but that for the 5 element is only in qualitative agreement with completely different sidelobe structure.

Tests to increase the number of pulse functions for possible convergence problems gave the same results as did converting the code to double precision.

A study was done by sweeping frequencies with the MININEC code to see if agreement could be obtained at any frequency. This procedure was suggested by Ed Miller from his experience with other narrowband antennas he has analyzed in the past. It was found that excellent agreement could be obtained at a frequency 1.7% higher than at the correct design modeling frequency. The results for this new frequency are shown for the 3 and 5 element Yagi antennas in figures 5 and 6. If one is going to model a known narrowband antenna, then he should be aware of this phenomena and run things at this offset frequency. We are looking into the possible causes of this problem and hope to report any findings and solutions in a future issue.

I hope this article has created interest in the subject of experimental and code validation. More of this type of work needs to be done, especially concerning the newer NEC-3 buried wire code. Also, there are probably many results of experimental and NEC results that have been generated by the NEC community, having never been published, which would be of great value in instilling confidence in NEC. We as a community need to report the results of such work, and propose new and useful experiments for improving the solutions on real-world problems. Computer database technology has reached a level of sophistication and ease, so that, an archive could be formed of all known models and results that would be available to anyone to help with a new model or prevent duplication of effort on some common problem. Your thoughts and comments are very welcome.

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TABLE 1. NBS YAGI ELEMENT LENGTHS (REFLECTOR SPACED .2λ BEHIND DRIVEN ELEMENT ELEMENT RADIUS 0.00425λ)

Yagi	3 El.	5 El.
Reflector Length, λ	.482	.482
1st Director Length, λ	.442	.428
2nd Director Length, λ		.424
3rd Director Length, λ		.428
Director Spacing, λ	.200	.200

TABLE 2. NEC DATA INPUT FOR THE NBS 3 AND 5 ELEMENT YAGIS

```
CE NBS 3 ELEMENT YAGI
GW 1 7 -.2 -.241 0 -.2 .241 0 .00425
GW 2 7 .2 -.221 0 .2 .221 0 .00425
GW 3 7 0 -.25 0 0 .25 0 .00425
GE
EX 0 3 4 0 1
PL 3 2 0 3
RP 0 1 181 1000 90 0 0 1
EN
```

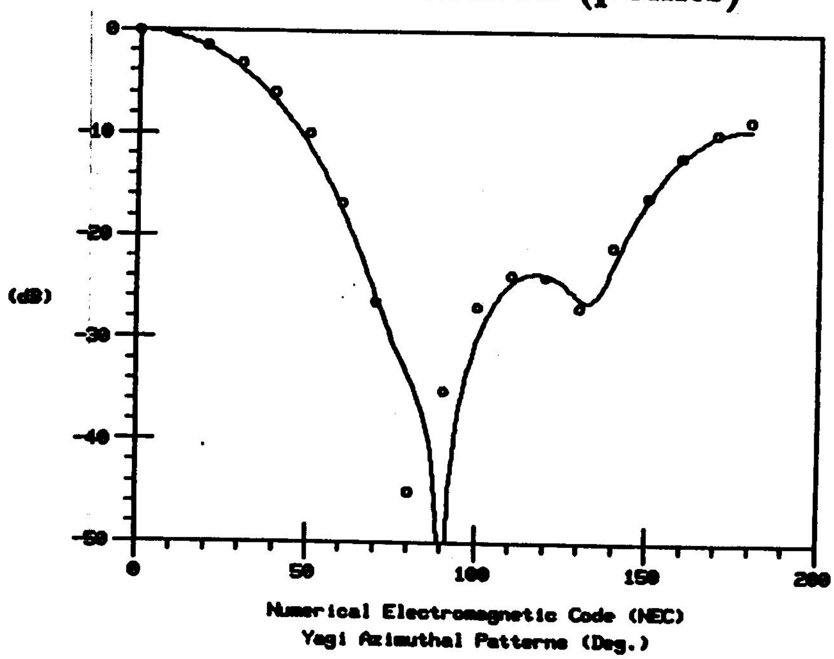
```
CE NBS 5 ELEMENT YAGI
GW 1 7 -.2 -.241 0 -.2 .2410 0 .00425
GW 2 7 0 -.25 0 0 .250 0 .00425
GW 3 7 .2 -.214 0 .2 .2140 0 .00425
GW 4 7 .4 -.212 0 .4 .2120 0 .00425
GW 5 7 .6 -.214 0 .6 .2140 0 .00425
GE
EX 0 2 4 0 1
PL 3 2 0 3
RP 0 1 181 1000 90 0 0 1
EN
```

TABLE 3. MININEC DATA INPUT FOR THE NBS 3 AND 5 ELEMENT YAGIS

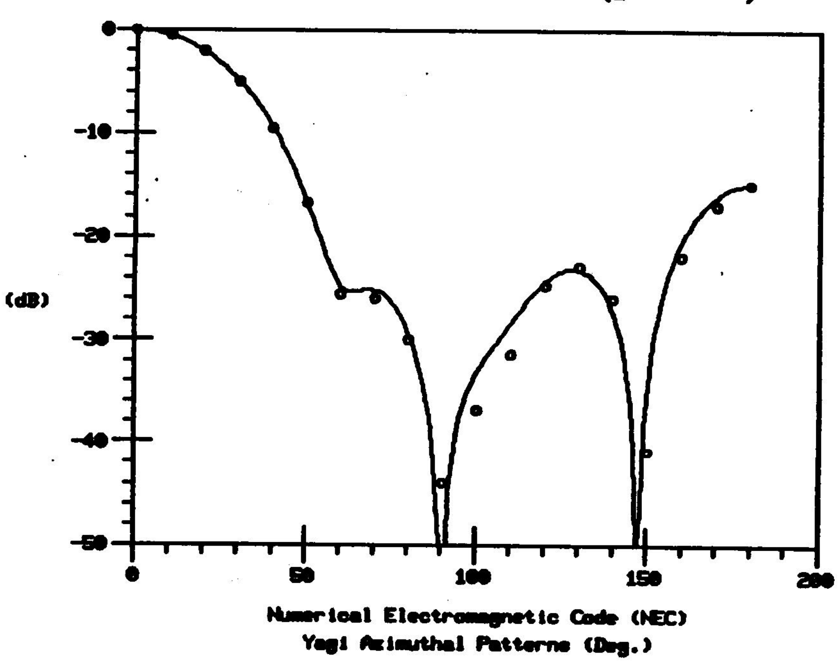
```
$ RUN MININEC
3
6
-.2 -.241 0
0
-.2 .241 0
0
.00425
6
.2 -.221 0
0
.2 .221 0
0
.00425
6
0 -.25 0
0
0 .25 0
0
.00425
N
299.8
1
1
13 1 0
Y
Y
90 0 1
0 1 361
0
N
N
N
N
```

```
$ RUN MININEC
5
6
-.2 -.241 0
0
-.2 .241 0
0
.00425
6
.2 -.214 0
0
.2 .214 0
0
.00425
6
.4 -.212 0
0
.4 .212 0
0
.00425
6
.6 -.214 0
0
.6 .214 0
0
.00425
6
0 -.25 0
0
0 .25 0
0
.00425
N
299.8
1
1
23 1 0
Y
Y
90 0 1
0 1 361
0
N
N
N
N
```

3 Element Yagi
NEC (solid)
NBS - Measured (points)



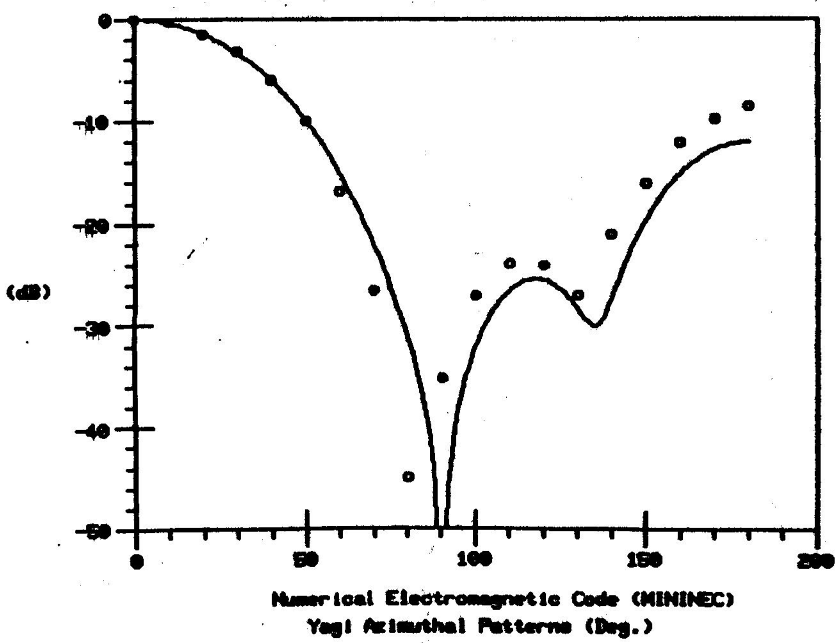
5 Element Yagi
NEC (solid)
NBS - Measured (points)



3 Element Yagi

MININEC (solid), Freq = 299.8 MHz

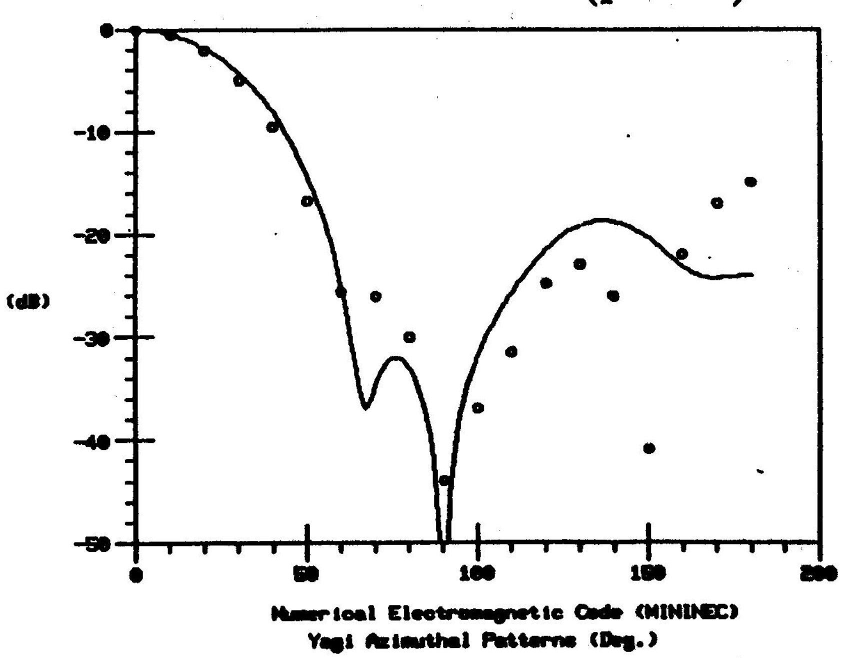
NBS - Measured (points)



5 Element Yagi

MININEC (solid), Freq = 299.8 MHz

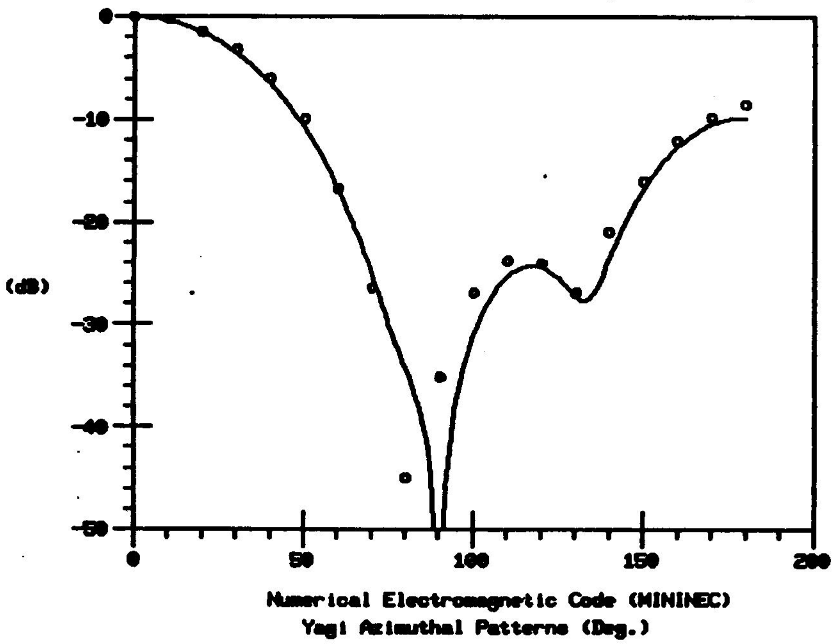
NBS - Measured (points)



3 Element Yagi

MININEC (solid), Freq = 305 MHz

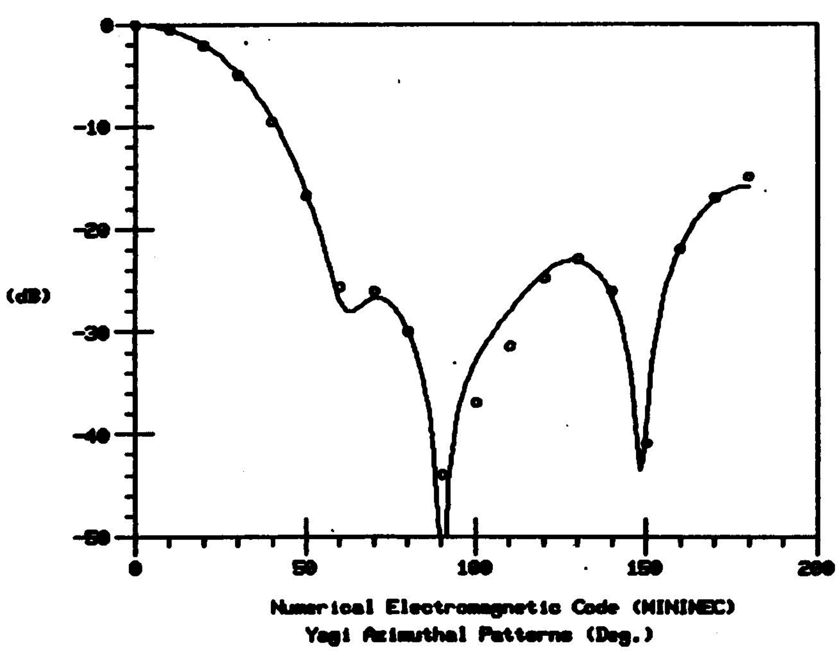
NBS - Measured (points)



5 Element Yagi

MININEC (solid), Freq = 305 MHz

NBS - Measured (points)



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EM Modeling Notes*

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In the first issue of the ACES Newsletter this column contained a summary of some sources of error in modeling with the Numerical Electromagnetics Code NEC – Method of Moments. It was pointed out that, as with all such codes, errors can result from computer system errors, code errors, numerical accuracy limitations, numerical and physical modeling errors, input errors, and incorrect interpretation of results by the user. Fortunately, the errors in the DEC/VAX Fortran compiler, involving optimization in complex-arithmetic expressions, appear to have been corrected in new releases of the compiler. We have found a couple of minor code errors in the VAX version of NEC for which corrections are given at the end of this column. The main topic for this column is the problems of modeling electrically small structures with NEC. We have both good news and bad news in this area. Recent work on the code has greatly improved precision at low frequencies. However, serious problems remain with small loops for which, at this time, we can only offer a warning of when to expect trouble.

Low frequency accuracy has been a problem with NEC, particularly when it is run in 32-bit single precision. The code was originally developed on computers with 60 bit word length, so little attention was given to preserving numerical accuracy. Both loss of precision and limitations in the numerical model can cause problems at low frequencies. Precision problems with the present code have forced the use of double precision for some problems. Hence we have NEC2S and NEC3S codes for single precision and NEC2D and NEC3D for double precision on VAX computers. Double precision, of course, increases the storage requirement and more than doubles the solution time, so some large VLF models are run in single precision because double is unaffordable.

To improve the accuracy of the single precision code, we have revised the code for evaluation of the basis functions and fields. The same spline basis functions are used, but rather than evaluating the current on each segment as

$$I_j(s) = A_j + B_j \sin(ks) + C_j \cos(ks)$$

it is evaluated as

$$I_j(s) = A'_j + B_j \sin(ks) + C_j[\cos(ks) - 1]$$

Series are used to evaluate A'_j, B_j and C_j for small ks to avoid loss of precision. To get to very low frequencies, it was also necessary to arrange the order of calculations to avoid overflow or underflow of intermediate results ($10^{\pm 37}$ is just not enough for this work.)

Precision loss is also a problem in the field evaluation. The present code evaluates the electric field of each segment, including the contributions of delta-function charges that

* Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

result from the current dropping abruptly to zero at the segment ends. These delta-function charge terms dominate the field at low frequency but cancel with adjacent segments, since current is continuous. Hence these terms have been dropped to preserve accuracy. Even these simplified field equations suffer severe cancellation problems that necessitate the use of series expansions for small kR, R much greater than segment length and ρ much less than z. To accurately compute the input resistance of small antennas it was necessary to maintain the accuracy of the real part of the electric field although, for some components, it decreases faster than the imaginary part by a factor of $(kR)^3$. The new field evaluation also runs faster than the old single precision code by twenty to forty percent for typical models.

A package is being prepared to upgrade NEC-3 with these changes (there may be a NEC-2 version later) but I do not know yet when it will be released or how it will be distributed. This revision may be called NEC3VLF for now, although it can be used at higher frequencies like the standard NEC-3. NEC3VLF will not, in its present stage, take care of all low frequency modeling problems, however. An examination of results for decreasing frequency will demonstrate the limitations of the present codes as well as the progress with NEC3VLF.

Results for a small dipole modeled with NEC3S, NEC3D and NEC3VLF are shown in Figure 1. The small dipole is representative of any open wire, as opposed to a loop. For the dipole NEC3S fails at a point that could cause problems in modeling practical VLF antennas. NEC3D could handle most practical applications, but at the expense of increased solution time and storage. NEC3VLF beats the old code in either single or double precision in this case, and also is faster than NEC3S. The solution with NEC3S can also become inaccurate for a fixed length dipole as the number of segments is increased. This problem has been corrected in NEC3VLF as shown in Figure 2.

Small loops involve other problems in the basis functions and field sampling than are encountered with open wires. The present changes do offer some improvement in the single precision accuracy for small loops, however. Results for a small loop fed by a voltage source are shown in Figure 3. Here NEC3VLF works to about an order of magnitude lower frequency than NEC3S but not as low as NEC3D. Accuracy was maintained to about half an order of magnitude lower frequency with each code when the loop was modeled with 4 segments rather than 22 as used in Figure 3. With all three codes, however, the small loop limit is something to worry about in modeling practical antennas.

The problems with small loops involve both numerical precision and limitations of the present numerical model. With the sub-domain, spline basis functions used in NEC the interaction matrix for a loop becomes ill-conditioned as frequency is reduced. The matrix conditioning contributes to the failure to compute the correct input admittance as shown in Figure 3. Another way of looking at this problem is that at low frequencies the electric field of the spline basis functions is dominated by the gradient of the scalar potential, while this term must cancel out for a constant current around a small loop. More numerical precision could extend the solution to somewhat lower frequencies. A better fix, however, appears to be to replace one of the spline basis functions with an entire domain basis function

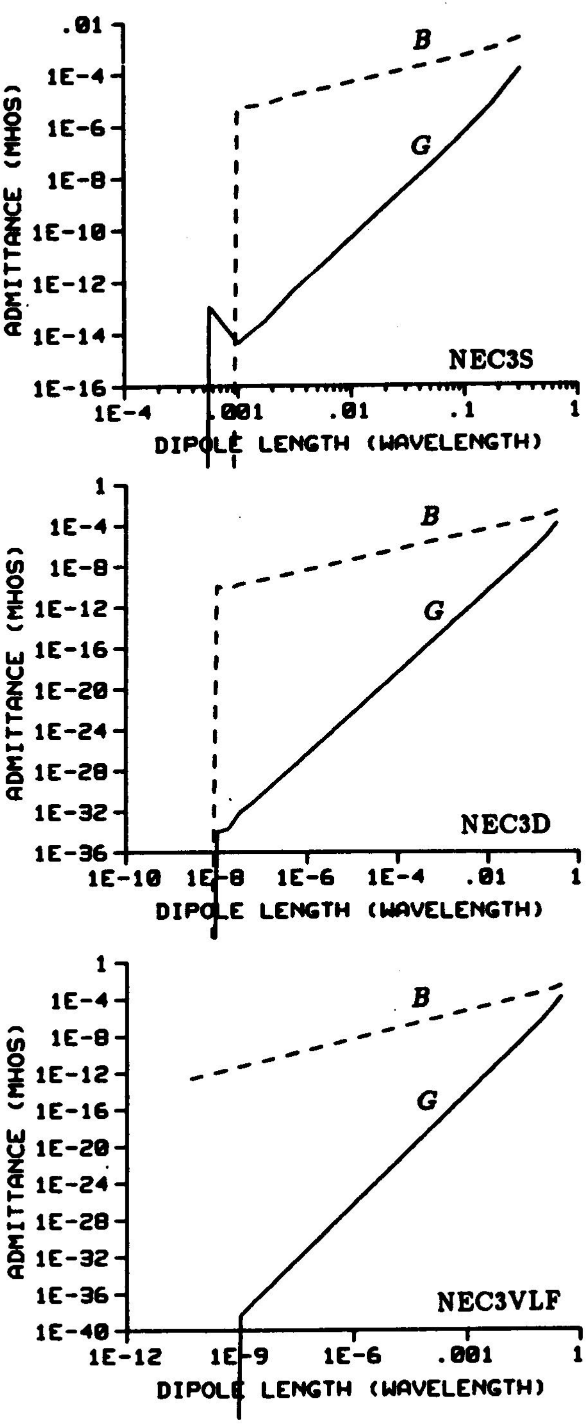


Figure 1. Input admittance of a dipole antenna computed by NEC3S, NEC3D and NEC3VLF. The dipole was modeled with 9 segments and the ratio of radius to dipole length was 10^{-3}. Solution failure is shown by the deviation from the low frequency asymptotic behavior.

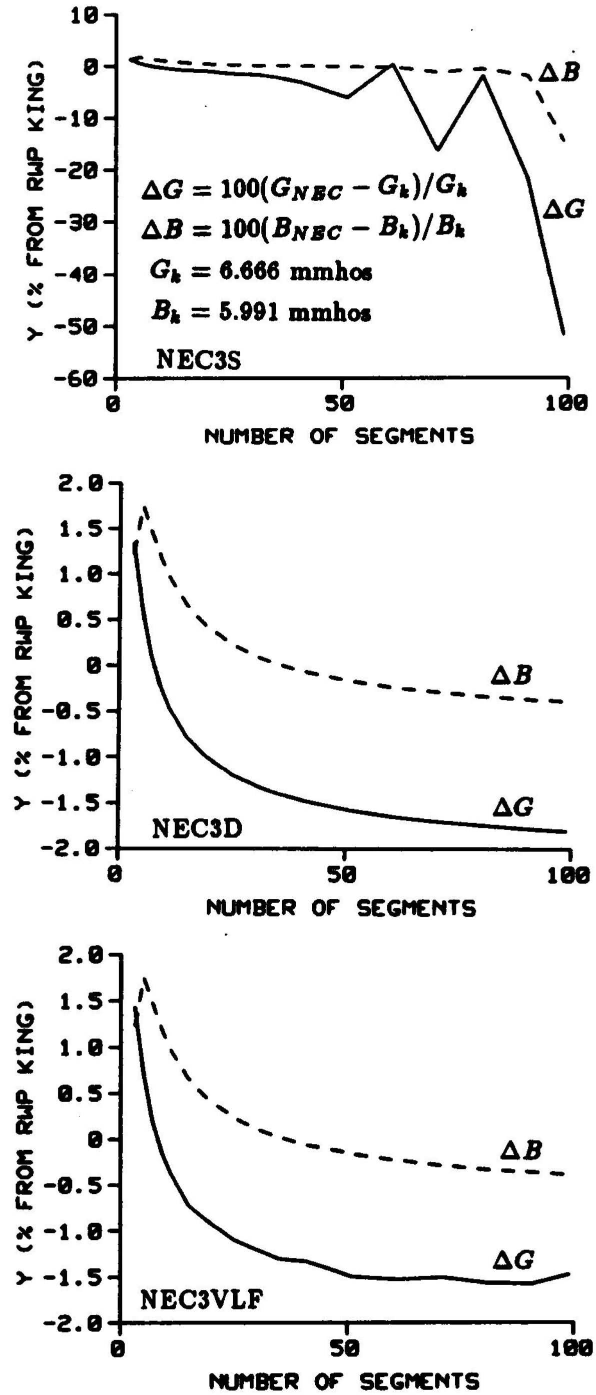


Figure 2. Input admittance of a $\lambda/2$ dipole antenna computed by NEC3S, NEC3D and NEC3VLF with varying number of segments. The difference from the King-Middleton result $(G_k + jB_k)$ is plotted. The ratio of dipole radius to length is $4.5(10^{-5})$ $(\Omega = 20)$.

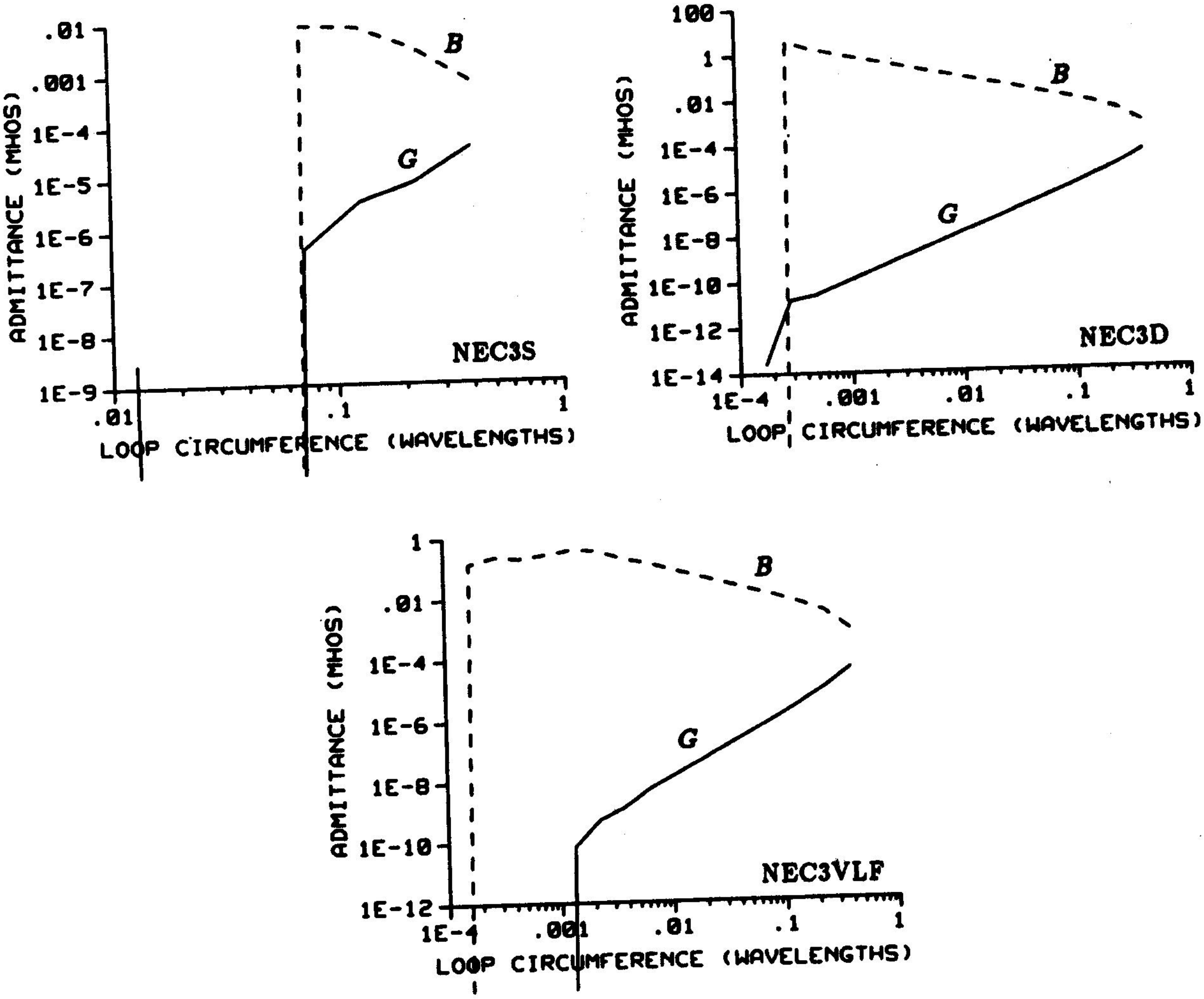


Figure 3. Input admittance of a loop antenna computed by NEC3S, NEC3D and NEC3VLF. The loop was modeled with 22 segments and the ratio of wire radius to loop radius was $4.2(10^{-2})$. Solution failure is shown by the deviation from the low frequency asymptotic behavior.

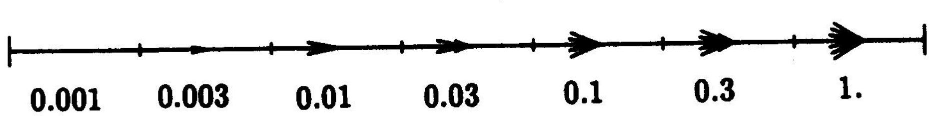


Figure 4. Arrow scale for normalized current on isometric structure plots

of constant value around the loop. This would avoid the ill-conditioned matrix, but is difficult to implement due to the need to identify small loops within a model. We plan to try this approach and hope to find a way to get it into NEC3VLF.

The situation is still worse when a small loop is excited by an electric field from a nearby source, such as a dipole, rather than a voltage source in the loop. Typical examples are shown in Figures 5 and 6. These figures were produced by a program that plots an isometric projection of a model with currents shown as arrows. Either the real or imaginary part of current can be displayed with the arrows in the direction of the current and the arrow size proportional to the log of normalized current. The arrow scale is shown in Figure 4. The solutions for these models appear correct at higher frequencies. As frequency is reduced the loop current eventually starts growing as f^{-1} while the dipole current is decreasing as f.

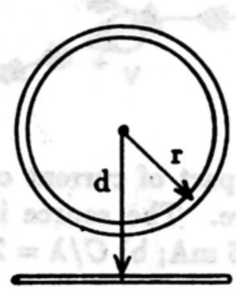
What is going on? The loop current should be proportional to the EMF induced by the field of the external source

$$\oint_{loop} \overline{E}_{dipole} \cdot \overline{dl} = -j\omega\mu \int_{loop} \overline{H}_{dipole} \cdot \overline{dS}$$

Since the current in a short dipole with constant voltage source decreases as f, the expression on the right will decrease as f^2. The electric field of a dipole with constant voltage becomes constant as frequency is reduced, however. Hence the decrease of the line integral as f^2 must result from cancellation around the contour, clearly a problem for numerical evaluation. The villain is again the gradient of the scalar potential which dominates the low frequency field of the dipole but canceles to zero in the line integral around the loop. Since NEC uses point matching of the electric field boundary condition it has only a relatively crude evaluation of the line integral of $\overline{E}_{dipole}$. The error in sampling the line integral represents an erroneous voltage source in the loop which produces a current proportional to f^{-1} at low frequencies, while the correct loop current should be proportional to f.

The frequency at which the spurious loop current may appear depends on both the size of the loop and the coupling to the external excitation. A quick test for the loop-dipole case of Figure 5 showed the following relationship:

d/r	minimum $(2\pi r/\lambda)$
1.01	$6(10^{-2})$
1.02	$6(10^{-2})$
1.05	$2(10^{-2})$
1.1	$2(10^{-2})$
1.2	$2(10^{-2})$
1.4	$6(10^{-3})$
1.8	$2(10^{-3})$
2.0	$6(10^{-4})$



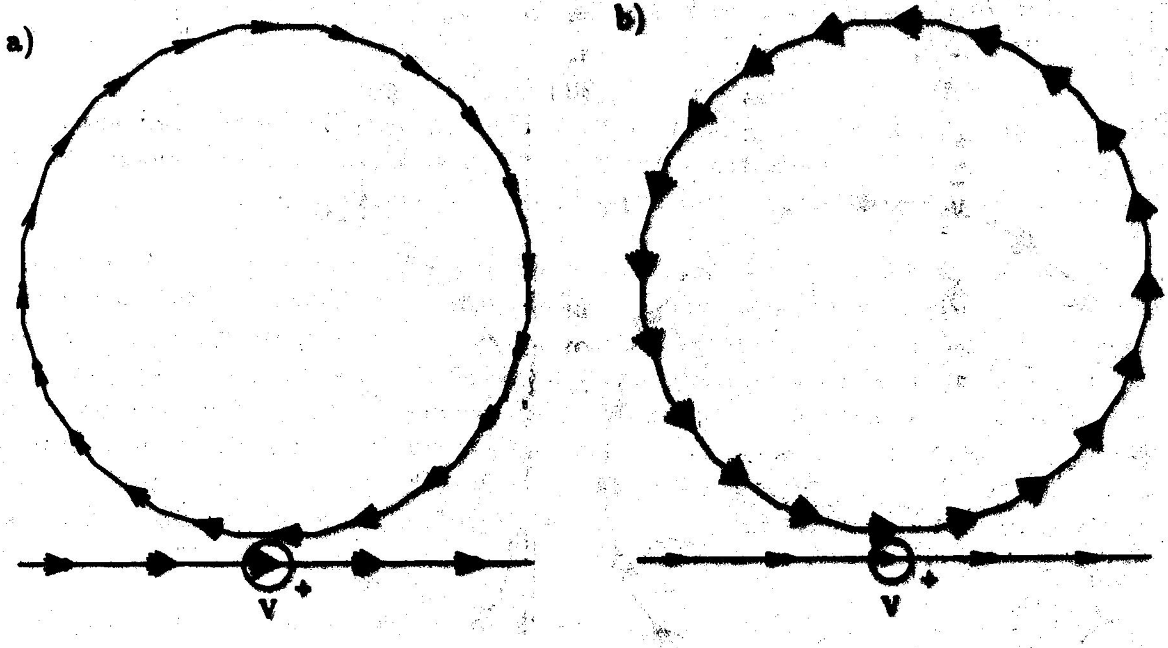


Figure 5. Imaginary part of current computed by NEC3D on a dipole coupled to a loop with circumference C. The source is one volt and current is normalized by I_{max}: a) $C/\lambda = 0.2$, $I_{max} = 0.26$ mA; b) $C/\lambda = 2(10^{-3})$, $I_{max} = 0.069$ mA with incorrect loop current.

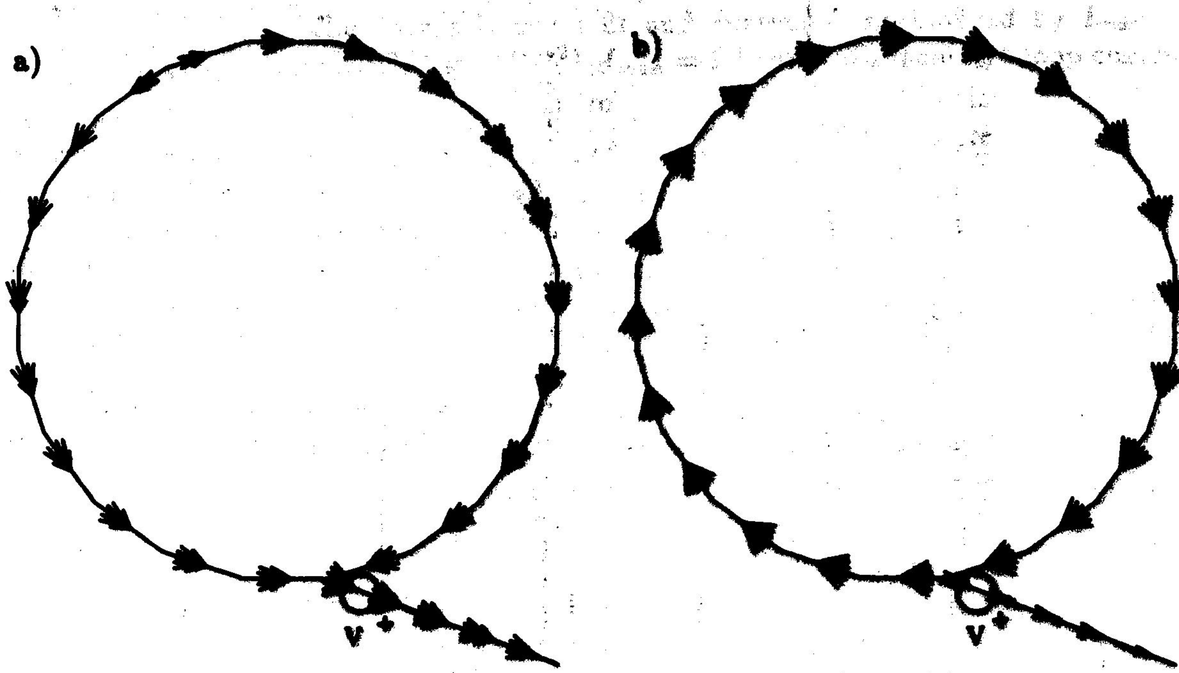


Figure 6. Imaginary part of current computed by NEC3D on a loop with circumference C and connected wire. The source is one volt and current is normalized by I_{max}; a) $C/\lambda = 0.6$, $I_{max} = 1.6$ mA; b) $C/\lambda = 2(10^{-2})$, $I_{max} = 1.1$ mA with incorrect loop current.

For the case of Figure 6 the loop current showed up at $C/\lambda = 0.06$. Incorrect loop currents can also occur in wire grids as shown in Figure 7. Here, again, the loop currents at low frequencies become proportional to f^{-1} while the probe current is proportional to f. Coupling from a loop source to another loop is not as bad a problem since the loop does not contribute a large scalar potential.

This loop problem is particularly nasty because it is a failure of the numerical model rather than of precision. Hence NEC3S, NEC3D and NEC3VLF can each give the same wrong result. The "average gain" check, often used in NEC to compare the radiated power with the computed input power, also may not indicate a problem, since the incorrect loop currents do not radiate strongly. With the current strength in the dipole proportional to f the radiated power from the dipole goes as f^4. The spurious loop current, proportional to f^{-1}, contributes a radiated power proportional to f^2. Hence, as frequency is reduced, the loop radiation will eventually dominate, and when it does the average gain starts increasing as f^{-2}. For the loop and dipole of Figure 5, however, the average gain remained close to 1.0 to a frequency two orders of magnitude below that at which the erroneous loop current became apparent. For the loop and stub in Figure 6 the average gain began increasing as f^{-2} almost simultaneously with the appearance of the circulating loop currents, due to tighter coupling to the stub.

This problem does not appear to have a simple solution. A pulse or higher order weighting function should help, but precision would still be a problem. A better solution is to include a weighting function that is constant around the loop so that we can consider only the vector potential when evaluating the weighted integral of the electric field. The need for such a treatment has been noted with other wire codes (D. Wilton, private communication.) Such a change could be a major task, however, with implications on the source models, ground treatment and other code functions. One suggestion (from E. K. Miller, U. of K) is to impose a condition of zero normal magnetic field at the center of a loop in a grid that represents a perfectly conducting surface. It would be interesting to see how other codes do on these models.

As I mentioned before, a couple of errors have been found in the VAX versions of NEC2 and NEC3. These are in features not officially supported, so it is not known who is to blame. One was found by the people at Eyring Research Inc. This occured in both subroutines READGM and READMN at line 52 in the NEC2S and NEC3S versions and line 57 in NEC2D and NEC3D. The correct code line is

```
BUFFER=BUFFER(1:INDE-1)//'.'//BUFFER(INDE:LEN-1)
```

where previously INDE was misspelled as INDD in the first occurrence. With this correction data can be entered in the form 1E−3, where omission of the decimal point would previously cause an error.

The other error involved the plotting output option (PL card.) The code to set plot output flags, at about line 360 of the main program, should be as follows:

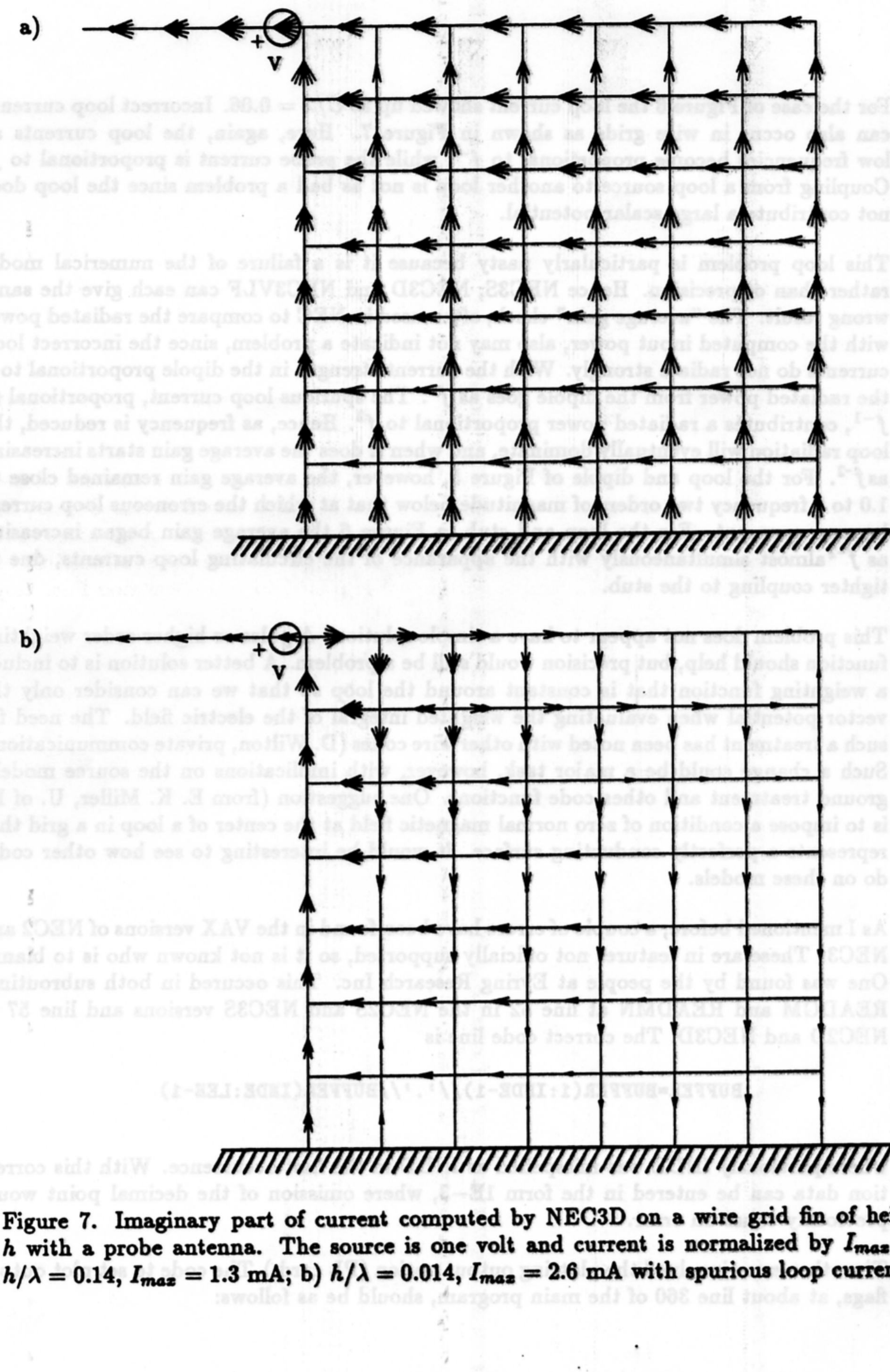


Figure 7. Imaginary part of current computed by NEC3D on a wire grid fin of height h with a probe antenna. The source is one volt and current is normalized by I_{max}; a) $h/\lambda = 0.14$, $I_{max} = 1.3$ mA; b) $h/\lambda = 0.014$, $I_{max} = 2.6$ mA with spurious loop currents.

```
      GO TO 14
C***
C
C     PLOT FLAGS
C
330   IPLP1=ITMP1
      IPLP2=ITMP2
      IPLP3=ITMP3
      IPLP4=ITMP4
      GO TO 14
```

In NEC2S and NEC2D the first `GO TO 14` was omitted while in NEC3S and NEC3D the second `GO TO 14` got lost.

I hope we can have some answers to the problems discussed here by the next newsletter. The work reported here was partially funded by the Naval Ocean Systems Center, San Diego. We would like to thank Jim Logan at NOSC for initially pointing out some of the problems discussed. I just received a report from R. Adler and S. Kershner of possible bad solutions for disipated power in a wire grid model of a bird on a transmission line. Hope this does not cause problems in cooking their turkeys.

MININEC3 UPDATES

This launches the update mechanism for MININEC3 (see p.27). The version of the code being distributed by Jim Logan is version 5, dated 11 Sept 1986. The following four updates will bring the distributed code up to version 9. To add lines of code, it is necessary to use the renumber option in BASIC to step the lines by more than one, add the appropriate lines, and then renumber by ones. Remember that the code as received will not run under the regular BASIC interpreter. You must compile it or reduce the large arrays which cause it to exceed BASIC's 64K memory limit.

VERSION 5

```
347 REM ----- S-PARAMETER LOADS
348 U1=0
349 U2=0
350 D1=0
351 D2=0
352 S=-1
353 FOR J=0 TO LS(I) STEP 2
354 U1=U1+LA(1,I,J)*(S*F5)^J
355 D1=D1+LA(2,I,J)*(S*F5)^J
356 L=J+1
357 U2=U2+LA(1,I,L)*(S*F5)^L
358 D2=D2+LA(2,I,L)*(S*F5)^L
359 NEXT J
360 J=LP(I)
```

UPDATE

```
 347 REM ----- S-PARAMETER LOADS
 348 U1=0
 349 U2=0
 350 D1=0
 351 D2=0
•352 S=1
 353 FOR J=0 TO LS(I) STEP 2
•354 U1=U1+LA(1,I,J)*S*F5^J
•355 D1=D1+LA(2,I,J)*S*F5^J
 356 L=J+1
•357 U2=U2+LA(1,I,L)*S*F5^L
•358 D2=D2+LA(2,I,L)*S*F5^L
•359 S=-S
 360 NEXT J
```

CHANGE FIVE; ADD ONE

```
744 REM ----- REAL GROUND CASE
745 REM ----- BEGIN BY FINDING SPECULAR DISTANCE
746 T4=100000!
747 IF R3=0 THEN 749
748 T4=-Z(J)*T3/R3
749 B9=T4*V2+X(J)
750 IF TB=1 THEN 753
751 B9=SQR(B9*B9+(Y(J)-T4*V1)^2)
752 REM ----- SEARCH FOR THE CORRESPONDING MEDIUM
```

```
  745 REM ----- REAL GROUND CASE
  746 REM ----- BEGIN BY FINDING SPECULAR DISTANCE
  747 T4=100000!
  748 IF R3=0 THEN 750
  749 T4=-Z(J)*T3/R3
  750 B9=T4*V2+X(J)
  751 IF TB=1 THEN 755
• 752 B9=B9*B9+(Y(J)-T4*V1)^2
• 753 IF B9>0 THEN B9=SQR(B9) ELSE 755
```

CHANGE ONE; ADD ONE

```
813 H2=(X1*T1+Y1*T2+Z1*T3)*G0
814 H1=(X2*T1+Y2*T2+Z2*T3)*G0
815 X4=(X1*V1+Y1*V2)*G0
816 X3=(X2*V1+Y2*V2)*G0
817 IF P$="D" THEN 825
818 IF RD=0 THEN 840
819 H1=H1/RD
820 H2=H2/RD
821 X3=X3/RD
822 X4=X4/RD
823 GOTO 840
824 REM ----- PATTERN IN DB
```

```
• 815 H2=-(X1*T1+Y1*T2+Z1*T3)*G0
  816 H1=(X2*T1+Y2*T2+Z2*T3)*G0
• 817 X4=-(X1*V1+Y1*V2)*G0
  818 X3=(X2*V1+Y2*V2)*G0
  819 IF P$="D" THEN 827
  820 IF RD=0 THEN 842
  821 H1=H1/RD
  822 H2=H2/RD
  823 X3=X3/RD
  824 X4=X4/RD
  825 GOTO 842
  826 REM ----- PATTERN IN DB
```

CHANGE TWO

```
882 REM ----- INPUT VARIABLES FOR NEAR FIELD CALCULATION
883 PRINT "FIELD LOCATION(S):"
884 A$="-COORDINATE (M): INITIAL,INCREMENT,NUMBER "
885 PRINT "   X";A$;
886 INPUT XX,XC,NX
887 IF NX=0 THEN NX=1
888 IF O$>"C" THEN PRINT #3,"X";A$;": ";XX;",";XC;",";NX
889 PRINT "   Y";A$;
890 INPUT YY,YC,NY
891 IF NY=0 THEN NY=1
892 IF O$>"C" THEN PRINT #3,"Y";A$;": ";YY;",";YC;",";NY
893 PRINT "   Z";A$;
894 INPUT ZZ,ZC,NZ
895 IF NZ=0 THEN NZ=1
896 IF O$>"C" THEN PRINT #3,"Z";A$;": ";ZZ;",";ZC;",";NZ
897 F1=1
```

```
  884 REM ----- INPUT VARIABLES FOR NEAR FIELD CALCULATION
  885 PRINT "FIELD LOCATION(S):"
  886 A$="-COORDINATE (M): INITIAL,INCREMENT,NUMBER "
  887 PRINT "   X";A$;
• 888 INPUT XI,XC,NX
  889 IF NX=0 THEN NX=1
• 890 IF O$>"C" THEN PRINT #3,"X";A$;": ";XI;",";XC;",";NX
  891 PRINT "   Y";A$;
• 892 INPUT YI,YC,NY
  893 IF NY=0 THEN NY=1
• 894 IF O$>"C" THEN PRINT #3,"Y";A$;": ";YI;",";YC;",";NY
  895 PRINT "   Z";A$;
• 896 INPUT ZI,ZC,NZ
  897 IF NZ=0 THEN NZ=1
• 898 IF O$>"C" THEN PRINT #3,"Z";A$;": ";ZI;",";ZC;",";NZ
  899 F1=1
```

CHANGE SIX

VERSION 5

UPDATE

```
920 REM ----- LOOP OVER Z DIMENSION
921 FOR IZ=1 TO NZ
922 REM ----- LOOP OVER Y DIMENSION
923 FOR IY=1 TO NY
924 REM ----- LOOP OVER Z DIMENSION
925 FOR IX=1 TO NX
926 REM ----- NEAR FIELD HEADER
```

```
  922 REM ----- LOOP OVER Z DIMENSION
  923 FOR IZ=1 TO NZ
• 924 ZZ=ZI+(IZ-1)*ZC
  925 REM ----- LOOP OVER Y DIMENSION
  926 FOR IY=1 TO NY
• 927 YY=YI+(IY-1)*YC
  928 REM ----- LOOP OVER X DIMENSION
  929 FOR IX=1 TO NX
• 930 XX=XI+(IX-1)*XC
  931 REM ----- NEAR FIELD HEADER
```

ADD THREE

```
1069 REM ----- IMAGINARY PART OF ELECTRIC FIELD
1070 U7=M*U7/S0
1071 REM ----- REAL PART OF ELECTRIC FIELD
1072 U8=-M*U8/S0
1073 REM ----- MAGNITUDE AND PHASE CALCULATION
1074 S1=0
```

```
  1074 REM ----- IMAGINARY PART OF ELECTRIC FIELD
• 1075 U7=-M*U7/S0
  1076 REM ----- REAL PART OF ELECTRIC FIELD
• 1077 U8=M*U8/S0
  1078 REM ----- MAGNITUDE AND PHASE CALCULATION
  1079 S1=0
```

CHANGE TWO

```
•1121 REM ----- INCREMENT X DIMENSION
•1122 XX=XX+XC
 1123 NEXT IX
•1124 REM ----- INCREMENT Y DIMENSION
•1125 YY=YY+YC
 1126 NEXT IY
•1127 REM ----- INCREMENT Z DIMENSION
•1128 ZZ=ZZ+ZC
 1129 NEXT IZ
 1130 CLOSE #2
 1131 RETURN
```

```
1126 NEXT IX
1127 NEXT IY
1128 NEXT IZ
1129 CLOSE #2
1130 RETURN
```

DELETE SIX

```
1455 REM ********** LOADS INPUT **********
1456 PRINT
1457 INPUT "NUMBER OF LOADS       ";NL
1458 IF NL<=ML THEN 1461
1459 PRINT "NUMBER OF LOADS EXCEEDS DIMENSION..."
1460 GOTO 1457
1461 IF OS>"C" THEN PRINT #3,"NUMBER OF LOADS";NL
1462 IF NL<1 THEN 1492
1463 INPUT "S-PARAMETER LOAD (Y/N)";L$
1464 IF L$<>"Y" AND L$<>"N" THEN 1463
1465 A$="PULSE NO.,RESISTANCE,REACTANCE"
1466 IF L$="Y" THEN A$= "PULSE NO., ORDER OF S-PARAMETER FUNCTION"
1467 FOR I=1 TO NL
```

```
  1454 REM ********** LOADS INPUT **********
  1455 PRINT
  1456 INPUT "NUMBER OF LOADS       ";NL
  1457 IF NL<=ML THEN 1460
  1458 PRINT "NUMBER OF LOADS EXCEEDS DIMENSION..."
  1459 GOTO 1456
  1460 IF OS>"C" THEN PRINT #3,"NUMBER OF LOADS";NL
  1461 IF NL<1 THEN 1492
• 1462 INPUT "S-PARAMETER (S=jw) IMPEDANCE LOAD (Y/N)";L$
  1463 IF L$<>"Y" AND L$<>"N" THEN 1462
  1464 A$="PULSE NO.,RESISTANCE,REACTANCE"
  1465 IF L$="Y" THEN A$= "PULSE NO., ORDER OF S-PARAMETER FUNCTION
  1466 FOR I=1 TO NL
```

CHANGE ONE