5:1 DIPOLE BENCHMARK CASE

A. C. Ludwig, editor; N. Kuster, A. Glisson
H. Thal, contributors

1. Introduction

The sphere is typically the first benchmark case used to validate a scattering code; it has the great virtue of having an analytic solution. It has a major disadvantage in that it is a completely smooth body, and is easier to handle numerically than a body whose surface contour has discontinuous first or second derivatives. For this reason a code may work very well for a sphere, and not so well with other bodies. Therefore a sphere benchmark is a necessary, but not sufficient, condition for validation. Recently a series of challenging benchmark cases have been defined [1], which have the virtue of stretching the capabilities of most codes, but in some cases requiring a supercomputer or large running times to obtain a solution. The case presented here is intended to be intermediate in that a solution can be obtained with a modest amount of computer time on commonly available computers, and is therefore useful in initial code development and validation. However it is also challenging in the sense that one can strive for very high accuracy. The agreement between the results presented below is typically better than .01 dB in the scattered field, which is extremely good by almost any standard. The case is also non-trivial in that it requires 3 Fourier modes for an accurate body-of-revolution solution, versus the one mode for an incident field parallel to the axis of revolution, and the surface contour has a discontinuous second derivative.

Scattered field results are typically less sensitive to error than surface currents. For validation purposes this means that surface currents are a more sensitive indicator, and for this reason are included in the results given below. Contributors have been encouraged to estimate error bars for their results, as proposed by Prof. L. Felson in a recent validation workshop [2]. Some analysts have questioned the utility of accuracies that are far better than can be measured. One response is that a benchmark should be as accurate as possible almost by definition, but in addition, there can be subtle errors that would escape notice in a less accurate benchmark comparison, but which could become far more serious in other problems where benchmarks are not available for comparison.

2. Definition of the case

The dipole is a perfectly conducting body with dimensions as given in figure 1. The incident field is also specified in figure 1, having a magnitude of 1 volt per meter and a phase of zero degrees at the origin of the coordinate system. The wavelength is 1 meter, and the polarization is parallel to the axis of rotation as shown.

Contributors are asked to compute the forward and backscattered field, and the surface currents along three cuts formed by intersections with the x-z and y-z planes, at phi=0, 90, and 180 degrees. A specific set of 11 points per cut are suggested for tabular numerical output, equally spaced in arc length along the body between the center and the tip. A standard software form proposed by Ling and Lee [3] is also suggested.

3. Comparison of key results

To date, four contributors have provided solutions using four different codes based on three different techniques. The magnitude of the backscattered field is shown graphically in figure 2. As noted previously the results generally agree to within .01 dB. The peak surface current on the body is in the center on the lit side (z=0, phi=180 degrees). The real and imaginary part of the peak current is plotted in figure 3. The error estimate in Ludwig's result is 0.3% of the magnitude, and all of the results are approximately within a cluster of this size. The computed currents are so close to each other that they would overlay on a full scale plot, so only one set of curves is given for the 3 cuts in figure 4.

4. Detailed results from the contributors

The following pages were provided by the individual contributors and are given without change, except that current plots have been omitted since they duplicate figure 4. Most contributors use the standard phi unit vector to define one current component, and the orthogonal component is defined as the unit normal cross phi, but the negative of these definitions are used by others.

REFERENCES

1. S. W. Lee and R. J. Marhefka, eds, "Data book of High-frequency RCS", compiled by High frequency subgroup, Joint Service Electromagnetic Code Consortium, (to be published).

2. AP-S Workshop on Software Validation, San Jose, CA, June 30, 1989, E. K. Miller, Chairman.

3. H. Ling and S. W. Lee, "Data Book for Cavity RCS", AP-S Workshop on Software Validation, San Jose, CA, June 30, 1989.

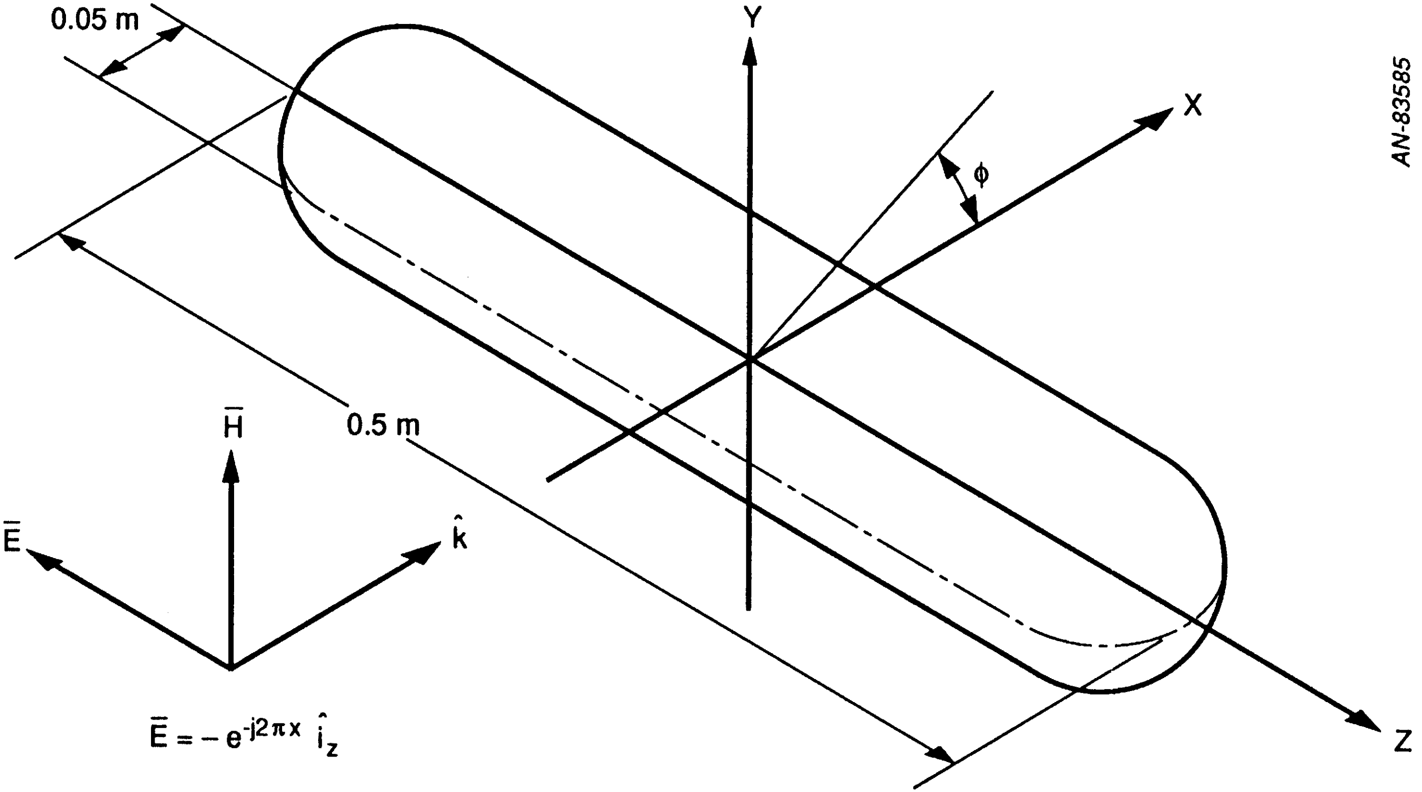

Figure 1. 5:1 dipole benchmark case.

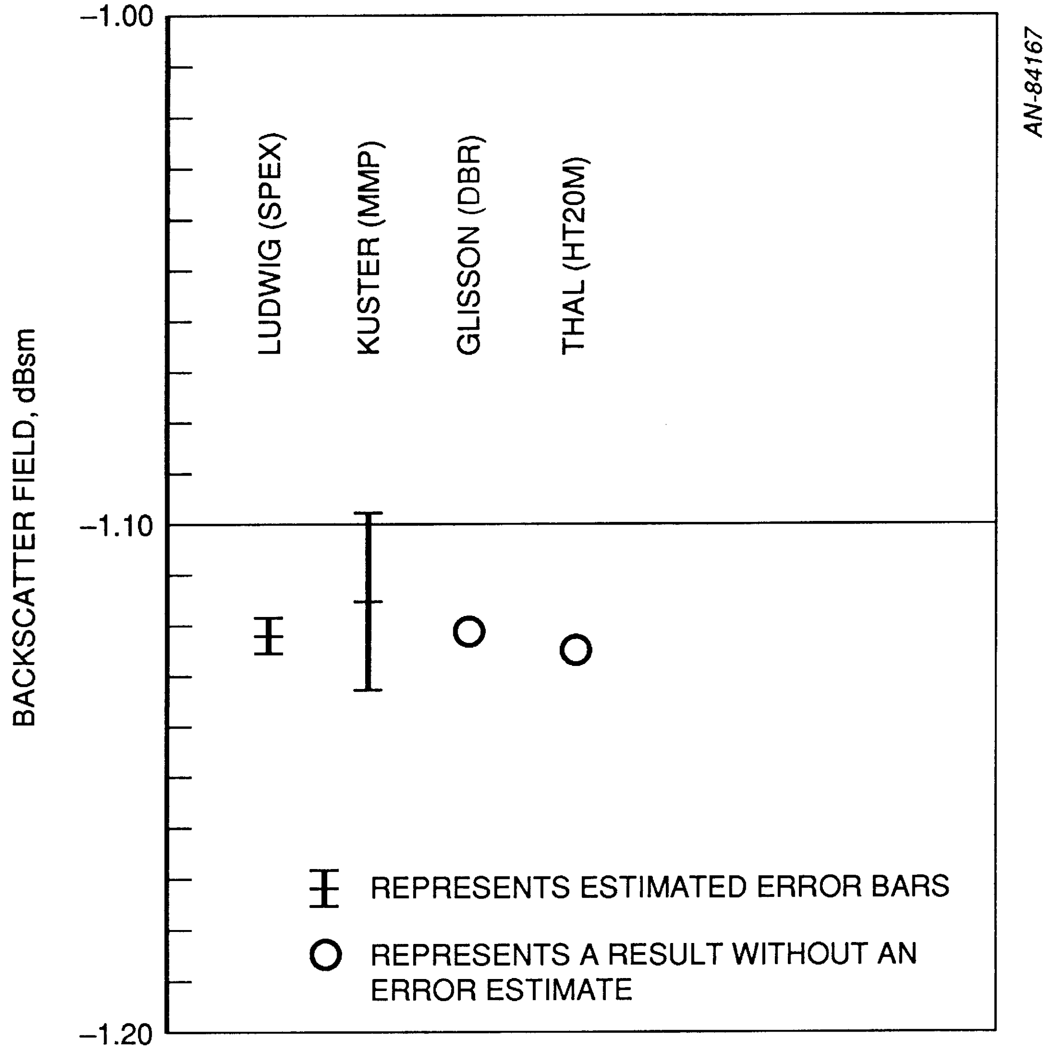

Figure 2. Comparison of backscattering results.

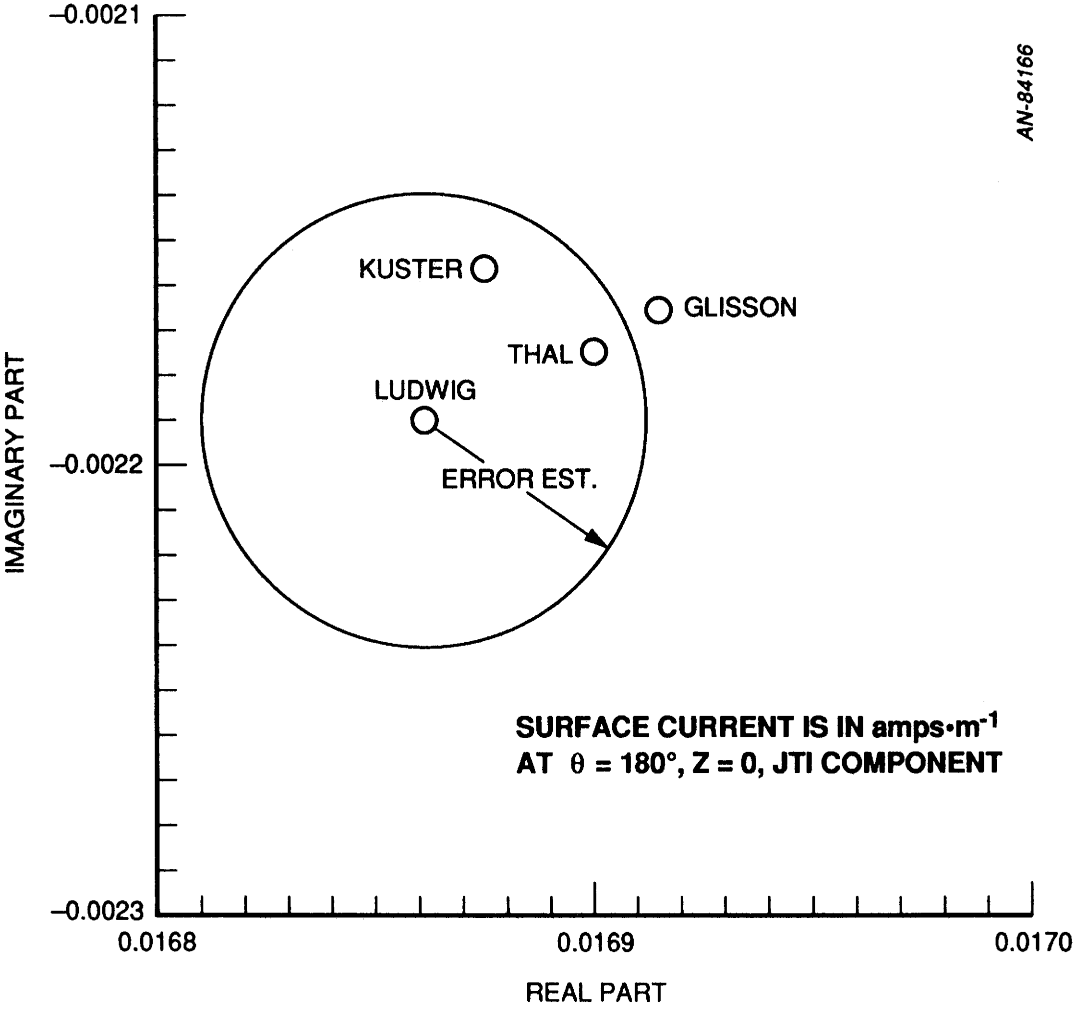

Figure 3. Comparison of surface current results.

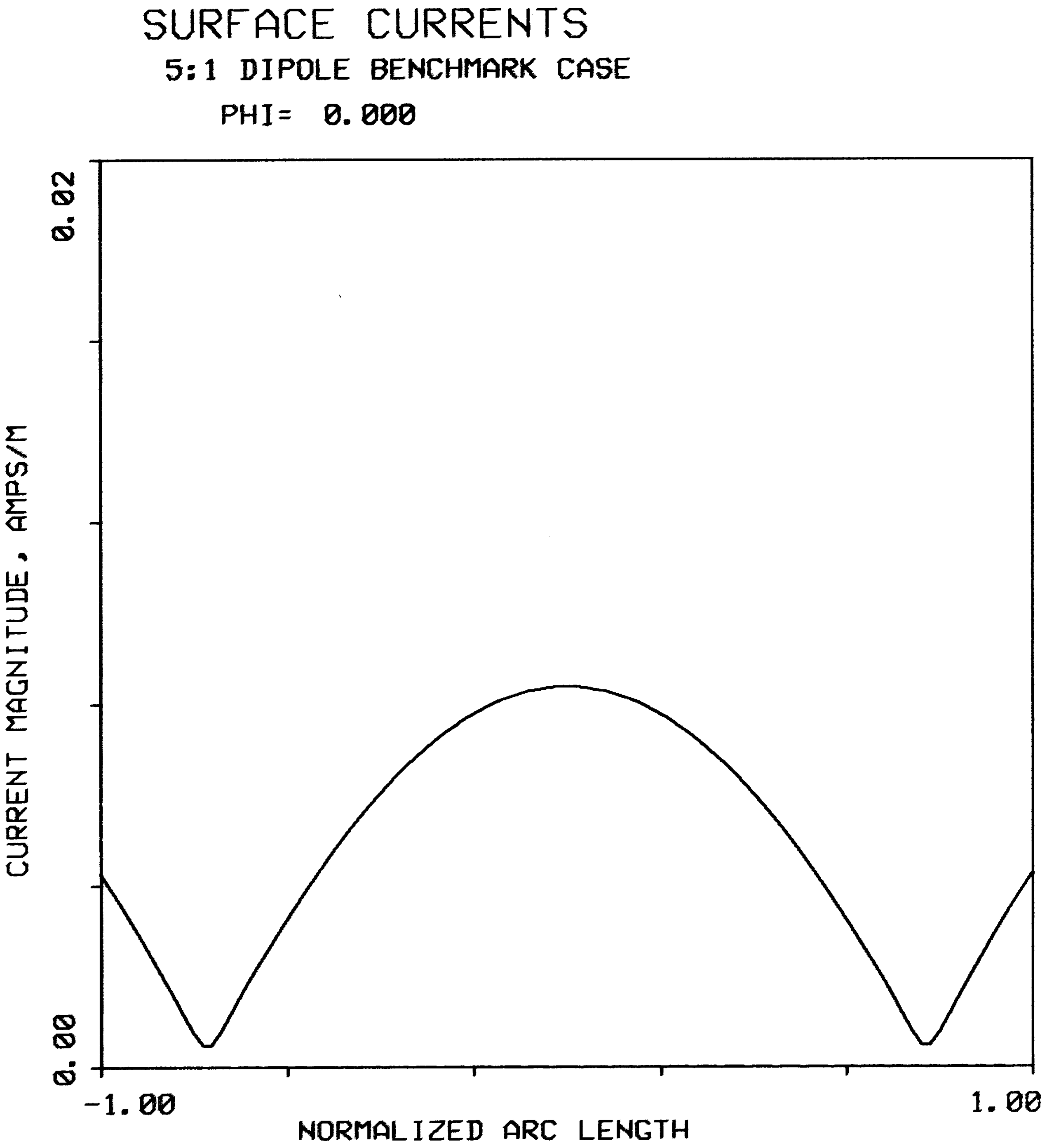
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 0.000
0.02
0.00
CURRENT MAGNITUDE, AMPS/M
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4a

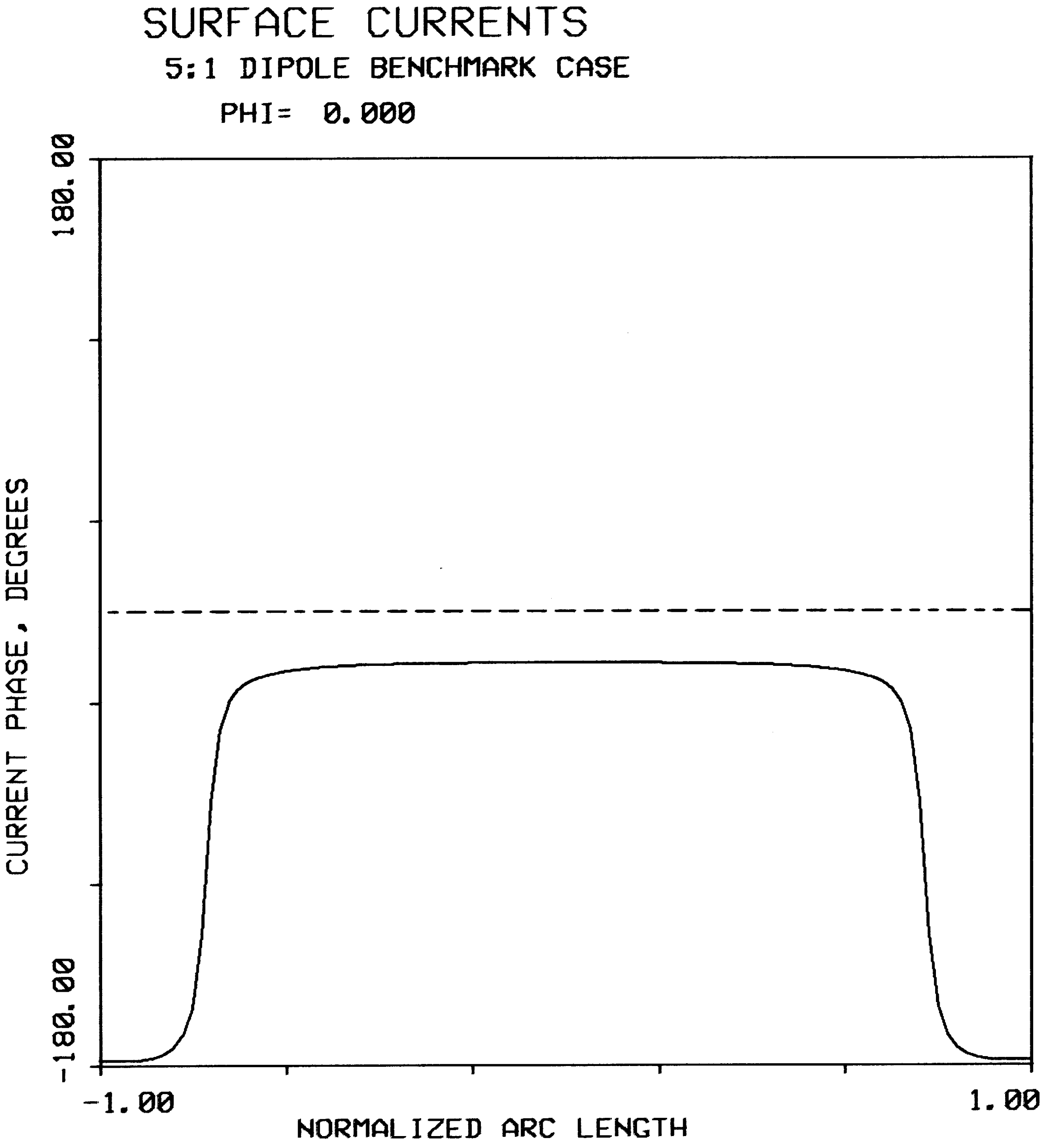
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 0.000
180.00
-180.00
CURRENT PHASE, DEGREES
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4b

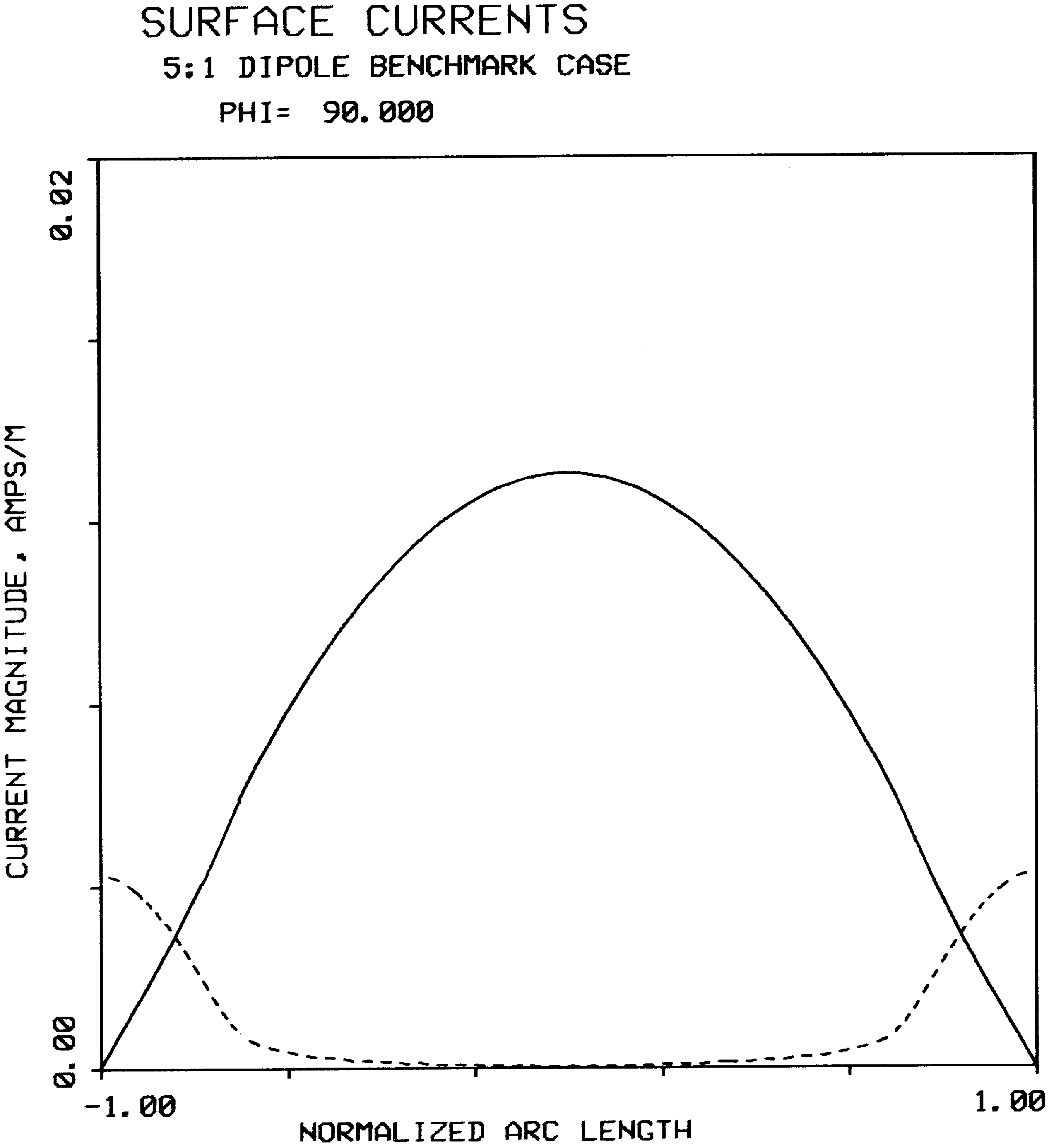
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 90.000
0.02
0.00
CURRENT MAGNITUDE, AMPS/M
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4c

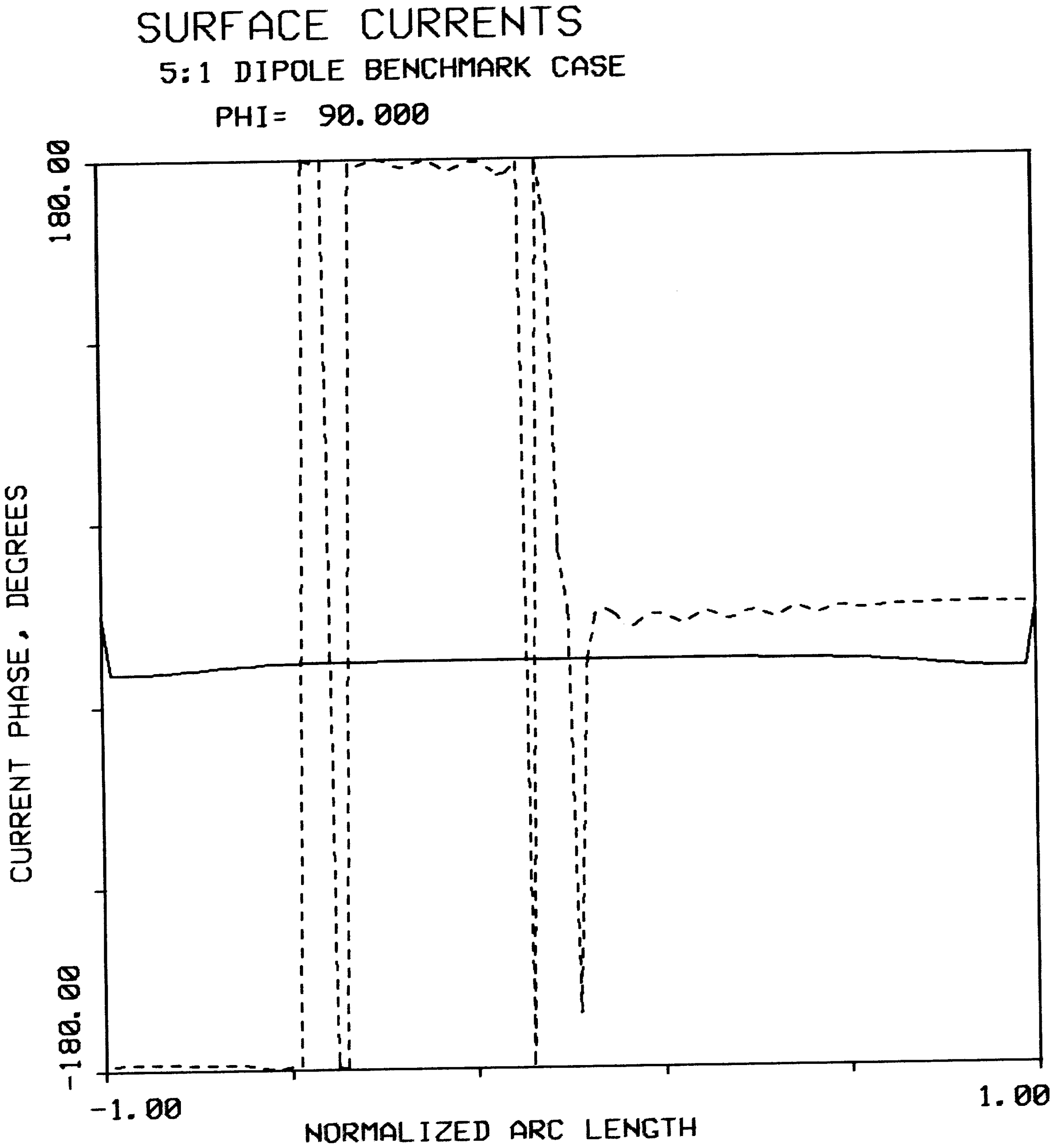
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 90.000
180.00
-180.00
CURRENT PHASE, DEGREES
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4d

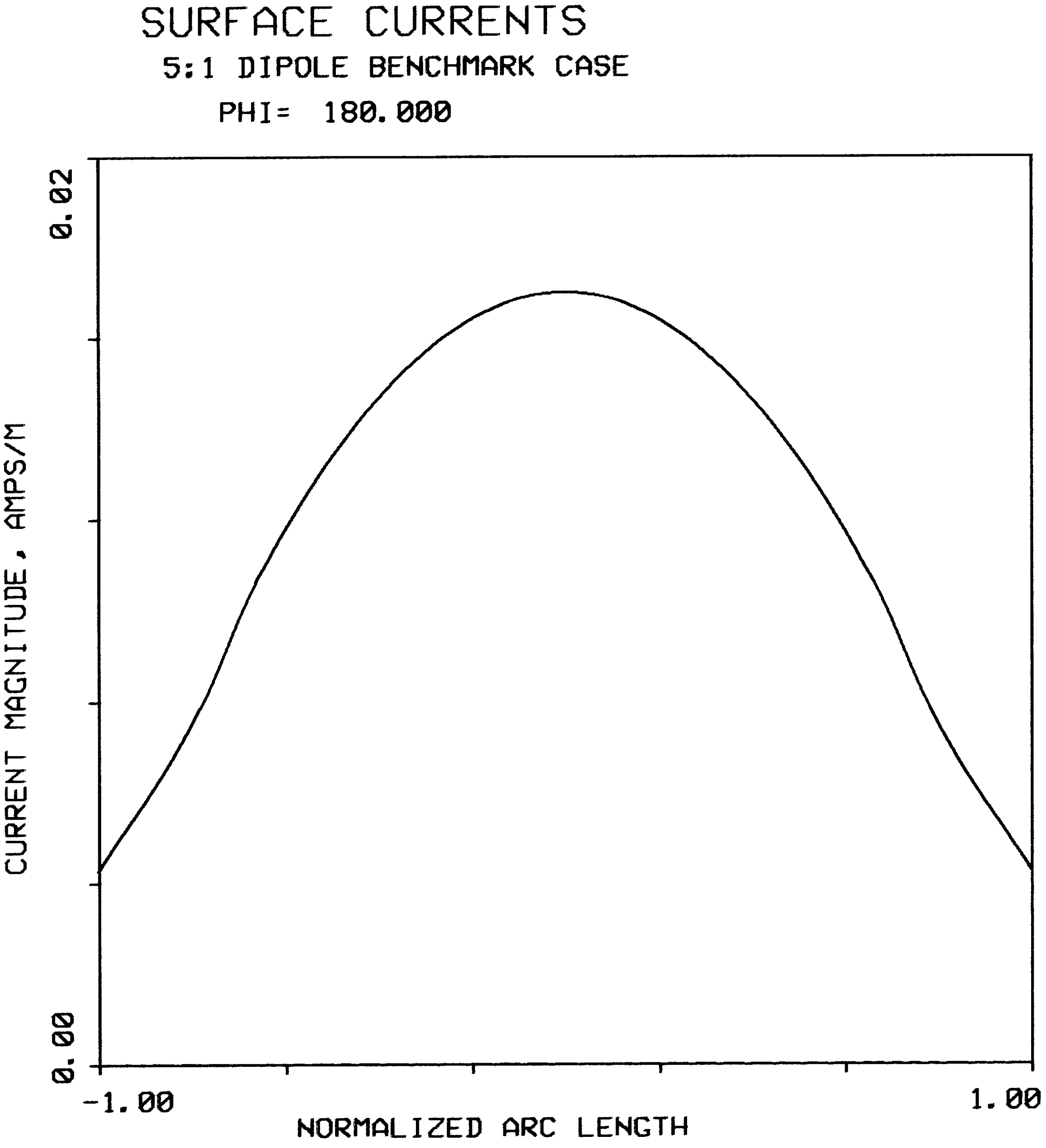
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 180.000
0.02
0.00
CURRENT MAGNITUDE, AMPS/M
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4e

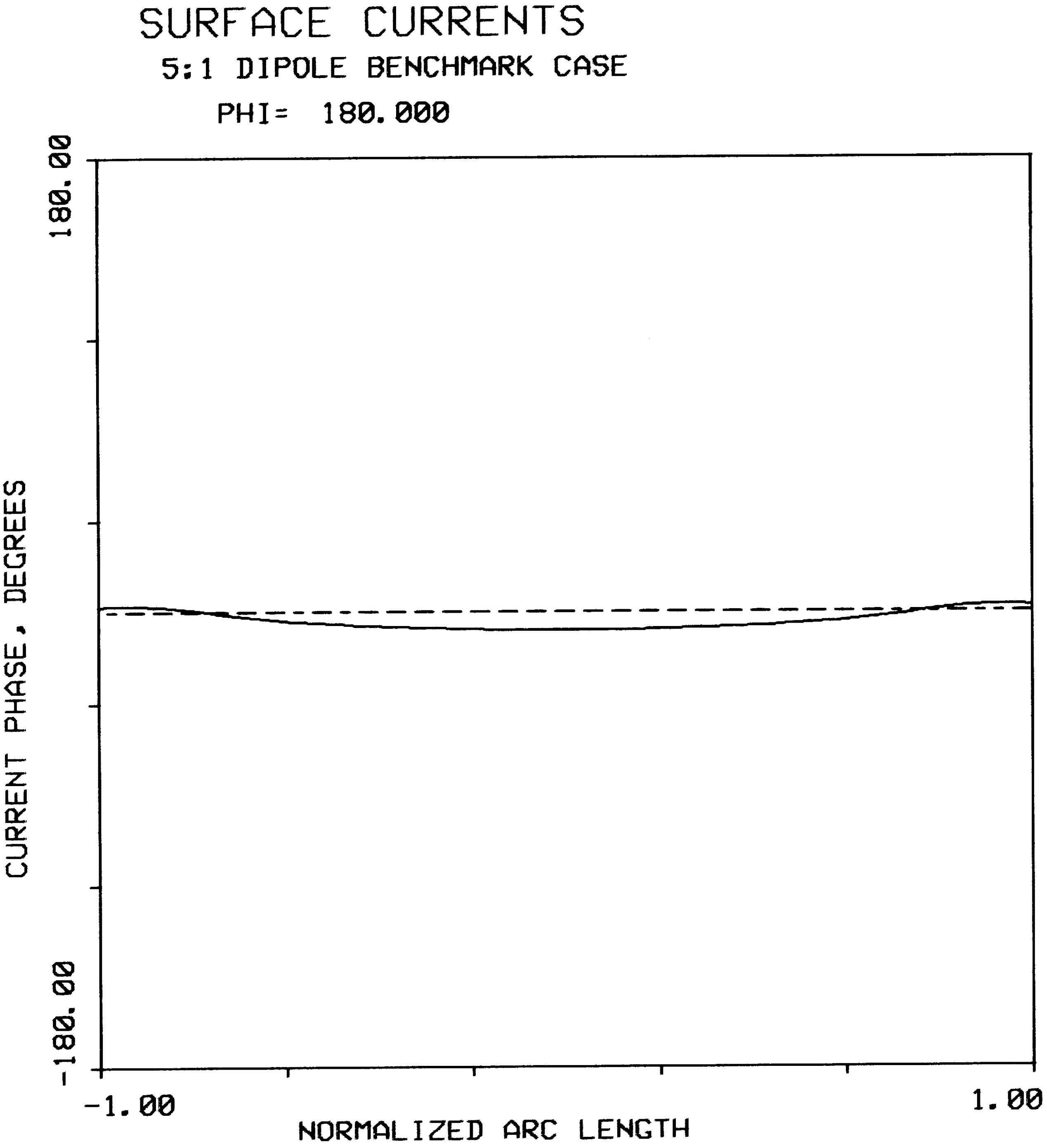
SURFACE CURRENTS
5:1 DIPOLE BENCHMARK CASE
PHI= 180.000
180.00
-180.00
CURRENT PHASE, DEGREES
-1.00
1.00
NORMALIZED ARC LENGTH

Figure 4f

Software Description Form

AN-83716

Method Generalized Multipole Technique

Author A. C. Ludwig

Address General Research Corporation
P. O. Box 6901, Santa Barbara, CA 93160

Telephone (805) 964-7724, ext. 465

Code SPEX (body of revolution version)

Description of Method

Incident field is resolved into azimuthal modes, m=0, 1, and 2 modes are used. Multipole sources are located at nine equally spaced points along the axis of the dipole, and the code solves for 166 source coefficients by matching the boundary condition in the least-squares sense. This solution is a compromise between accuracy and running time. The RMS error in the tangential E-field is 0.024 volts, which is 32 dB below the incident field, and 49 dB below the peak E-field normal to the surface. The scattered field is believed to be accurate to ± 0.003 dB.

Computer Model VAX 785, without floating point accelerator

Number of Unknowns: 166 total **Running Time:** 88 seconds

References

1. A. C. Ludwig (Ed.), "The Generalized Multipole Technique", 1989 IEEE AP-S International Symposium.
2. A. C. Ludwig, "A Comparison of Spherical Wave Boundary Value Matching Versus Integral Equation Scattering Solutions for a Perfectly Conducting Body", IEEE Transactions on Antennas and Propagation, AP-34, No. 7, July 1986, pp. 857-865.

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5:1 DIPOLE BENCHMARK CASE - SPEX BOR CODE RESULTS, JULY 1989
BASED ON COMPARING RESULTS FOR DIFFERENT COMBINATIONS OF
MULTIPOLE SOURCES IT IS BELIEVED THAT THE SCATTERED FIELD IS
ACCURATE TO WITHIN .003 DB.


FAR FIELD SCATTERED PATTERN, PHI=   0.000

                E THETA                E PHI                 MAGNITUDE
   THETA  AMPLITUDE   PHASE   AMPLITUDE   PHASE               IN DB
 90.0000   0.92183 -108.5977   0.00000    0.0000              -0.707


FAR FIELD SCATTERED PATTERN, PHI= 180.000

                E THETA                E PHI                 MAGNITUDE
   THETA  AMPLITUDE   PHASE   AMPLITUDE   PHASE               IN DB
 90.0000   0.87893 -100.4306   0.00000 -132.2641              -1.121
```

5:1 DIPOLE BENCHMARK CASE - SPEX BOR CODE RESULTS, JULY 1989. SURFACE CURRENTS ARE IN AMPS PER METER; JT2 IS THE PHI COMPONENT, AND JTI IS (PHI)X(NORMAL) COMPONENT. BASED ON COMPARING RESULTS FOR DIFFERENT COMBINATIONS OF MULTIPOLE SOURCES IT IS BELIEVED THAT CURRENTS ARE ACCURATE TO WITHIN .005E-02 AMPS PER METER.

SURFACE CURRENTS, PHI= 0.000

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	0.836846E-02	-20.429	0.000000E+00	0.000
0.02785	0.821658E-02	-20.456	0.000000E+00	0.000
0.05571	0.776333E-02	-20.517	0.000000E+00	0.000
0.08356	0.702081E-02	-20.698	0.000000E+00	0.000
0.11142	0.600405E-02	-21.082	0.000000E+00	0.000
0.13927	0.473129E-02	-21.836	0.000000E+00	0.000
0.16712	0.322597E-02	-23.645	0.000000E+00	0.000
0.19498	0.149954E-02	-31.019	0.000000E+00	0.000
0.22205	0.746410E-03	-157.563	0.000000E+00	0.000
0.24244	0.256183E-02	-177.684	0.000000E+00	0.000
0.25000	0.424504E-02	-177.912	0.000000E+00	0.000

SURFACE CURRENTS, PHI= 90.000

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	0.130389E-01	-18.672	0.846548E-06	175.568
0.02785	0.128874E-01	-18.679	0.243192E-04	-1.374
0.05571	0.124373E-01	-18.722	0.521758E-04	-1.001
0.08356	0.116929E-01	-18.779	0.866760E-04	-0.487
0.11142	0.106648E-01	-18.875	0.135794E-03	0.089
0.13927	0.936556E-02	-19.085	0.211728E-03	0.575
0.16712	0.779566E-02	-19.514	0.352742E-03	1.094
0.19498	0.588757E-02	-20.402	0.744580E-03	1.708
0.22205	0.364393E-02	-21.899	0.224996E-02	2.008
0.24244	0.173606E-02	-22.958	0.365172E-02	2.181
0.25000	0.169802E-09	2.088	0.424504E-02	2.088

SURFACE CURRENTS, PHI= 180.000

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	0.170028E-01	-7.401	0.739971E-13	-4.473
0.02785	0.168538E-01	-7.314	0.270280E-11	-141.903
0.05571	0.164090E-01	-7.033	0.503842E-11	-154.785
0.08356	0.156742E-01	-6.572	0.765197E-11	171.971
0.11142	0.146561E-01	-5.898	0.119177E-10	175.142
0.13927	0.133576E-01	-4.941	0.185656E-10	-175.671
0.16712	0.117622E-01	-3.611	0.311876E-10	-171.333
0.19498	0.975428E-02	-1.724	0.664973E-10	-168.053
0.22205	0.745139E-02	0.809	0.211640E-09	-163.897
0.24244	0.576068E-02	2.273	0.299664E-09	-167.075
0.25000	0.424504E-02	2.088	0.382053E-09	-177.912

Canonical Problem Description Form

Problem: Dipole (suggested by A.C.Ludwig) **APS/ACES-Nr:**

Method: Generalized Multipole Technique

Code: MMP Program Package (3D) **Version:** Bomholt 10.89

Description of Simulation:

3 planes of symmetry were used. The outside of the perfectly conductive dipole is simulated by Multipole sources which are located at 4 equally-spaced points along the axis of the half dipole (together 100 unknowns). The boundary conditions are matched in 51 points. This solution is a compromise between accuracy and running time.

Accuracy:

The error in the tangential E-field on the surface of the dipole is below 1% of the E-field normal to the surface and below 28dB of the incident field. Scattered field is believed to be accurate to better than within ±0.2%. The tubular numerical values in the points on the surface suggested by A.C. Ludwig are given in the data sheet.

Computer:	Running Time:
PC Toshiba 5200, 80386+80387/20MHz	31 s
Transputer, T800/20 MHz	31 s
Sun 3/260c	17 s
Sun 4/110	11 s

References:

Ch. Hafner, "Numerische Berechnung elektromagnetischer Felder," Springer, Berlin, 1987

L. Bomholt, Ch. Hafner, "A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Annual Review of Progress in Applied Computational Electromagnetics, Conference Proceedings, March, 1989 pp. 245-250.

N.Kuster,"Computations of 3D Problems of High Complexity with GMT," IEEE AP-S International Symposium, Vol. I, 1989, pp. 168-171.

Author: Niels Kuster **Date:** 7.11.89

Address:
Electromagnetics Group
Swiss Federal Inst.of Technology
8092 Zurich, Switzerland

Telephon: xx411 256 2737 **Fax:** xx411 251 2127

Data Sheet

1. Far Field Scattered Pattern

	Eteta	Ephi
PHI	AMPLITUDE	AMPLITUDE
0.0	9.21867E-0001	0.00000E+0000
180.0	8.79465E-0001	0.00000E+0000

2. Surface Currents

JT2 = phi component
JT1 = n x phi component (n outward directed unit normal)

PHI = 0.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	8.37008E-0003	159.820	7.95187E-0015	-12.612
0.02785	8.21834E-0003	159.793	5.04936E-0011	-12.150
0.05571	7.76430E-0003	159.710	9.64606E-0011	-5.041
0.08356	7.02072E-0003	159.532	1.59891E-0010	-2.408
0.11142	6.00164E-0003	159.187	2.55747E-0010	-3.997
0.13927	4.72739E-0003	158.469	4.06096E-0010	-5.277
0.16712	3.21898E-0003	156.690	6.85434E-0010	-5.738
0.19498	1.47969E-0003	149.314	1.48858E-0009	-8.752
0.22205	7.41181E-0004	21.706	4.44997E-0009	-18.759
0.24244	2.55683E-0003	2.170	5.92493E-0009	-21.472
0.25000	4.22169E-0003	2.138	6.09867E-0009	-23.596

PHI = 90.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.30424E-0002	161.470	3.89237E-0009	4.570
0.02785	1.28887E-0002	161.463	2.52078E-0005	-2.302
0.05571	1.24357E-0002	161.438	4.83541E-0005	-2.712
0.08356	1.16890E-0002	161.385	8.00600E-0005	-2.218
0.11142	1.06606E-0002	161.274	1.27661E-0004	-1.362
0.13927	9.36030E-0003	161.064	2.02131E-0004	-0.459
0.16712	7.78654E-0003	160.640	3.40760E-0004	0.430
0.19498	5.86619E-0003	159.754	7.36206E-0004	1.355
0.22205	3.63754E-0003	158.257	2.24310E-0003	2.058
0.24244	1.73550E-0003	157.103	3.66261E-0003	2.143
0.25000	6.09867E-0009	156.404	4.22169E-0003	2.138

PHI = 180.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.70122E-0002	172.718	8.30884E-0015	20.990
0.02785	1.68579E-0002	172.801	5.17697E-0011	7.301
0.05571	1.64076E-0002	173.064	9.71023E-0011	-0.397
0.08356	1.56750E-0002	173.526	1.60350E-0010	-2.028
0.11142	1.46623E-0002	174.212	2.55188E-0010	1.278
0.13927	1.33600E-0002	175.166	4.05177E-0010	4.368
0.16712	1.17571E-0002	176.489	6.85538E-0010	6.596
0.19498	9.73768E-0003	178.373	1.50076E-0009	11.380
0.22205	7.44589E-0003	-179.114	2.79981E-0009	149.820
0.24244	5.75740E-0003	-177.637	5.18968E-0009	155.738
0.25000	4.22169E-0003	-177.862	6.09867E-0009	156.404

Software Description Form

AN-83716

Method Method of Moments (Surface Integral Equation)

Author A. W. Glisson

Address
Department of Electrical Engineering
University of Mississippi
University, MS 38677

Telephone (601) 232-5353

Code DBR (Version 5.07-B)

Description of Method

The incident field and surface currents are expanded in Fourier modes. Modes 0, 1, and 2 are used in the solution. The generating contour for the body of revolution is modeled by 56 segments of approximately equal length, resulting in 111 unknown coefficients representing the surface currents for each mode. The method of moments is applied the surface integral equation formulation in which the surface currents are the unknown quantity.

Computer Model AMDAHL 470/V8

Number of Unknowns: 111

Running Time: 90 seconds

References

1. A.W. Glisson and D.R. Wilton, "Simple and efficient numerical methods for problems of electromagnetic radiation and scattering from surfaces," IEEE Trans. Antennas Propagat., vol. AP-28, no. 5, pp. 593-603, Sept. 1980.
2. A.W. Glisson and D.R. Wilton, "Simple and efficient numerical techniques for treating bodies of revolution," Tech. Rep. RADC-TR-79-22, Rome Air Development Center, Griffiss AFB, NY, March 1979.

5:1 Dipole Benchmark Case -- DBR Body of Revolution Code Results, September 1989. Data was obtained using a 111 unknown model of the dipole scatterer.

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                       BISTATIC RADAR CROSS SECTION

             (---COMPUTED USING MODES  0 THROUGH  2---)

(ALPHA-BETA REFERS TO THE ALPHA COMPONENT RESULTING DUE TO A BETA-POLARIZED
EXCITATION)

  A VALUE OF -1.E35 DBSM INDICATES A ZERO EXCITATION OR ZERO SCATTERING


    THETA         PHI         THETA-THETA              PHI-PHI


    90.00       180.00     -1.120505E+00 DBSM     -9.999996E+34 DBSM
    90.00         0.00     -7.096636E-01 DBSM     -9.999996E+34 DBSM
```

5:1 Dipole Benchmark Case -- DBR Body of Revolution Code Results, September 1989. Data was obtained using a 111 unknown model of the dipole scatterer.

Surface current data. Surface currents are in amps per meter. JP is the phi component of current. JT is the t-directed component, where t = n cross phi, with n the outward directed unit normal.

JT, phi=0.0

z	magnitude	phase
-5.9604600E-08	8.3515400E-03	1.5972780E+02
1.9999900E-02	8.2729340E-03	1.5971360E+02
4.0000000E-02	8.0382460E-03	1.5967050E+02
5.9999900E-02	7.6498970E-03	1.5958970E+02
7.9999900E-02	7.1120550E-03	1.5945550E+02
9.9999900E-02	6.4309150E-03	1.5923920E+02
1.2000000E-01	5.6131390E-03	1.5888630E+02
1.4000000E-01	4.6669020E-03	1.5827870E+02
1.6000000E-01	3.5996800E-03	1.5712380E+02
1.8000000E-01	2.4171940E-03	1.5445000E+02
2.0000000E-01	1.1071580E-03	1.4380930E+02
2.1913400E-01	6.0547100E-04	3.0802190E+01
2.4157300E-01	2.5282100E-03	2.2233730E+00
2.4619400E-01	3.1596050E-03	1.8031280E+00
2.4903900E-01	3.8428670E-03	1.8273140E+00

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          JT,  phi=90.0

     z              magnitude         phase

-5.9604600E-08  1.3053670E-02  1.6145700E+02
 1.9999900E-02  1.2975130E-02  1.6145380E+02
 4.0000000E-02  1.2740430E-02  1.6144260E+02
 5.9999900E-02  1.2351610E-02  1.6142070E+02
 7.9999900E-02  1.1811900E-02  1.6138240E+02
 9.9999900E-02  1.1125720E-02  1.6131900E+02
 1.2000000E-01  1.0297270E-02  1.6121420E+02
 1.4000000E-01  9.3296420E-03  1.6104460E+02
 1.6000000E-01  8.2214910E-03  1.6076730E+02
 1.8000000E-01  6.9581770E-03  1.6030550E+02
 2.0000000E-01  5.4565930E-03  1.5948840E+02
 2.1913400E-01  3.8660850E-03  1.5836130E+02
 2.4157300E-01  1.8037100E-03  1.5709790E+02
 2.4619400E-01  1.1635040E-03  1.5679780E+02
 2.4903900E-01  5.0258620E-04  1.5563130E+02



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          JT,  phi=180.0

     z              magnitude         phase

-5.9604600E-08  1.7053600E-02  1.7271090E+02
 1.9999900E-02  1.6976370E-02  1.7275520E+02
 4.0000000E-02  1.6745230E-02  1.7288990E+02
 5.9999900E-02  1.6362040E-02  1.7311900E+02
 7.9999900E-02  1.5829240E-02  1.7344970E+02
 9.9999900E-02  1.5149890E-02  1.7389270E+02
 1.2000000E-01  1.4326060E-02  1.7446530E+02
 1.4000000E-01  1.3357120E-02  1.7519060E+02
 1.6000000E-01  1.2235230E-02  1.7610540E+02
 1.8000000E-01  1.0932240E-02  1.7726820E+02
 2.0000000E-01  9.3282370E-03  1.7881410E+02
 2.1913400E-01  7.7065410E-03 -1.7934440E+02
 2.4157300E-01  5.8535570E-03 -1.7764510E+02
 2.4619400E-01  5.3012890E-03 -1.7751890E+02
 2.4903900E-01  4.7607720E-03 -1.7750180E+02
```

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        ------------------------------

                 JP,  phi=0.0

         z              magnitude          phase

    4.9999400E-03  0.0000000E+00  0.0000000E+00
    2.4999900E-02  0.0000000E+00  0.0000000E+00
    4.5000000E-02  0.0000000E+00  0.0000000E+00
    6.4999900E-02  0.0000000E+00  0.0000000E+00
    8.4999900E-02  0.0000000E+00  0.0000000E+00
    1.0500000E-01  0.0000000E+00  0.0000000E+00
    1.2500000E-01  0.0000000E+00  0.0000000E+00
    1.4500000E-01  0.0000000E+00  0.0000000E+00
    1.6500000E-01  0.0000000E+00  0.0000000E+00
    1.8500000E-01  0.0000000E+00  0.0000000E+00
    2.0487700E-01  0.0000000E+00  0.0000000E+00
    2.2345600E-01  0.0000000E+00  0.0000000E+00
    2.4388400E-01  0.0000000E+00  0.0000000E+00
    2.4761600E-01  0.0000000E+00  0.0000000E+00
    2.4952000E-01  0.0000000E+00  0.0000000E+00
```

```
        ------------------------------

                 JP,  phi=90.0

         z              magnitude          phase

    4.9999400E-03  4.2159400E-06 -2.7027490E+00
    2.4999900E-02  2.0145750E-05 -3.1710140E+00
    4.5000000E-02  3.8005540E-05 -2.8780490E+00
    6.4999900E-02  5.7877100E-05 -2.5673890E+00
    8.4999900E-02  8.3507130E-05 -2.0131080E+00
    1.0500000E-01  1.1505360E-04 -1.5036900E+00
    1.2500000E-01  1.5881350E-04 -8.9829170E-01
    1.4500000E-01  2.2306830E-04 -2.5858000E-01
    1.6500000E-01  3.2708400E-04  4.0018590E-01
    1.8500000E-01  5.2626640E-04  1.0619870E+00
    2.0487700E-01  1.1470090E-03  1.7398380E+00
    2.2345600E-01  2.3293860E-03  2.0740520E+00
    2.4388400E-01  3.7890400E-03  2.1348710E+00
    2.4761600E-01  4.0438820E-03  2.1292800E+00
    2.4952000E-01  4.2887070E-03  2.1847180E+00
```

```
------------------------------

          JP,  phi=180.0

     z             magnitude         phase

4.9999400E-03  0.0000000E+00  0.0000000E+00
2.4999900E-02  0.0000000E+00  0.0000000E+00
4.5000000E-02  0.0000000E+00  0.0000000E+00
6.4999900E-02  0.0000000E+00  0.0000000E+00
8.4999900E-02  0.0000000E+00  0.0000000E+00
1.0500000E-01  0.0000000E+00  0.0000000E+00
1.2500000E-01  0.0000000E+00  0.0000000E+00
1.4500000E-01  0.0000000E+00  0.0000000E+00
1.6500000E-01  0.0000000E+00  0.0000000E+00
1.8500000E-01  0.0000000E+00  0.0000000E+00
2.0487700E-01  0.0000000E+00  0.0000000E+00
2.2345600E-01  0.0000000E+00  0.0000000E+00
2.4388400E-01  0.0000000E+00  0.0000000E+00
2.4761600E-01  0.0000000E+00  0.0000000E+00
2.4952000E-01  0.0000000E+00  0.0000000E+00
```

METHOD Method of Moments with Internal Field Matching

AUTHOR Herbert L. Thal, Jr.

ADDRESS GE Astrospace, Box 8555, Philadelphia, PA 19101
(effective 11/1/89):
Microlab/FXR
10 Microlab Rd.
Livingston, NJ 07039

TELEPHONE (201) 992-7700 (215) 687-0434 (H)

CODE HT20M

DESCRIPTION of METHOD

The method is an extension of reference [1] which used (modified) sin(x)/x current basis functions and matched the on-axis field components to obtain m=0 and 1 solutions. In the present version the field matching utilizes (on a modal basis) the E and H field components tangent to circles perpendicular to the axis; no axial fields are used. The location of each matching circle is normally aligned in some manner with a current mode. Best stability is generally obtained when the circle diameters are in the range of 0.5 to 0.9 times the local body diameter, but the circles may be located on the body surface, e.g. for hollow objects. This method is in many regards similar to the generalized multipole technique [2] since converting the matching circles to loops of electric and magnetic currents and computing the fields at the surface would, due to reciprocity, leave most of the program mechanics unchanged.

COMPUTER MODEL Honeywell 6000 (time-sharing system)

NUMBER of UNKNOWNS: 30 or 24 RUNNING TIME: CPU time not known
i.e 15 or 12 each, phi and orthogonal currents

REFERENCES

[1] Thal and Garzarelli, "Radar Cross Section of Axisymmetric Objects", IEEE Transactions on AP, January 1975, pp 118-122
[2] A.C. Ludwig (Ed), "The Generalized Multipole Technique", 1989 IEEE-APS International Symposium

5:1 Dipole benchmark case 'HT20M' code results October 1989

The configuration consists of a 0.4 meter cylinder with .05 m radius hemispherical caps at each end with an incident wavelength of one meter. It was solved twice using different parameters to test convergence. In the first case 30 current modes (15 phi and 15 orthogonal) were used with the matching circles at points projected normally inward from the surface to a relative radius of 0.75; 18 integration steps per current interval were used in computing the fields due to each current mode. The second case used 24 modes, a relative radius of 0.70 and 14 integration steps. The RMS difference between the two RCS results was computed on a modal, polarization, and composite basis for aspects from 0 to 180 degrees in 10 degree steps. The largest RMS deviation was at -68 dBsm for the m=0 horizontal polarization (dipole mode); the composite was -71 dBsm; the deviation due to omitting the m=3 mode which was computed only for the 24 mode case was -114 dBsm. The program contains an internal reciprocity check of the forward scattering for diametrically opposite incidence which provides useful convergence information for objects without front-to-back symmetry (e.g. a flat-backed cone) but not for symmetrical objects. The back and forward scattering results for 90 degree incidence along with the convergence results are given below:

30 modes

```
  theta     E theta (phi=180)      E theta (phi=0)
              (dB)       (deg)      (dB)       (deg)
   90.0     -1.1249 -100.4354     -0.7106 -108.6055
```

24 modes (for comparison)

```
  theta     E theta (phi=180)      E theta (phi=0)
              (dB)       (deg)      (dB)       (deg)
   90.0     -1.1253 -100.4743     -0.7102 -108.6445
```

Comparison between 30 and 24 mode results

```
m  0 RMS(Total,HH,VV):  -70.98    -67.97 -101.50
m  1 RMS(Total,HH,VV):  -89.75    -90.22  -89.33
m  2 RMS(Total,HH,VV): -121.30   -121.61 -121.02
m  3 RMS(Total,HH,VV): -113.77   -113.90 -113.64
     theta    HH        VV      theta     HH        VV
  1     0.  -85.23    -85.23    180.    -85.23    -85.23
  2    10.  -82.92    -85.92    170.    -82.92    -85.92
  3    20.  -77.73    -88.58    160.    -77.73    -88.58
  4    30.  -73.12    -96.77    150.    -73.12    -96.77
  5    40.  -69.83    -97.99    140.    -69.83    -97.99
  6    50.  -67.63    -90.19    130.    -67.63    -90.19
  7    60.  -66.21    -91.55    120.    -66.21    -91.55
  8    70.  -65.29   -109.09    110.    -65.29   -109.06
  9    80.  -64.72    -87.93    100.    -64.72    -87.93
 10    90.  -64.52    -84.91     90.    -64.52    -84.91
      RMS(Total,HH,VV):  -71.00    -68.02  -88.59
```

5:1 Dipole benchmark case 'HT20M' code results October 1989

The surface currents in milliamps/meter are given below. The current index indicates the location relative to the points at which the current modes are defined. Integer values indicate directly computed results whereas decimal values represent cases where the currents have been interpolated parabolically from adjacent mode currents by an auxiliary program. Since the MoM program utilizes total current rather than current density, more accurate calculations at these points would require internal changes to the program. The current densities are given at equally spaced points along the perimeter starting at the center as defined for this benchmark case. Values are not given for the end (on-axis) points since a numerical indeterminacy exists here due to the manner in which the currents are defined. The program assumes an incident magnetic field intensity of 1 amp/meter which provides a convenient comparison between the actual and physical optics current densities; the conversion to 1 volt/meter has been made using eta equal to 376.73 ohms.

30 Mode results

PHI(deg)	0.0	(J ortho)		(J phi)	
I(index)	n	J (ma/m)	Phase(dg)	J (ma/m)	Phase(dg)
8.000	1	8.31962	159.547	0.00000	888.000
7.250	2	8.18585	159.455	0.00000	888.000
6.500	3	7.72750	159.383	0.00000	888.000
5.750	4	6.97980	159.214	0.00000	888.000
5.000	5	5.98309	158.750	0.00000	888.000
4.250	6	4.69057	158.071	0.00000	888.000
3.500	7	3.19646	156.249	0.00000	888.000
2.750	8	1.45002	147.903	0.00000	888.000
2.000	9	0.76220	21.442	0.00000	888.000
1.250	10	2.53290	2.198	0.00000	888.000
	11	-	-		

PHI(deg)	90.0				
I(index)	n	J (ma/m)	Phase(dg)	J (ma/m)	Phase(dg)
8.000	1	13.03879	161.276	0.00000	-172.746
7.250	2	12.88084	161.332	0.01558	174.754
6.500	3	12.43080	161.287	0.05436	177.750
5.750	4	11.68859	161.211	0.08457	178.071
5.000	5	10.65635	161.180	0.10314	178.036
4.250	6	9.36468	160.883	0.21697	179.609
3.500	7	7.79297	160.466	0.30605	-179.755
2.750	8	5.85609	159.670	0.87598	-178.400
2.000	9	3.66692	158.005	2.20039	-177.976
1.250	10	1.74374	156.783	3.52940	-177.858
	11	-	-		

PHI(deg)	180.0				
I(index)	n	J (ma/m)	Phase(dg)	J (ma/m)	Phase(dg)
8.000	1	17.03970	172.665	0.00000	888.000
7.250	2	16.87630	172.692	0.00000	888.000
6.500	3	16.43604	172.978	0.00000	888.000
5.750	4	15.70626	173.460	0.00000	888.000
5.000	5	14.67354	174.072	0.00000	888.000
4.250	6	13.39216	175.109	0.00000	888.000
3.500	7	11.78428	176.428	0.00000	888.000
2.750	8	9.75705	178.278	0.00000	888.000
2.000	9	7.50912	-179.137	0.00000	888.000
1.250	10	5.74029	-177.636	0.00000	888.000
	11	-	-		

5:1 Dipole benchmark case 'HT20M' code results October 1989

24 Mode results (for comparison)

```
PHI(deg)      0.0
 I(index)    n     J (ma/m)  Phase(dg)      J (ma/m)  Phase(dg)
   6.500     1    8.32869    159.454       0.00000    888.000
   5.900     2    8.17780    159.416       0.00000    888.000
   5.300     3    7.72683    159.299       0.00000    888.000
   4.700     4    6.98320    159.121       0.00000    888.000
   4.100     5    5.96715    158.788       0.00000    888.000
   3.500     6    4.70949    157.981       0.00000    888.000
   2.900     7    3.18734    156.061       0.00000    888.000
   2.300     8    1.41285    148.021       0.00000    888.000
   1.700     9    0.71397     26.439       0.00000    888.000
   1.100    10    2.53728      2.050       0.00000    888.000
            11       -           -
PHI(deg)     90.0
 I(index)    n     J (ma/m)  Phase(dg)      J (ma/m)  Phase(dg)
   6.500     1   13.03342    161.272       0.00000      3.526
   5.900     2   12.88140    161.269       0.05545   -177.434
   5.300     3   12.42730    161.258       0.02474    169.622
   4.700     4   11.68510    161.196       0.06876    176.069
   4.100     5   10.66424    161.062       0.18510   -179.467
   3.500     6    9.37865    160.878       0.13651    178.315
   2.900     7    7.76049    160.478       0.27710    179.574
   2.300     8    5.78035    159.526       0.97041   -178.346
   1.700     9    3.74091    158.206       2.06567   -177.954
   1.100    10    1.77771    156.508       3.53466   -177.864
            11       -           -
PHI(deg)    180.0
 I(index)    n     J (ma/m)  Phase(dg)      J (ma/m)  Phase(dg)
   6.500     1   17.02743    172.603       0.00000    888.000
   5.900     2   16.87800    172.685       0.00000    888.000
   5.300     3   16.43132    172.940       0.00000    888.000
   4.700     4   15.69993    173.412       0.00000    888.000
   4.100     5   14.68663    174.116       0.00000    888.000
   3.500     6   13.40442    175.058       0.00000    888.000
   2.900     7   11.73730    176.376       0.00000    888.000
   2.300     8    9.63442    178.348       0.00000    888.000
   1.700     9    7.58550   -179.418       0.00000    888.000
   1.100    10    5.80090   -177.566       0.00000    888.000
            11       -           -
```