6 Types of Canonical Problems Based on One Geometrical Model

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Abstract - **Six canonical problems are hereafter proposed, which represent different types of EMF problems with bodies in the size of wavelength. These are lossy and coated bodies radiated by a plane wave and conductive and lossy bodies radiated either by a concentrated or by a more distributed near field source. All cases are based on the same geometrically simple body of revolution. These canonical problems can therefore be used as benchmarks for the applicability and efficiency for both BOR as well as full 3D codes and only very simple input and output routines are required. The problems have been solved with the MMP3D program package. Tabular field values in sensitive points and an estimation of accuracy are given in the data sheet to each case. It was attempted to "optimize" the compromise between running time and accuracy.**

Introduction

Different numerical techniques like FDTD, GMT, MoM etc. have different preferences for certain types of EMF problems. At the first moment, artificial bodies which combine different types of problems would be well appropriate benchmarks for testing the capabilities and efficiency of the codes. The problem is that most of these 3D bodies would already stretch the capabilities of the existing codes. At least, the validation of the results with an estimation of accuracy would be very difficult. Additional handicaps for complex problems are the necessity of powerful computers and large RAM's, which makes the computation of an optimal solution extensive in both time and cost. A lot of experience in modeling these particular types of problems is also necessary because certain combinations of bodies can often be efficiently simulated only by certain "tricks". Therefore, very complex problems can be used to demonstrate the present capability of a code rather than are useful benchmarks.

On the other hand, canonical problems of simple bodies imply the risk that codes which perform well for simple problems may not be applicable for composed bodies. Nevertheless, the 6 hereafter proposed problems are all based on the same geometrically simple cylinder of revolution which is adopted from Ludwig [1]. This has several advantages: BOR as well as 3D codes can be tested on accuracy and efficiency on small computers respectively with short running times and only very simple input and output routines are required. The benchmarks are not only valuable for sophisticated but also for experimental codes.

Definition of the problems

As previously mentioned, all bodies are based on the same cylinder and all sources are operating at the resonance wavelength of 1m. The figures of the model given to each case are supposed to be self-explaining.

Lossy dielectric cylinder:
In contrast to Ludwig's case the material of the cylinder has similar electrical properties as muscle tissue. The incident plane wave have an amplitude of 1V/m and a phase of zero degrees in the plane x=0 (for additional details see figure A1).

Coated cylinder:
Three coatings of different thickness have been calculated because the numerical approach for thinner or thicker layers could be different. The same incident plane wave as above has been used

Conductive or lossy cylinder radiated by an infinite small dipole:
The perfectly conductive or muscle tissue-like cylinder is radiated by an infinite small dipole placed on the x-axis 10 cm in front of the surface. The field equations are given in the figures C1, D1. The horizontal radiated power (plane z=0) without scatterer multiplied with the square of the distance from the source was normalized to 1W.

Conductive or lossy cylinder radiated by a half wavelength dipole:
To simplify the benchmark the interaction between the half wavelength antenna and the dipole was not taken

into account. The length of the antenna is only 48cm, because the diameter of the antenna could not be reduced to less than 5mm with the present code. The computed feedpoint impedance is 72 Ohm. It is expected that the given field values differ only slightly compared to thinner antennas. The horizontal radiated power of the dipole source without scatterer multiplied with the square of the distance to the source was normalized to 1W. The present MMP3D code is not efficient in computing the fields of the half wavelength dipole, which almost doubled the running time. This will be improved in the next version.

Results

The problems are solved with the latest version of the MMP3D program package (Bomholt Oct. 89) [2]. An attempt was made to find a optimal compromise between running time and accuracy. The running times are given for different types of computers: Pc's, SUN's and Transputers (INMOS T800). The parallel code version written for the transputers, which results in an increase in efficiency of a factor about 6 to 8 for the 9 transputer board, would only take full effect for larger problems [3]. One transputer is about 3 times faster than a 80386+80387 machine.

To have a good test of the accuracy tabular field values are given in sensitive points. The set of test points for the conductive cylinders was adopted from Ludwig [1]: forward and backscattered field and the surface currents along three cuts. For the lossy cylinders the specific absorption rate (SAR) within the cylinder in a set of points and the maximum and average SAR are listed instead of the surface currents. In addition to these data sheets, plots of the results are given for illustration.

Accuracy

The internal check routines which are described in [4] are used to validate the solution and to estimate the accuracy. Additional runs in which the location and the order of the multipole expansions were varied, gave more confidence in the results. Nevertheless systematical errors or trivial errors in the output routines can not be totally excluded because these cases have not been verified by others yet. This publication is an invitation for confirmation.

Conclusion

The canonical cases proposed in this paper can be considered as basic but non trivial benchmarks for scattering problems with far and near field radiations. They allow to test the efficiency and the achievable accuracy of the different codes for these types of EMF problems. More complex problems with composed bodies will follow.

References

[1] Ludwig A.C., Kuster N., Glisson A., Thal H., "5:1 Dipole Benchmark Case, " (to be published)

[2] Bomholt L., Hafner Ch., "Computation of 3D Electromagnetic Fields on PC's", 5th Annual Review of Progress in Applied Computational Electromagnetics (ACES), Conference Proceedings, March, 1989

[3] Hafner Ch, "Parallel Computations of Electromagnetic Fields on PC's using Transputers," IEEE AP-S Symposium, San Jose, June, 1989

[4] Kuster N., "Internal Check Routines of the MMP Program Packages for Model Validation," IEEE AP-S Workshop on Software Validation, San Jose, June, 1989

Canonical Problem Description Form

Problem: Lossy Dielectric Dipole (see figure A1)

Method: Generalized Multipole Technique

Code: MMP3D Program Package **Version:** Bomholt 10.89

Description of Simulation:
3 planes of symmetry were used. The domain outside of the lossy dipole is simulated by Multipole sources which are located at four equally-spaced points along the axis of the half dipole and the domain inside by a single Multipole (Bessel-Expansions) at the origin of the coordinate system (in total 127 unknowns). The boundary conditions are matched in 74 points. This solution is a compromise between accuracy and running time.

Accuracy:
Based on comparisons of the results for different combinations of multipole sources it is believed that the computed specific absorption rate (SAR) is accurate to within ±2% and the scattered field within ±0.2%. The computed average SAR is 0.0438 W/m3 and the peak SAR 0.131W/m3. Further numerical values for comparisons are given in the data sheet.

Computer:	Running Time:
PC Toshiba 5200, 80386+80387/20MHz	79 s
Sun 3/260c	37 s
Sun 4/110	26 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

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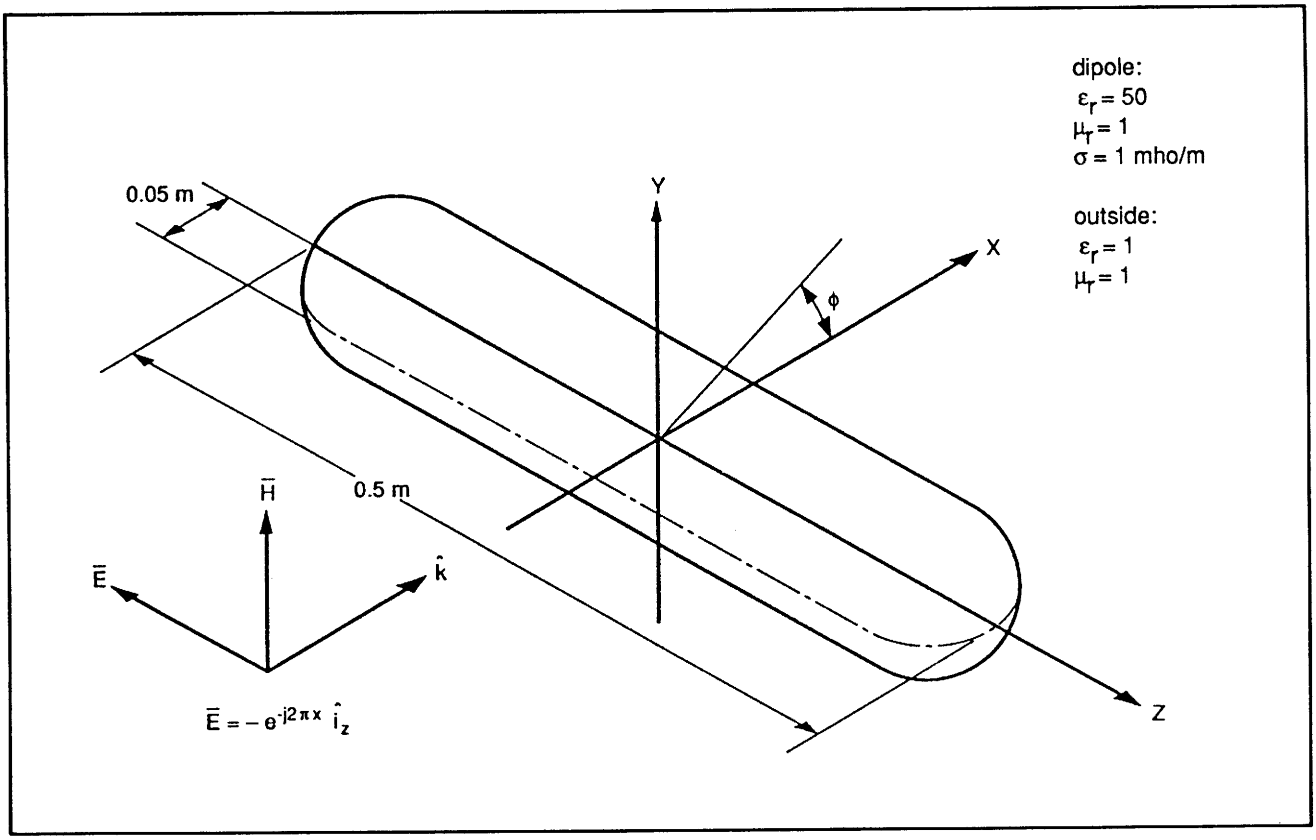

Figure A1: Lossy Dielectric Dipole

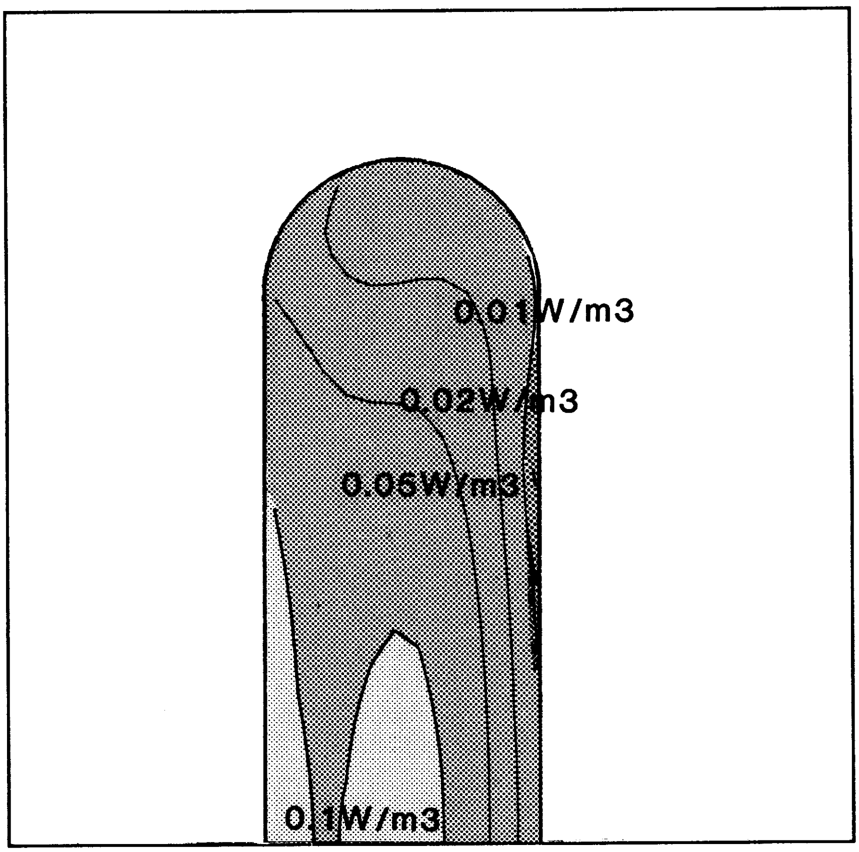

Figure A2: Specific Absorbtion Rate (SAR)

Data Sheet

1. Far field scattered pattern

PHI	THETA	E THETA [V/m] AMPLITUDE	E PHI [V/m] AMPLITUDE
0.0	90.0	6.98491E-0001	0.00000E+0000
180.0	90.0	5.92323E-0001	0.00000E+0000

2. Absorption

The average SAR was calculated by averaging the values in points of a 0.5 cm grid (front-lower-right corner: -0.0475,-0.0475, -0.2475). The whole-body average SAR was 0.0438 W/m^3 and the highest value found on that grid was 0.131 W/m^3 (-0.0475,0.0125, 0.025).

PHI = 0.000

X	Y	Z	SAR [W/m^3]
0.03000	0.00000	0.00000	4.28196E-0002
0.03000	0.00000	0.02500	4.20131E-0002
0.03000	0.00000	0.05000	3.94340E-0002
0.03000	0.00000	0.07500	3.55878E-0002
0.03000	0.00000	0.10000	3.07883E-0002
0.03000	0.00000	0.12500	2.56112E-0002
0.03000	0.00000	0.15000	2.20972E-0002
0.03000	0.00000	0.17500	2.00425E-0002
0.03000	0.00000	0.20000	1.70359E-0002
0.02210	0.00000	0.22100	1.49263E-0002
0.00000	0.00000	0.23000	1.53861E-0002

PHI = 90.000

X	Y	Z	SAR [W/m^3]
0.00000	0.03000	0.00000	5.77620E-0002
0.00000	0.03000	0.02500	5.63898E-0002
0.00000	0.03000	0.05000	5.32102E-0002
0.00000	0.03000	0.07500	4.83471E-0002
0.00000	0.03000	0.10000	4.20110E-0002
0.00000	0.03000	0.12500	3.42331E-0002
0.00000	0.03000	0.15000	2.66103E-0002
0.00000	0.03000	0.17500	1.86053E-0002
0.00000	0.03000	0.20000	1.24335E-0002
0.00000	0.02210	0.22100	1.27576E-0002
0.00000	0.00000	0.23000	1.53861E-0002

PHI = 180.000

X	Y	Z	SAR [W/m^3]
-0.03000	0.00000	0.00000	9.00805E-0002
-0.03000	0.00000	0.02500	8.85436E-0002
-0.03000	0.00000	0.05000	8.49414E-0002
-0.03000	0.00000	0.07500	7.96857E-0002
-0.03000	0.00000	0.10000	7.27747E-0002
-0.03000	0.00000	0.12500	6.45106E-0002
-0.03000	0.00000	0.15000	5.48129E-0002
-0.03000	0.00000	0.17500	4.15417E-0002
-0.03000	0.00000	0.20000	2.61102E-0002
-0.02210	0.00000	0.22100	1.77836E-0002
-0.00000	0.00000	0.23000	1.53861E-0002

Canonical Problem Description Form

Problem: Coated Dipole (see figure B1)

Method: Generalized Multipole Technique

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

Description of Simulation:
3 planes of symmetry were used. 3 different thicknesses of the coating (d=10,5,2.5mm) are calculated, all with the same location and order of the expansions. The domain outside of the coated dipole is simulated by Multipole sources which are located at four equally-spaced points along the axis of the half dipole and the thin layer by four equally-spaced multipoles plus a single multipole (Bessel-Expansions) in the center of the axis (in total 236 unknowns). The boundary conditions are matched in 139 points. This solution is a compromise between accuracy and running time.

Accuracy:
Based on comparisons of the results for different combinations of multipole sources it is believed that the field on the inner (metallic) surface is accurate to within ±3% and the scattered field within ±0.6% (see data sheet).

Computer:	Running Time:
PC Toshiba 5200, 80386+80387/20MHz	571 s
9 Transputer,9xT800/20 MHz	112 s
Sun 3/260c	203 s
Sun 4/110	173 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

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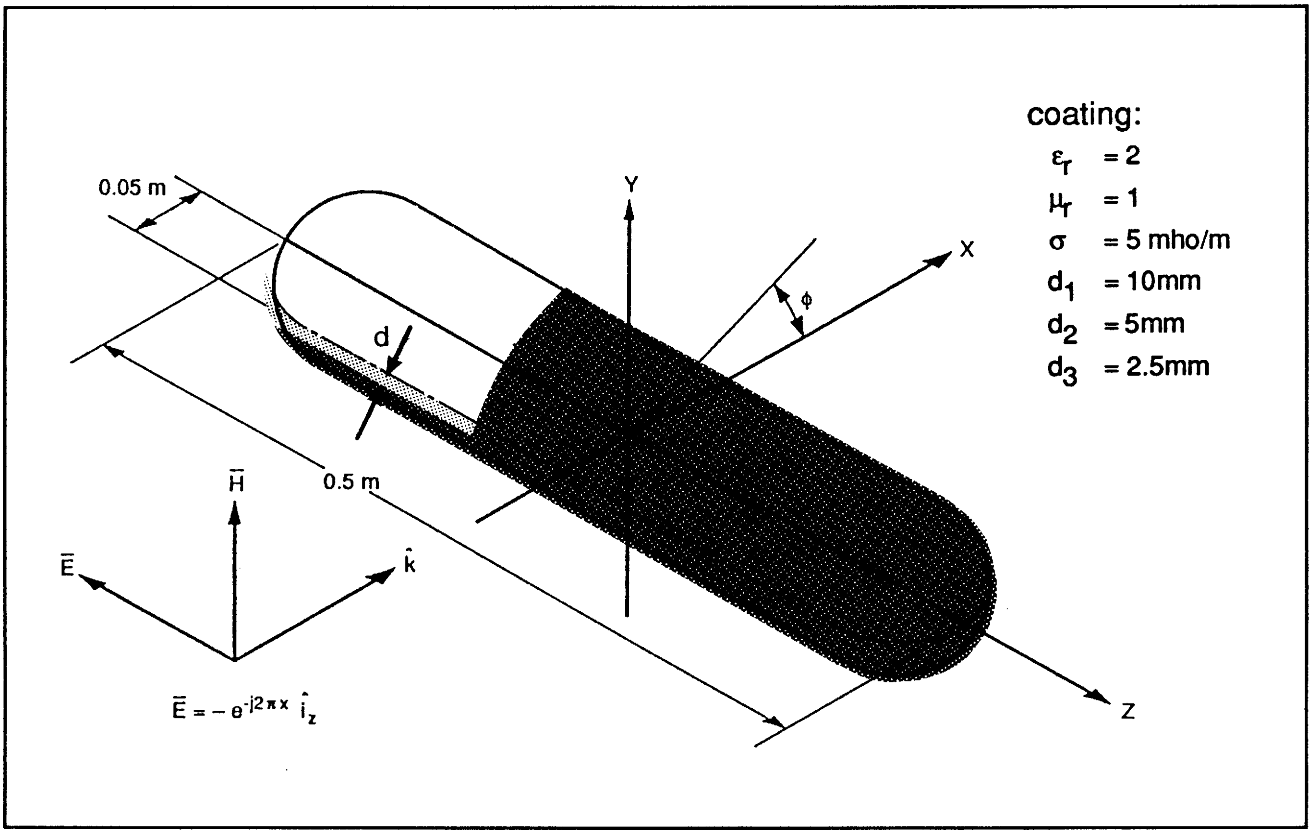

Figure B1: Coated Dipole

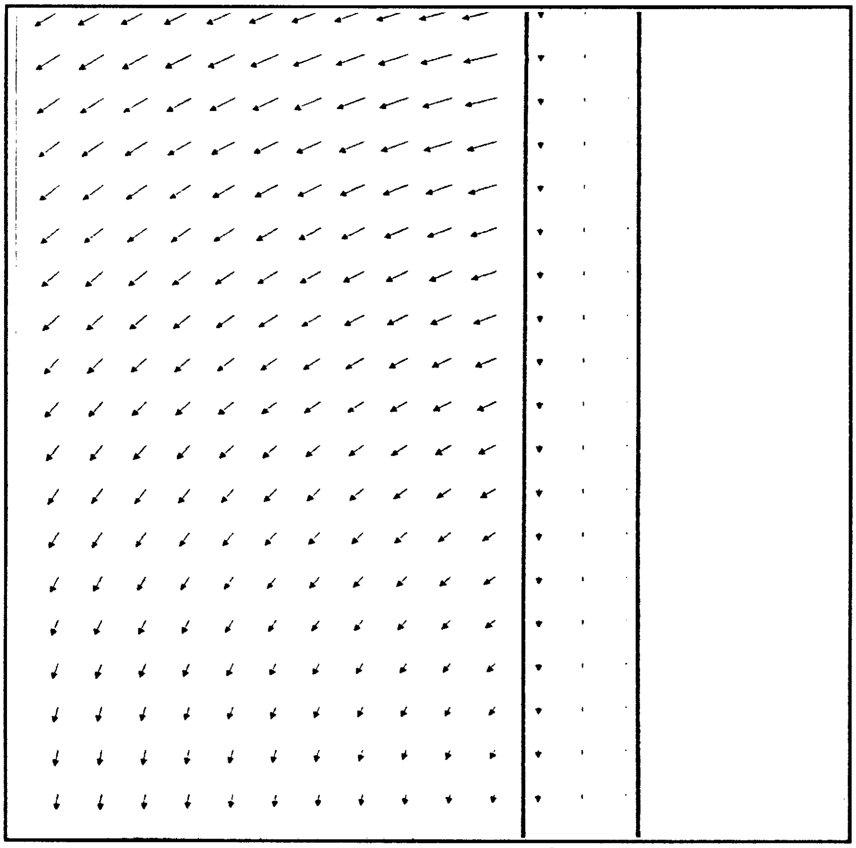

Figure B2: E-Field (zoomed picture)

Data Sheet (10mm coating)

1. Far Field Scattered Pattern

PHI	Eteta AMPLITUDE	Ephi AMPLITUDE
0.0	8.35678E-0001	0.00000E+0000
180.0	7.56814E-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	6.23588E-0003	108.962	2.15658E-0015	-120.141
0.02785	6.11527E-0003	108.916	7.44727E-0011	-50.196
0.05571	5.74193E-0003	108.269	3.08816E-0010	-38.442
0.08356	5.18621E-0003	107.173	2.22762E-0010	-35.269
0.11142	4.39321E-0003	105.606	1.40510E-0010	-19.439
0.13927	3.46216E-0003	102.119	4.37509E-0010	1.973
0.16712	2.36002E-0003	95.282	9.47514E-0010	-30.533
0.19498	1.34020E-0003	73.879	1.58408E-0009	-40.125
0.22205	1.29376E-0003	-3.567	4.03529E-0009	-51.222
0.24244	2.66634E-0003	-25.518	4.97741E-0009	-52.650
0.25000	3.80603E-0003	-24.073	4.07613E-0009	-52.125

PHI = 90.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.02420E-0002	118.917	1.38908E-0009	-67.816
0.02785	1.01809E-0002	118.818	2.12713E-0005	88.350
0.05571	9.81953E-0003	118.829	9.91803E-0005	-37.462
0.08356	9.21036E-0003	118.927	7.99162E-0005	-25.944
0.11142	8.46851E-0003	119.354	1.03820E-0004	-32.996
0.13927	7.49714E-0003	118.697	2.27660E-0004	-4.364
0.16712	6.17490E-0003	118.604	4.30203E-0004	-25.359
0.19498	4.90590E-0003	120.230	7.39055E-0004	-27.904
0.22205	3.10177E-0003	120.999	2.16919E-0003	-25.818
0.24244	1.35982E-0003	126.587	3.41390E-0003	-25.413
0.25000	4.07613E-0009	127.875	3.80603E-0003	-24.073

PHI = 180.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.32604E-0002	134.549	4.57022E-0015	-45.887
0.02785	1.31985E-0002	134.586	1.49266E-0010	107.637
0.05571	1.28092E-0002	135.040	8.79838E-0011	-34.020
0.08356	1.21929E-0002	135.901	1.06099E-0010	-6.025
0.11142	1.15552E-0002	137.266	2.80577E-0010	-39.740
0.13927	1.06295E-0002	138.036	4.78247E-0010	-10.159
0.16712	9.28770E-0003	139.799	7.81567E-0010	-19.081
0.19498	8.04583E-0003	144.651	1.44614E-0009	-14.512
0.22205	6.41347E-0003	149.747	2.25650E-0009	103.826
0.24244	5.08244E-0003	155.641	4.00602E-0009	124.766
0.25000	3.80603E-0003	155.927	4.07613E-0009	127.875

Data Sheet (5mm coating)

1. Far Field Scattered Pattern

PHI	Eteta AMPLITUDE	Ephi AMPLITUDE
0.0	8.88203E-0001	0.00000E+0000
180.0	8.29561E-0001	0.00000E+0000

2. Surface Currents

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

PHI = 0.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	7.81349E-0003	140.381	2.58069E-0015	-98.092
0.02785	7.66109E-0003	140.263	1.12904E-0010	-44.076
0.05571	7.22041E-0003	139.909	2.90910E-0010	-8.284
0.08356	6.52771E-0003	139.349	2.43490E-0010	-30.406
0.11142	5.57642E-0003	138.226	1.79426E-0010	-1.363
0.13927	4.39982E-0003	136.047	3.37528E-0010	11.501
0.16712	3.03034E-0003	131.488	9.24701E-0010	-11.620
0.19498	1.56955E-0003	116.471	1.59225E-0009	-21.150
0.22205	1.11930E-0003	22.142	4.36560E-0009	-28.891
0.24244	2.73644E-0003	-3.530	5.90905E-0009	-35.394
0.25000	4.24252E-0003	-5.391	5.47846E-0009	-35.950

PHI = 90.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	1.23289E-0002	146.345	1.73332E-0009	-51.024
0.02785	1.22142E-0002	146.318	1.66481E-0005	147.239
0.05571	1.17926E-0002	146.281	9.45255E-0005	0.949
0.08356	1.10794E-0002	146.276	8.95286E-0005	-21.672
0.11142	1.01229E-0002	146.371	1.29583E-0004	-17.753
0.13927	8.92046E-0003	145.938	2.02603E-0004	8.505
0.16712	7.39873E-0003	145.706	4.40187E-0004	-6.899
0.19498	5.73225E-0003	145.582	7.39040E-0004	-9.094
0.22205	3.50908E-0003	144.379	2.26862E-0003	-4.768
0.24244	1.65184E-0003	143.626	3.67961E-0003	-6.485
0.25000	5.47846E-0009	144.050	4.24252E-0003	-5.391

PHI = 180.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	1.59647E-0002	159.719	5.50853E-0015	-30.959
0.02785	1.58728E-0002	159.837	1.78684E-0010	140.123
0.05571	1.54274E-0002	160.169	1.02143E-0010	28.149
0.08356	1.47096E-0002	160.754	1.23067E-0010	-4.197
0.11142	1.38035E-0002	161.795	3.49734E-0010	-26.080
0.13927	1.26270E-0002	162.670	4.73299E-0010	6.372
0.16712	1.10999E-0002	164.286	8.42505E-0010	-1.720
0.19498	9.37358E-0003	167.148	1.43776E-0009	4.280
0.22205	7.14749E-0003	170.773	2.61213E-0009	130.670
0.24244	5.64788E-0003	172.935	4.96829E-0009	142.106
0.25000	4.24252E-0003	174.609	5.47846E-0009	144.050

Data Sheet (2.5mm coating)

1. Far Field Scattered Pattern

PHI	Eteta AMPLITUDE	Ephi AMPLITUDE
0.0	9.07976E-0001	0.00000E+0000
180.0	8.57252E-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	8.15338E-0003	151.903	2.43766E-0015	-97.819
0.02785	7.99282E-0003	151.776	8.70210E-0011	-47.492
0.05571	7.53906E-0003	151.553	2.54918E-0010	-1.048
0.08356	6.81548E-0003	151.244	2.39679E-0010	-26.431
0.11142	5.82966E-0003	150.423	1.66098E-0010	7.637
0.13927	4.59166E-0003	148.980	2.92848E-0010	12.862
0.16712	3.15605E-0003	145.750	8.67729E-0010	-6.730
0.19498	1.54856E-0003	133.950	1.57031E-0009	-15.764
0.22205	9.32503E-0004	26.349	4.40393E-0009	-20.952
0.24244	2.63976E-0003	1.588	6.06032E-0009	-27.722
0.25000	4.24898E-0003	0.602	5.74457E-0009	-26.214

PHI = 90.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.27561E-0002	155.758	1.79156E-0009	-46.988
0.02785	1.26204E-0002	155.730	2.72893E-0005	175.049
0.05571	1.21887E-0002	155.685	8.10900E-0005	9.351
0.08356	1.14573E-0002	155.658	9.01465E-0005	-15.572
0.11142	1.04491E-0002	155.639	1.27846E-0004	-13.525
0.13927	9.19808E-0003	155.333	1.90616E-0004	10.580
0.16712	7.64509E-0003	154.977	4.13345E-0004	-1.868
0.19498	5.84814E-0003	154.393	7.24165E-0004	-3.420
0.22205	3.60405E-0003	153.088	2.25134E-0003	1.463
0.24244	1.69917E-0003	152.070	3.66572E-0003	-0.667
0.25000	5.74457E-0009	153.786	4.24898E-0003	0.602

PHI = 180.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	1.65711E-0002	168.059	5.93431E-0015	-28.427
0.02785	1.64619E-0002	168.174	1.82947E-0010	156.286
0.05571	1.60233E-0002	168.471	8.67408E-0011	41.378
0.08356	1.52823E-0002	168.970	1.32996E-0010	4.281
0.11142	1.43113E-0002	169.853	3.61290E-0010	-23.079
0.13927	1.30686E-0002	170.786	4.69616E-0010	9.162
0.16712	1.15191E-0002	172.198	7.92069E-0010	3.461
0.19498	9.61477E-0003	174.469	1.40314E-0009	10.419
0.22205	7.33610E-0003	177.664	2.72095E-0009	140.846
0.24244	5.72170E-0003	179.283	5.12383E-0009	150.890
0.25000	4.24898E-0003	-179.398	5.74457E-0009	153.786

Canonical Problem Description Form

Problem: Conductive Dipole radiated by a infinte small dipole nearby (see figure C1)

Method: Generalized Multipole Technique

Code: MMP3D Program Package **Version:** Bomholt 10.89

Description of Simulation:

3 planes of symmetry were used. The scattered field of the perfectly conductive dipole is simulated by multipole expansions which are located at 3 equally-spaced points along the axis of the half dipole (in total 202 unknowns). The boundary conditions are matched in 143 points.

Accuracy:

Based on comparisons of the results for different combinations of multipole sources it is believed that the field on the surface is accurate to better than within ±1% and the scattered field within ±0.2% (see data sheet). This solution is a compromise between accuracy and running time.

Computer:	Running Time:
PC Toshiba 5200, 80386+80387/20MHz	205 s
Sun 3/260c	103 s
Sun 4/110	68 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

N. Kuster, R. Ballisti, "MMP Method Simulation of Antennae with Scattering Objects in the Closer Nearfield," IEEE Trans. on Magnetics, Vol.25, No.4, July 1989, pp. 2881-2884

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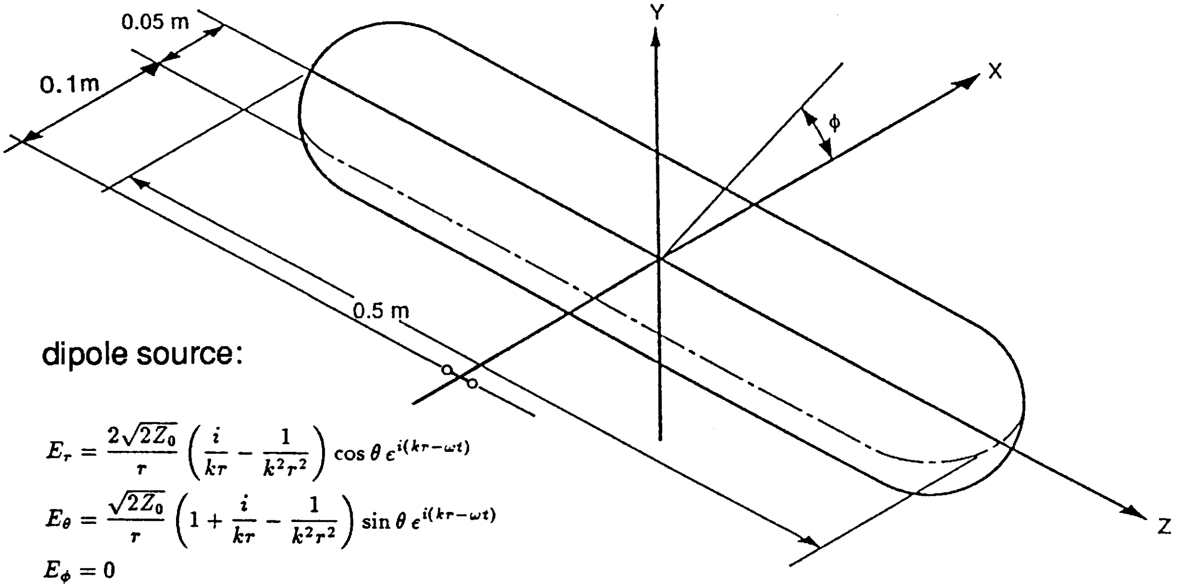

dipole source:

$$E_r = \frac{2\sqrt{2Z_0}}{r}\left(\frac{i}{kr} - \frac{1}{k^2r^2}\right)\cos\theta\, e^{i(kr-\omega t)}$$

$$E_\theta = \frac{\sqrt{2Z_0}}{r}\left(1 + \frac{i}{kr} - \frac{1}{k^2r^2}\right)\sin\theta\, e^{i(kr-\omega t)}$$

$$E_\phi = 0$$

$$H_r = 0$$

$$H_\theta = 0$$

$$H_\phi = \sqrt{\frac{2}{Z_0}}\frac{1}{r}\left(1 + \frac{1}{ikr}\right)\sin\theta\, e^{i(kr-\omega t)}$$

Figure C1: Perfectly conductive dipole radiated by a infinte small dipole

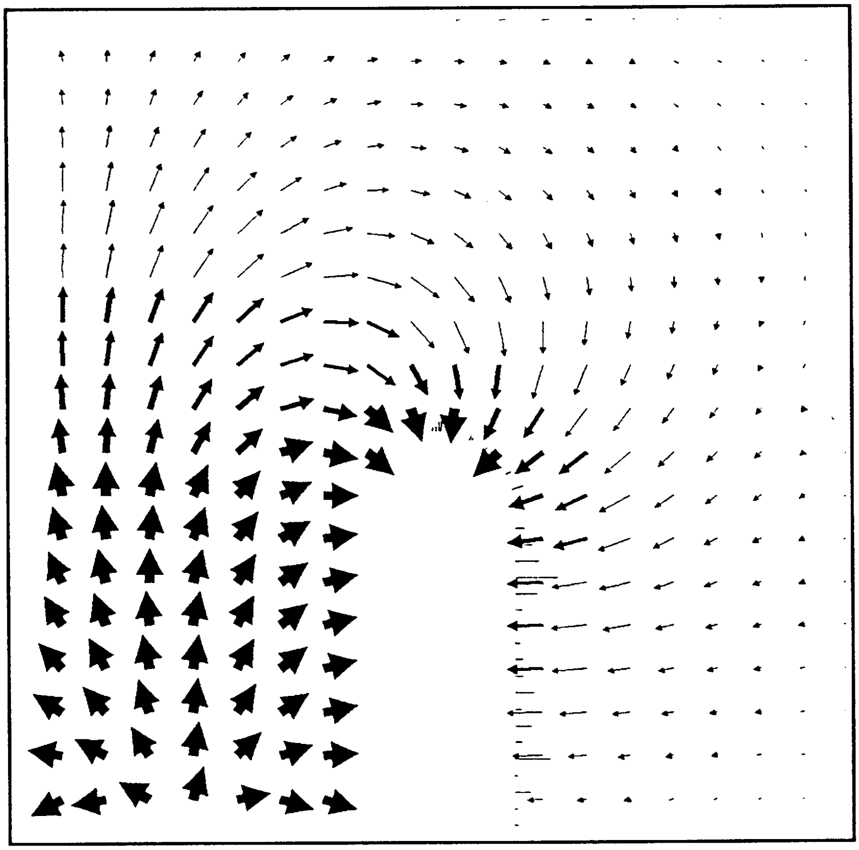

Figure C2: E-Field

Data Sheet

1. Far Field Scattered Pattern

PHI	Eteta AMPLITUDE	Ephi AMPLITUDE
0.0	8.61069E+0001	0.00000E+0000
180.0	8.02742E+0001	0.00000E+0000

2. Surface Currents

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

PHI = 0.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	4.75510E-0001	-46.064	0.00000E+0000	0.000
0.02785	4.65478E-0001	-46.397	0.00000E+0000	0.000
0.05571	4.46487E-0001	-45.971	0.00000E+0000	0.000
0.08356	4.11144E-0001	-45.703	0.00000E+0000	0.000
0.11140	3.58183E-0001	-45.807	0.00000E+0000	0.000
0.13930	2.95104E-0001	-45.490	0.00000E+0000	0.000
0.16710	2.20566E-0001	-44.705	0.00000E+0000	0.000
0.19500	1.33968E-0001	-42.140	0.00000E+0000	0.000
0.22210	3.44226E-0002	-21.967	0.00000E+0000	0.000
0.24240	6.97984E-0002	120.562	0.00000E+0000	0.000
0.25000	1.73228E-0001	130.825	0.00000E+0000	0.000

PHI = 90.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	9.87190E-0001	-32.082	0.00000E+0000	0.000
0.02785	9.67744E-0001	-32.431	8.29323E-0004	90.429
0.05571	9.12146E-0001	-33.193	6.74343E-0003	166.074
0.08356	8.24191E-0001	-34.687	7.69327E-0003	146.299
0.11140	7.20530E-0001	-36.444	8.19669E-0003	132.295
0.13930	6.05816E-0001	-38.186	8.95070E-0003	130.960
0.16710	4.80908E-0001	-40.186	1.57403E-0002	134.082
0.19500	3.45868E-0001	-42.492	3.48068E-0002	135.415
0.22210	2.01395E-0001	-44.892	1.03775E-0001	135.187
0.24240	9.25913E-0002	-46.405	1.55558E-0001	132.084
0.25000	0.00000E+0000	0.000	1.73228E-0001	130.825

PHI = 180.0

Z	JT1 AMPLITUDE	JT1 PHASE	JT2 AMPLITUDE	JT2 PHASE
0.00000	4.13273E+0000	-10.292	0.00000E+0000	0.000
0.02785	3.81594E+0000	-11.047	0.00000E+0000	0.000
0.05571	3.09647E+0000	-13.252	0.00000E+0000	0.000
0.08356	2.38077E+0000	-16.494	0.00000E+0000	0.000
0.11140	1.80244E+0000	-20.443	0.00000E+0000	0.000
0.13930	1.37031E+0000	-24.530	0.00000E+0000	0.000
0.16710	1.03434E+0000	-28.642	0.00000E+0000	0.000
0.19500	7.43560E-0001	-32.661	0.00000E+0000	0.000
0.22210	4.76606E-0001	-37.856	0.00000E+0000	0.000
0.24240	2.99007E-0001	-43.308	0.00000E+0000	0.000
0.25000	1.73228E-0001	-49.175	0.00000E+0000	0.000

Canonical Problem Description Form

Problem: Lossy Dipole radiated by a infinte small dipole nearby (see figure D1)

Method: Generalized Multipole Technique

Code: MMP3D Program Package **Version:** Bomholt 10.89

Description of Simulation:

3 planes of symmetry were used. The scattered field of the lossy dipole is simulated by multipoles located at 3 equally-spaced points along the axis of the half dipole and the domain inside the cylinder by a single ansatz in the origin of the coordinate system (in total 302 unknowns). The boundary conditions are matched in 177 points. This solution is a compromise between accuracy and running time.

Accuracy:

Based on comparisons of results for different combinations of multipole sources it is believed that the specific absorption rate (SAR) is accurate to within ±2% and the scattered field within ±0.2% (see data sheet).

Computer:	Running Time:
PC Toshiba 5200, 80386+80387/20MHz	684 s
Sun 3/260c	310 s
Sun 4/110	212 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

N. Kuster, R. Ballisti, "MMP Method Simulation of Antennae with Scattering Objects in the Closer Nearfield," IEEE Trans. on Magnetics, Vol.25, No.4, July 1989, pp. 2881-2884

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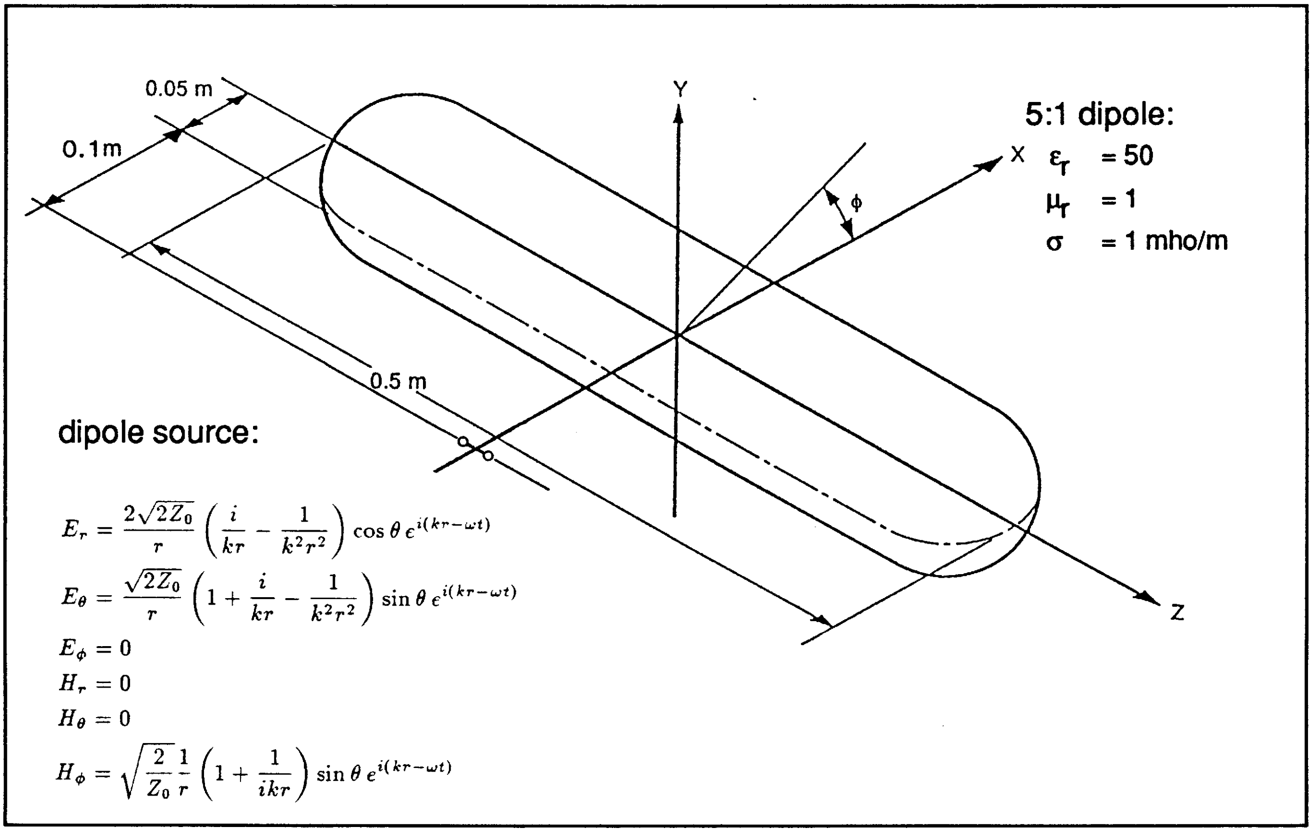

Figure D1: Lossy dipole radiated by a infinte small dipole

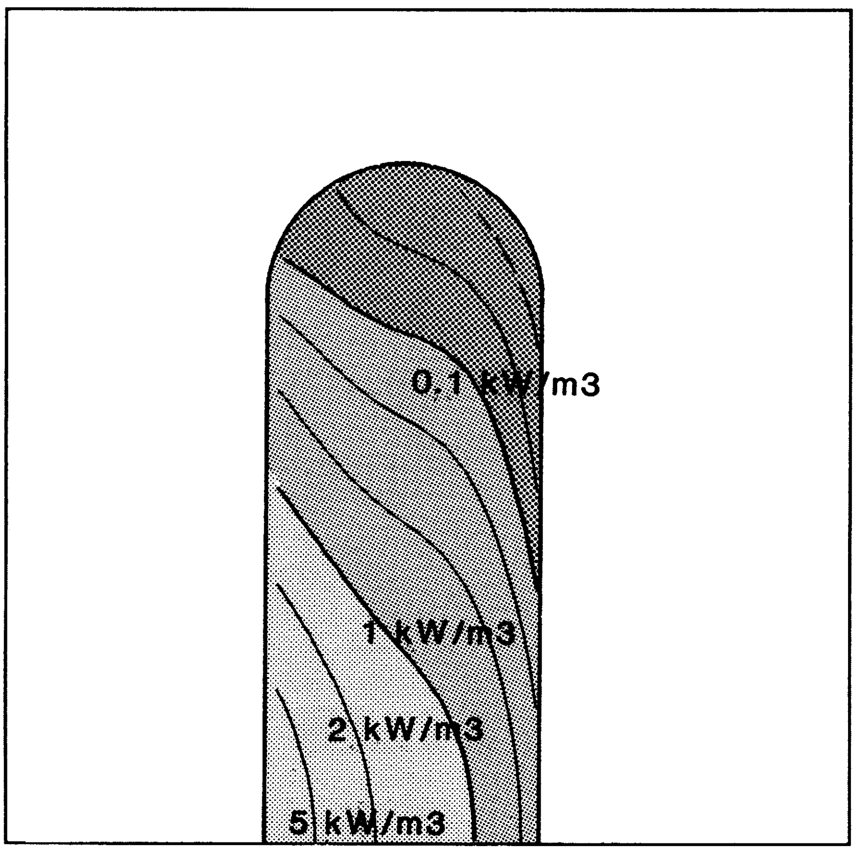

Figure D2: specific absorption rate (SAR)

Data Sheet

1. Far field scattered pattern

PHI	THETA	E THETA [V/m] AMPLITUDE	E PHI [V/m] AMPLITUDE
0.0	90.0	2.93286E+0001	0.00000E+0000
180.0	90.0	6.97676E+0001	0.00000E+0000

2. Absorption

The average SAR was calculated by averaging the values in points of a 0.5 cm grid (front-lower-right corner: -0.0475,-0.0475, -0.2475). The whole-body average SAR was 0.945 kW/m^3 and the highest value found on that grid was 11.37 kW/m^3 (-0.0475,0.0125, 0.025).

PHI = 0.000

X	Y	Z	SAR [W/m^3]
0.03000	0.00000	0.00000	9.06124E+0002
0.03000	0.00000	0.02500	8.42867E+0002
0.03000	0.00000	0.05000	6.87204E+0002
0.03000	0.00000	0.07500	4.98336E+0002
0.03000	0.00000	0.10000	3.28628E+0002
0.03000	0.00000	0.12500	2.07629E+0002
0.03000	0.00000	0.15000	1.26324E+0002
0.03000	0.00000	0.17500	7.67290E+0001
0.03000	0.00000	0.20000	4.40727E+0001
0.02210	0.00000	0.22100	3.27489E+0001
0.00000	0.00000	0.23000	3.76561E+0001

PHI = 90.000

X	Y	Z	SAR [W/m^3]
0.00000	0.03000	0.00000	1.08362E+0003
0.00000	0.03000	0.02500	9.98874E+0002
0.00000	0.03000	0.05000	7.96308E+0002
0.00000	0.03000	0.07500	5.65158E+0002
0.00000	0.03000	0.10000	3.70285E+0002
0.00000	0.03000	0.12500	2.30073E+0002
0.00000	0.03000	0.15000	1.37388E+0002
0.00000	0.03000	0.17500	7.56314E+0001
0.00000	0.03000	0.20000	3.82977E+0001
0.00000	0.02210	0.22100	3.17095E+0001
0.00000	0.00000	0.23000	3.76561E+0001

PHI = 180.000

X	Y	Z	SAR [W/m^3]
-0.03000	0.00000	0.00000	4.34333E+0003
-0.03000	0.00000	0.02500	3.93184E+0003
-0.03000	0.00000	0.05000	2.95045E+0003
-0.03000	0.00000	0.07500	1.95147E+0003
-0.03000	0.00000	0.10000	1.21200E+0003
-0.03000	0.00000	0.12500	7.22995E+0002
-0.03000	0.00000	0.15000	4.28545E+0002
-0.03000	0.00000	0.17500	2.40480E+0002
-0.03000	0.00000	0.20000	1.16259E+0002
-0.02210	0.00000	0.22100	5.74624E+0001
-0.00000	0.00000	0.23000	3.76561E+0001

Canonical Problem Description Form

Problem: Conductive dipole radiated by a half wavelength dipole nearby (see figure E1)

Method: Generalized Multipole Technique

Code: MMP3D Program Package **Version:** Bomholt 10.89

Description of Simulation:

Initially, the half wavelength dipole in free space was calculated and the radiated power in z=0 multiplied by the square of the distance was normalized to 1W. The solution of this simulation was used as the new incident source. 2 planes of symmetry could only be used. The scattered field of the lossy dipole is simulated by multipole expansions which are located at 4 equally-spaced points along the axis of the half dipole (in total 148 unknowns). The boundary conditions are matched in 204 points. This solution is a compromise between accuracy and running time.

Accuracy:

Based on comparisons of the results for different combinations of multipole sources it is believed that the field on the surface is accurate to within ±2% and the scattered field within ±0.5% (see data sheet).

Computer:	Running Time:
Sun 3/260c	409 s
Sun 4/110	243 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

N. Kuster, R. Ballisti, "MMP Method Simulation of Antennae with Scattering Objects in the Closer Nearfield," IEEE Trans. on Magnetics, Vol.25, No.4, July 1989, pp. 2881-2884

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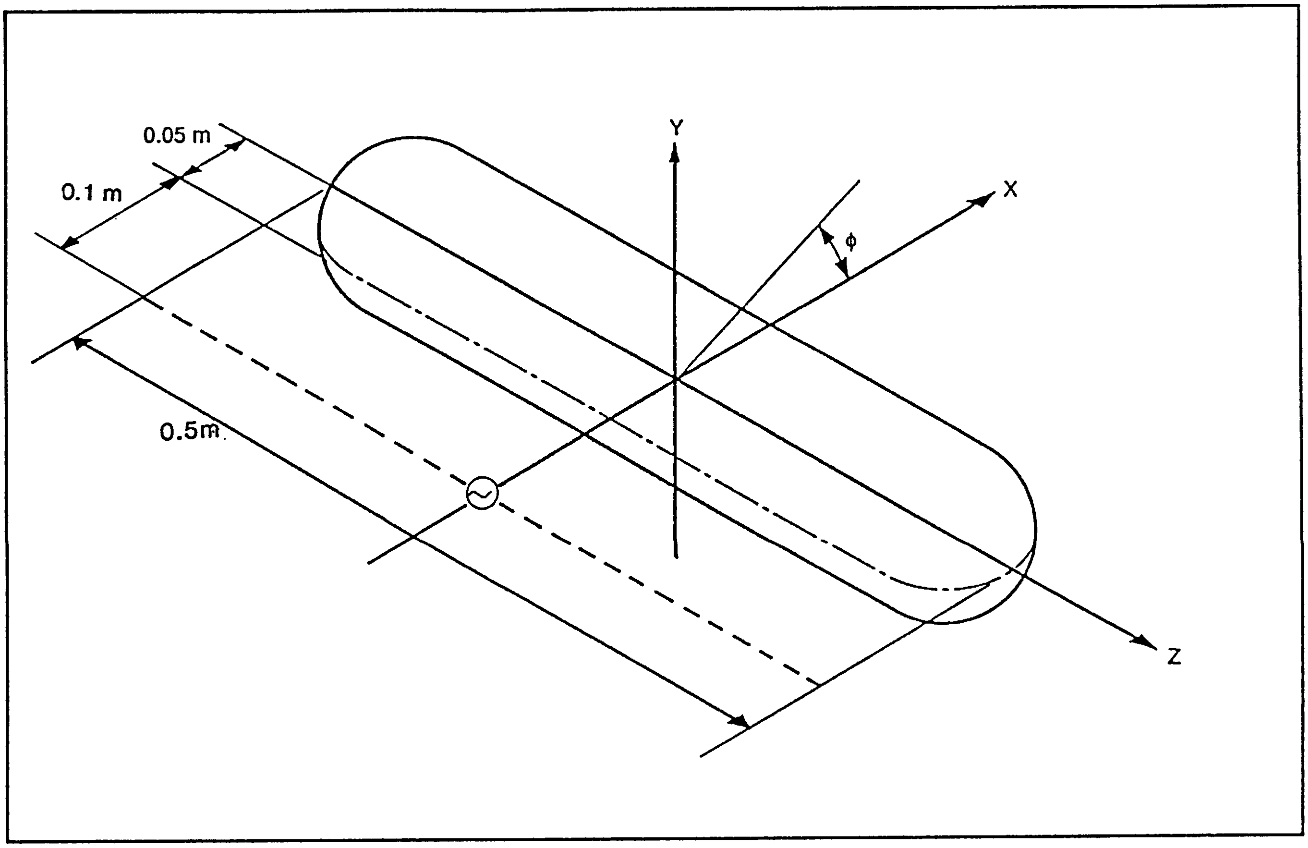

Figure E1: Conductive Dipole radiated by a half wavelength dipole

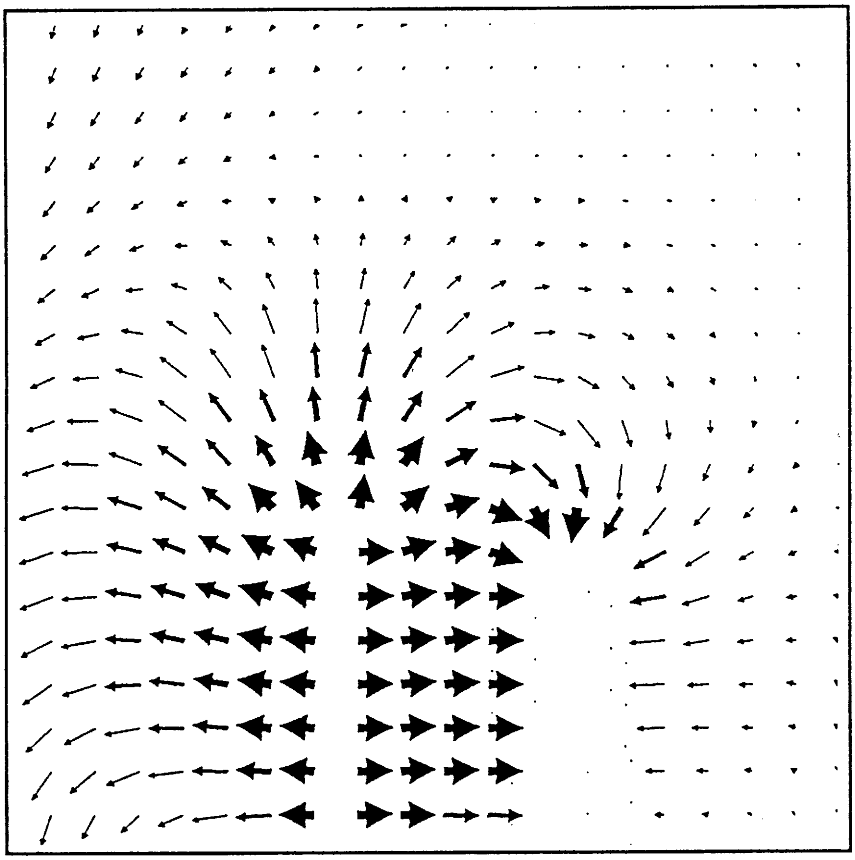

Figure E1: E-Field

Data Sheet

1. Far field scattered pattern

PHI	THETA	E THETA [V/m] AMPLITUDE	E PHI [V/m] AMPLITUDE
0.0	90.0	6.41021E+0001	0.00000E+0000
180.0	90.0	4.92753E+0001	0.00000E+0000

2. Absorption

PHI = 0.000

X	Y	Z	SAR [W/m^3]
0.03000	0.00000	0.00000	3.42646E+0002
0.03000	0.00000	0.02500	3.33954E+0002
0.03000	0.00000	0.05000	3.10644E+0002
0.03000	0.00000	0.07500	2.73663E+0002
0.03000	0.00000	0.10000	2.28297E+0002
0.03000	0.00000	0.12500	1.81420E+0002
0.03000	0.00000	0.15000	1.39965E+0002
0.03000	0.00000	0.17500	1.05842E+0002
0.03000	0.00000	0.20000	7.38925E+0001
0.02210	0.00000	0.22100	6.44892E+0001
0.00000	0.00000	0.23000	8.50067E+0001

PHI = 90.000

X	Y	Z	SAR [W/m^3]
0.00000	0.03000	0.00000	5.43551E+0002
0.00000	0.03000	0.02500	5.30804E+0002
0.00000	0.03000	0.05000	4.95560E+0002
0.00000	0.03000	0.07500	4.39586E+0002
0.00000	0.03000	0.10000	3.69262E+0002
0.00000	0.03000	0.12500	2.90200E+0002
0.00000	0.03000	0.15000	2.09257E+0002
0.00000	0.03000	0.17500	1.34814E+0002
0.00000	0.03000	0.20000	7.86489E+0001
0.00000	0.02210	0.22100	7.15368E+0001
0.00000	0.00000	0.23000	8.50067E+0001

PHI = 180.000

X	Y	Z	SAR [W/m^3]
-0.03000	0.00000	0.00000	1.79610E+0003
-0.03000	0.00000	0.02500	1.75988E+0003
-0.03000	0.00000	0.05000	1.65440E+0003
-0.03000	0.00000	0.07500	1.48802E+0003
-0.03000	0.00000	0.10000	1.27659E+0003
-0.03000	0.00000	0.12500	1.03922E+0003
-0.03000	0.00000	0.15000	7.88375E+0002
-0.03000	0.00000	0.17500	5.28351E+0002
-0.03000	0.00000	0.20000	2.84924E+0002
-0.02210	0.00000	0.22100	1.42730E+0002
-0.00000	0.00000	0.23000	8.50067E+0001

Canonical Problem Description Form

Problem: Lossy Dipole radiated by a half wavelength dipole nearby (see figure F1)

Method: Generalized Multipole Technique

Code: MMP3D Program Package **Version:** Bomholt 10.89

Description of Simulation:

Initially, the half wavelength dipole in free space was calculated and the radiated power multiplied by the square of the distance was normalized to 1W. The solution of this simulation was used as the new incident field. 2 planes of symmetry were used. The scattered field of the lossy dipole is simulated by multipoles located at 4 equally-spaced points along the axis of the half dipole and the domain inside of the cylinder by a single ansatz in the origin of (in total 255 unknowns). The boundary conditions are matched in 203 points. This solution is a compromise between accuracy and running time.

Accuracy:

Based on comparisons of the results for different combinations of multipole sources it is believed that the specific absotption rate (SAR) is accurate to within ±4% and the scattered field within ±0.8% (see data sheet).

Computer:	Running Time:
Sun 3/260c	681 s
Sun 4/110	451 s

References:

L.Bomholt,Ch.Hafner," A MMP Program for Computations of 3D Electromagnetic Fields on PC's," 5th Ann. Rev. of Progress in Applied Computational Electromagnetics, Conference Proc., 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.

N. Kuster, R. Ballisti, "MMP Method Simulation of Antennae with Scattering Objects in the Closer Nearfield," IEEE Trans. on Magnetics, Vol.25, No.4, July 1989, pp. 2881-2884

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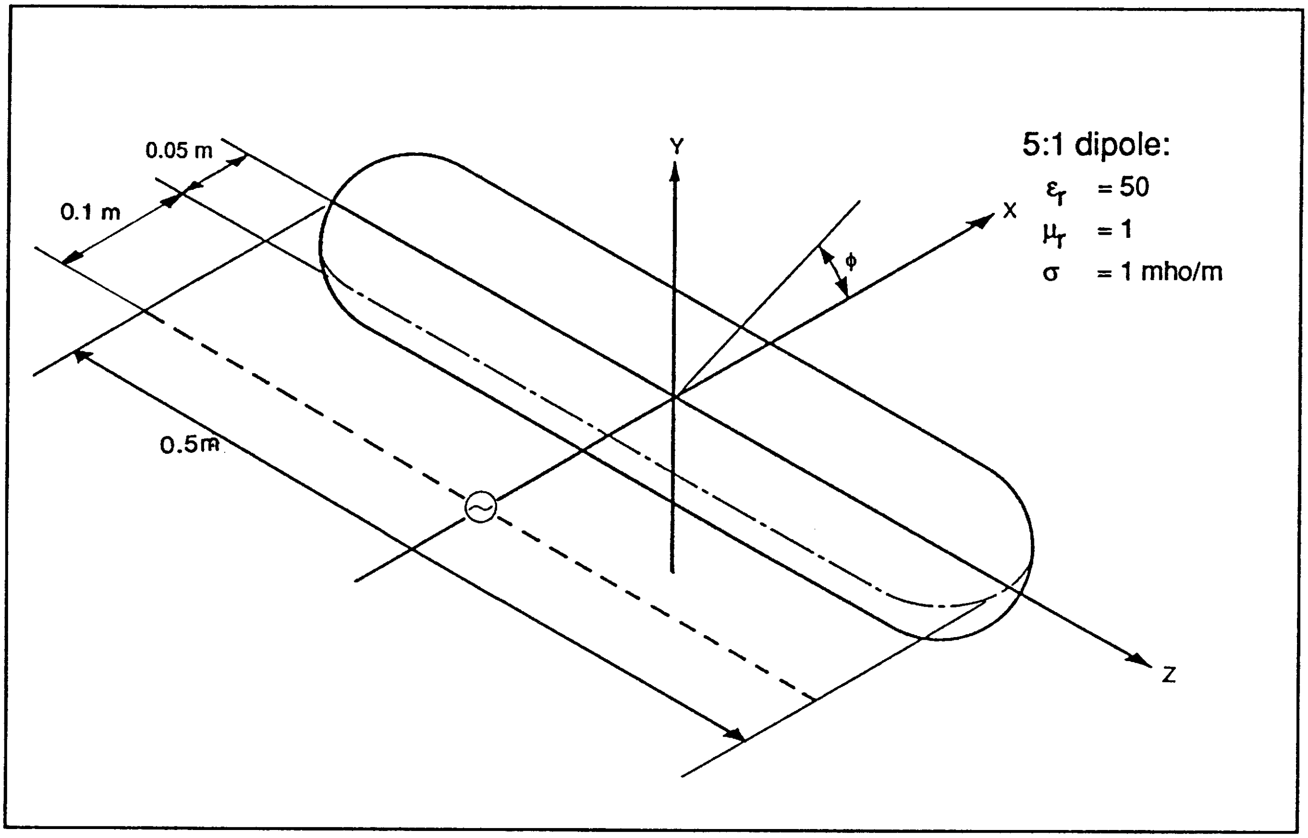

Figure F1: Lossy Dielectric Dipole radiated by a half wavelength dipole nearby

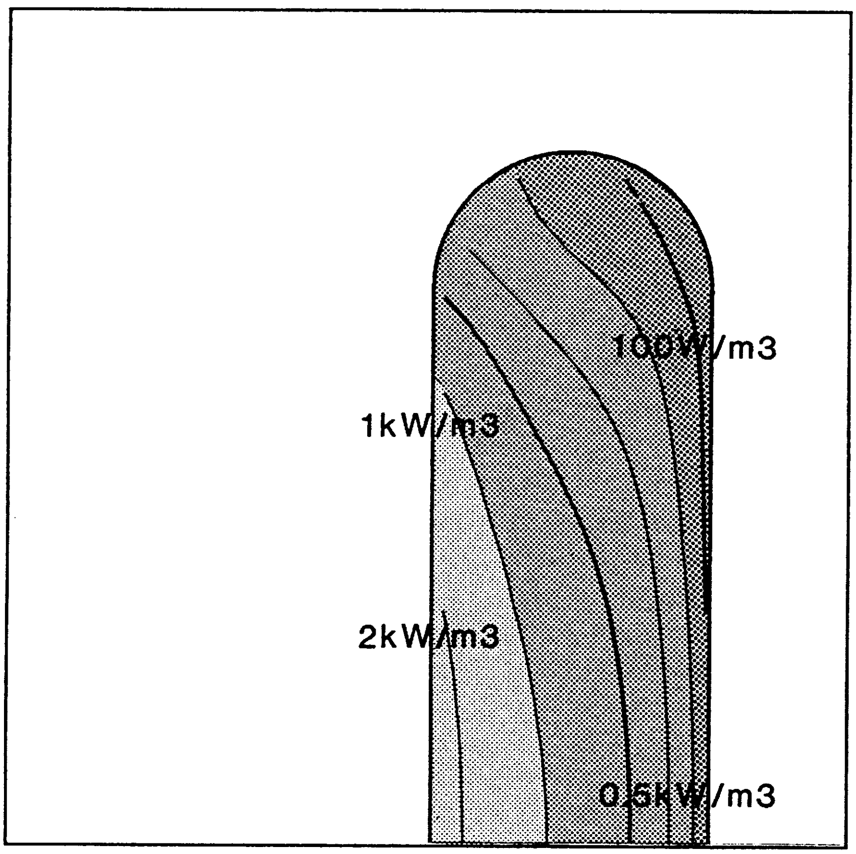

Figure F2: Specific Absorbtion Rate (SAR)

Data Sheet

1. Far Field Scattered Pattern

PHI	Eteta AMPLITUDE	Ephi AMPLITUDE
0.0	8.05113E+0001	0.00000E+0000
180.0	7.79269E+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	4.82238E-0001	-33.517	8.15100E-0013	154.603
0.02785	4.75146E-0001	-33.420	5.86057E-0009	150.107
0.05571	4.51326E-0001	-33.221	1.36690E-0008	159.994
0.08356	4.13033E-0001	-32.857	1.50110E-0008	153.636
0.11142	3.60199E-0001	-32.210	1.28668E-0008	127.884
0.13927	2.94425E-0001	-31.029	1.78711E-0008	120.983
0.16712	2.16363E-0001	-28.696	3.13413E-0008	127.324
0.19498	1.26036E-0001	-22.477	8.24250E-0008	139.270
0.22205	3.02255E-0002	37.352	2.37453E-0007	140.639
0.24244	1.08996E-0001	129.572	3.17417E-0007	141.489
0.25000	2.41736E-0001	141.016	2.99978E-0007	139.220

PHI = 90.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	8.83609E-0001	-31.987	8.29338E-0007	164.418
0.02785	8.71443E-0001	-32.063	2.70384E-0003	16.633
0.05571	8.37728E-0001	-32.184	2.20235E-0003	55.692
0.08356	7.79819E-0001	-32.509	3.59742E-0003	116.154
0.11142	6.99784E-0001	-33.015	1.15610E-0002	149.988
0.13927	6.00839E-0001	-33.679	1.60420E-0002	147.217
0.16712	4.82426E-0001	-34.662	2.27336E-0002	142.730
0.19498	3.46854E-0001	-35.909	4.67212E-0002	141.956
0.22205	1.98257E-0001	-38.000	1.43237E-0001	143.263
0.24244	8.99978E-0002	-39.312	2.16481E-0001	141.677
0.25000	2.99978E-0007	-40.780	2.41736E-0001	141.016

PHI = 180.0

	JT1		JT2	
Z	AMPLITUDE	PHASE	AMPLITUDE	PHASE
0.00000	2.55215E+0000	-18.194	1.90367E-0012	165.134
0.02785	2.51978E+0000	-18.342	5.15729E-0008	173.763
0.05571	2.42634E+0000	-18.737	4.23598E-0008	170.326
0.08356	2.26602E+0000	-19.389	2.97044E-0008	162.953
0.11142	2.04624E+0000	-20.234	2.24489E-0008	18.352
0.13927	1.77524E+0000	-21.288	1.51860E-0008	103.648
0.16712	1.45709E+0000	-22.644	6.71493E-0008	152.484
0.19498	1.09857E+0000	-24.402	1.68907E-0007	155.531
0.22205	7.00579E-0001	-27.709	1.23622E-0007	-42.307
0.24244	4.22136E-0001	-32.801	2.50706E-0007	-41.538
0.25000	2.41736E-0001	-38.984	2.99978E-0007	-40.780