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A User's Manual for the General Cylinder Code (GCYL)

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This report serves as a users manual for the "General Cylinder" (GCYL) code. GCYL is a user oriented computer code for analyzing the ($e^{j\omega t}$) time harmonic TM (i.e. E_z) or TE (i.e. H_z) scattering from a general cylinder. A general cylinder is composed of open or closed perfectly conducting surfaces and/or lossy and inhomogeneous dielectric/ferrite cylinders of arbitrary cross section, as well as thin dielectric strips modeled by uniform or tapered sheet impedances. The perfectly conducting surfaces and the sheet impedance strips may contact or even penetrate the dielectric/ferrite regions. This report provides a description of the inputs and outputs of GCYL.

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A USER's Manual for the General Cylinder Code (GCYL)

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Chapter 1

Introduction

This report serves as a users manual for the "General Cylinder" (GCYL) code. GCYL is a user oriented computer code for the computation of the TM or TE back or bistatic echo width of a general cylinder. A general cylinder is composed of:

1. perfectly conducting cylinders of arbitrary cross section
2. lossy and inhomogeneous dielectric and/or ferrite material cylinders of arbitrary cross section
3. electrically thin dielectric strips modeled by a sheet impedance (including tapered sheet impedances).

GCYL models an inhomogeneous, arbitrary cross section, material cylinder by a number of homogeneous material cylinders of quadrilateral cross section. The size, shape, location, and material properties of each quadrilateral cylinder are chosen so that collectively they approximate the cross section and material properties of the actual material cylinder. The arbitrary cross section perfectly conducting surfaces are modeled by a number of flat perfectly conducting strips which are arranged to form a piecewise flat approximation to the actual (possibly curved) surface. Similarly, a number of flat sheet impedance strips are used to approximate the thin dielectric shells. A zero ohm sheet impedance strip is identical to a perfectly conducting strip. Note that the problem is two dimensional (2D) with the incident and scattered electric field being polarized parallel to the cylinder axis (i.e. E_z) in the TM case and the incident and scattered magnetic field being polarized parallel to the cylinder axis (i.e. H_z) in the TE case.

The theoretical basis for the GCYL code is described elsewhere [1]. In brief, the perfectly conducting and sheet impedance cylinders are represented by equivalent electric surface currents, the dielectric cylinders are represented by equivalent electric volume currents, and the ferrite cylinders are represented by equivalent magnetic volume currents [2]. For TM plane wave incidence, the electric currents are $\hat{z}$ polarized and the magnetic currents are $\hat{x}$ and $\hat{y}$ polarized, whereas for TE incidence the electric currents are $\hat{x}$ and $\hat{y}$ polarized and the magnetic currents are $\hat{z}$ polarized. A set of coupled integral equations for these currents are obtained by enforcing the appropriate boundary conditions at the surface of the perfectly conducting or sheet impedance cylinders, and the volume equivalence theorems in the dielectric/ferrite cylinders. The coupled integral equations are solved by the method of moments (MM) [3]. In the TM case, a pulse or piecewise constant expansion and weighting function Galerkin MM solution, identical to that developed by Wang [4], is employed on the perfectly conducting and sheet impedance surfaces. For the TE case, a sinusoidal expansion and weighting function Galerkin MM solution, identical to that developed by Richmond [6], is utilized on the perfectly conducting and sheet impedance surfaces. The equivalent electric and magnetic polarization currents representing the dielectric/ferrite cylinder are expanded in terms of quadrilateral cross section piecewise constant expansion or basis functions, with Dirac delta weighting functions being used to minimize the computer CPU time required to fill the impedance matrix [3]. The use of Dirac delta weighting functions is referred to as point matching, since one is enforcing the integral equations at a number of points at the centroid of the quadrilateral expansion functions.

The MM transforms the four coupled integral equations into a system of simultaneous linear algebraic equations, commonly referred to as a matrix equation of the form

$$[Z]I = V, \tag{1.1}$$

where $[Z]$ is the $N \times N$ impedance matrix ($N =$ the total number of expansion modes) and V is the length N voltage vector. The main effort of the MM solution is to find $[Z]$ and V. Once this is done, Equation (1.1) can be solved for the solution vector I which contains the N coefficients in the expansions for the equivalent currents. Once these currents are known, the scattered fields are simply the free space fields of these currents and thus can be computed in a straight forward manner.

The main advantage of the above described MM solution is its accuracy. It is a direct numerical solution of the exact coupled integral equations describing the scattering from the general cylinder. As such, the solution automatically contains all phenomena of the problem, including surface waves, creeping waves, edge conditions, multiple diffractions, etc. As the number of expansion functions is increased the MM solution in principle should approach the exact solution. The main limitation of the MM solution is a result of the fact that the number of expansion functions, and hence the required computer CPU and storage, is proportional to the electric size of the cylinders. Thus, as the frequency is increased, the required computer resources increase, and at some point the MM solution becomes impractical.

GCYL models a general cylinder as a combination of basic building blocks. Chapter 2 describes these five basic building blocks. Chapter 3 describes the inputs to GCYL. That is, the methods for describing the general cylinder geometry, plus the frequency, patterns desired, etc. to GCYL. Chapter 4 further illustrates the code inputs and describes the code outputs through the use of a number of example problems. Finally, Chapter 5 describes the dimensioning of arrays in GCYL, and describes the output files PPLOT, which can be used to obtain pattern plots, and GPLOT, which can be used to generate a plot of the problem geometry. Appendix A shows a subroutine CGEOM which describes the general cylinder geometry for the material coated circular cylinder of example 5 in Chapter 4. Appendix B lists the Fortran code GEOMP, which uses the output file GPLOT to generate a plot of the building block and/or mode geometry. Appendix C lists the Fortran code PATP, which reads the file PPLOT and generates a pattern plot. Finally, Appendices D-H list the output files for example runs 1-5, respectively, of Chapter 4.

Chapter 2

GCYL Building Blocks

2.1 Introduction

The general cylinder geometry is described to GCYL as a combination of the following five building blocks:

1. straight sheet impedance strips, with perfectly conducting strips being the special case where the sheet impedance $Z_s = 0\ \Omega/\Box$,
2. quadrilateral cross section material cylinders of arbitrary complex permittivity and permeability,
3. straight sheet impedance strips coated with a quadrilateral cross section material cylinder on one side,
4. straight sheet impedance strips coated with a quadrilateral cross section material cylinder on both sides,
5. quadrilateral cross section material cylinders coated on any/all or no sides by a sheet impedance strip.

Using the above five building blocks it is possible to construct a piecewise flat approximation to an almost arbitrary cylinder. Note that each quadrilateral material cylinder may have a different complex permittivity and permeability, and that each sheet impedance strip may have a different tapered Z_s. The next sections define the sheet impedance model for a thin dielectric slab and the five GCYL building blocks.

2.2 Definition of Sheet Impedance

This section will describe the modeling of a thin dielectric slab by a sheet impedance strip. Figure 2.1a shows a dielectric slab of thickness T and permittivity ϵ. The slab must be non-magnetic with free space permeability μ_0. The sheet impedance approximations requires that two conditions be met by the dielectric slab. First, the slab must be sufficiently thin so that the electric field can be taken as essentially constant through its thickness, i.e.,

$$kT \ll 1,$$

where k is the wavenumber in the dielectric slab media. The second condition is that the polarization of the electric field in the slab should be parallel to the broad surfaces of the slab. This condition is always true for the TM polarization, but not always true for the TE polarization. In the TE plane wave incidence case, there is in general a component of electric field perpendicular to the broad surface of the slab, which violates the second condition. Thus, as the incidence wave progresses from broadside incidence to grazing incidence, the sheet impedance approximation will fail at some point toward grazing incidence. However, for dense material the electric field vector in the slab tends to align itself parallel to the broad surface of the slab, thus making the approximation good for angles not too close to grazing incidence.

Assuming that both of the above conditions are met, then as illustrated in Figure 2.1b, the thin slab can be modeled as an infinitesimally thin strip of sheet impedance

$$Z_s = \frac{1}{j\omega(\epsilon - \epsilon_0)T}, \tag{2.1}$$

where ω is the radian frequency, and ϵ_0 is the permittivity of free space. Thin multilayered slabs can be easily treated via the sheet impedance approximation since the sheet impedance of a multilayered slab is simply the parallel combination of the sheet impedance of each individual layer [4] (caution: reference [4] employs the $e^{-j\omega t}$ time convention). If the thickness or permittivity of the dielectric slab are not constant, then Z_s in Equation (2.1) will not be constant. GCYL allows for constant sheet impedances, as well as sheet impedances with a linear or an exponential taper.

If the dielectric is lossy, with conductivity σ, then its complex permittivity can be written as

$$\epsilon = \left(\epsilon' - \frac{j\sigma}{\omega}\right). \tag{2.2}$$

If the dielectric is so lossy that the imaginary part of its permittivity dominates its real part, then the sheet impedance of Equation (2.1) becomes

$$Z_s \approx \frac{1}{\sigma T} \qquad \frac{\sigma}{\omega} \gg \epsilon', \tag{2.3}$$

and is essentially pure real. Such a material is commonly referred to as a resistive sheet. Finally, it is important to note that an infinitesimally thin perfectly conducting strip is simply a sheet impedance strip with $Z_s = 0$.

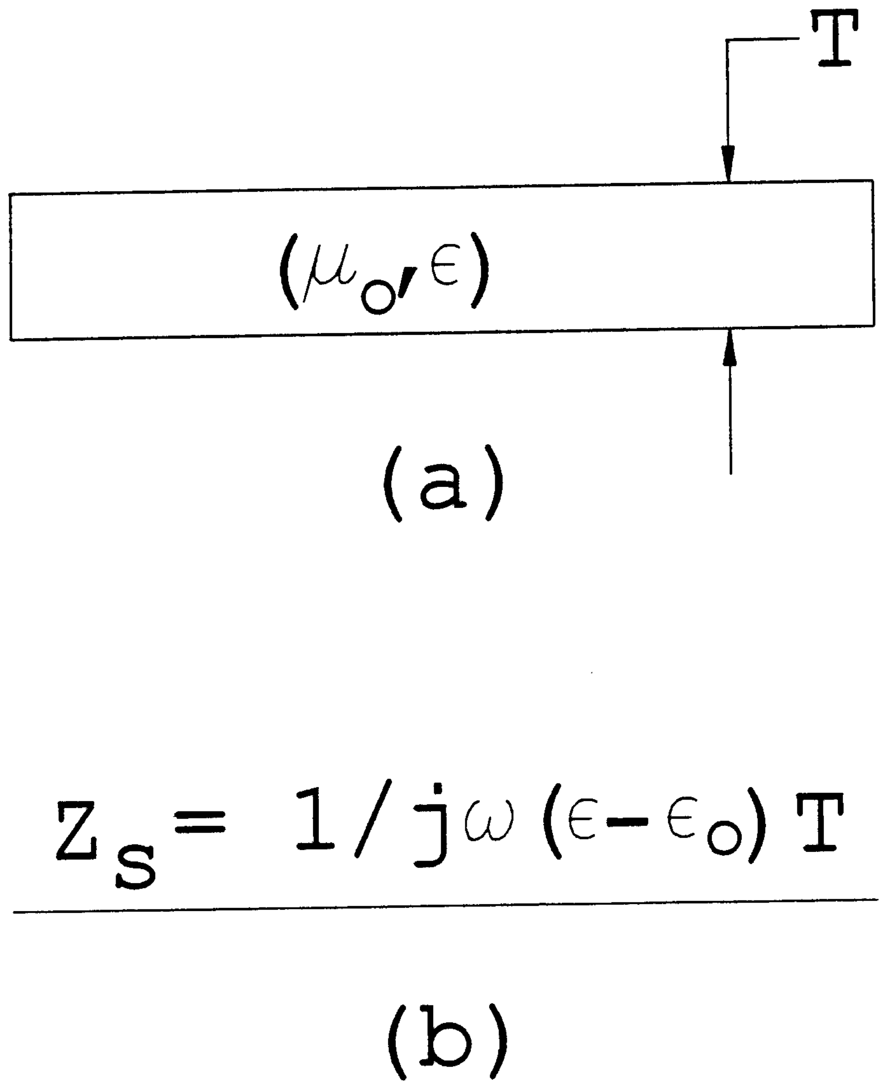

Figure 2.1: (a) An electrically thin dielectric slab and (b) the equivalent sheet impedance of the slab.

2.3 General Cylinder Building Blocks

As described above, GCYL models a general cylinder as a combination of the five building block types shown in Figure 2.2. These five types will now be described in more detail.

Building Block 1

Figure 2.2a shows a typical Type 1 building block, i.e., a sheet impedance strip. The sheet impedance strip is defined by the (x, y) coordinates of its endpoints, by the value of Z_s at each endpoint, and by the type of taper. If $Z_s = 0$, then the sheet impedance strip is a perfectly conducting strip. A particular geometry may contain several sheet impedance strips, each with a different sheet impedance. As illustrated in Figure 2.3a, the sheet impedance strips may only contact each other at their endpoints.

Building Block 2

Figure 2.2b shows a typical Type 2 building block, i.e., a quadrilateral material cylinder. The location of the material cylinder is specified by the (x, y) coordinates of its four corner points. The quadrilateral region is assumed to contain a homogeneous dielectric/ferrite material whose complex permittivity and permeability are related to the relative permittivity and permeability and to the electric and magnetic loss tangents by

$$\begin{aligned} \epsilon &= \epsilon_r \epsilon_0 (1 - j \tan \delta_e) \\ \mu &= \mu_r \mu_0 (1 - j \tan \delta_m). \end{aligned} \tag{2.4}$$

A particular geometry may contain several quadrilateral material cylinders, each with different cross section shape and material parameters. Two quadrilateral material cylinders may not overlap, however, as illustrated in

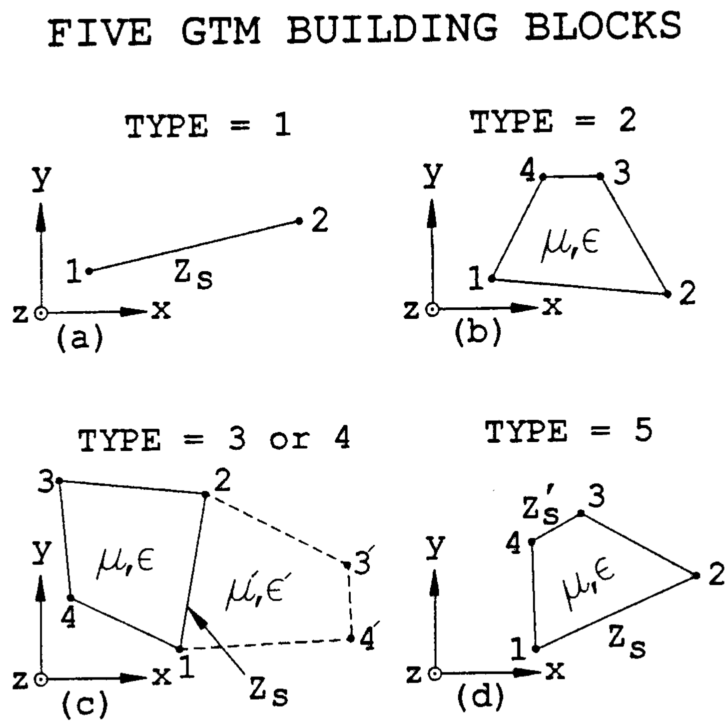

Figure 2.2: A general cylinder may be constructed from a combination of (a) sheet impedance strips, (b) quadrilateral material cylinders, and (c) sheet impedance strips coated on one or both sides by quadrilateral material cylinders, (d) quadrilateral material cylinders coated on any side(s) by sheet impedance strips.

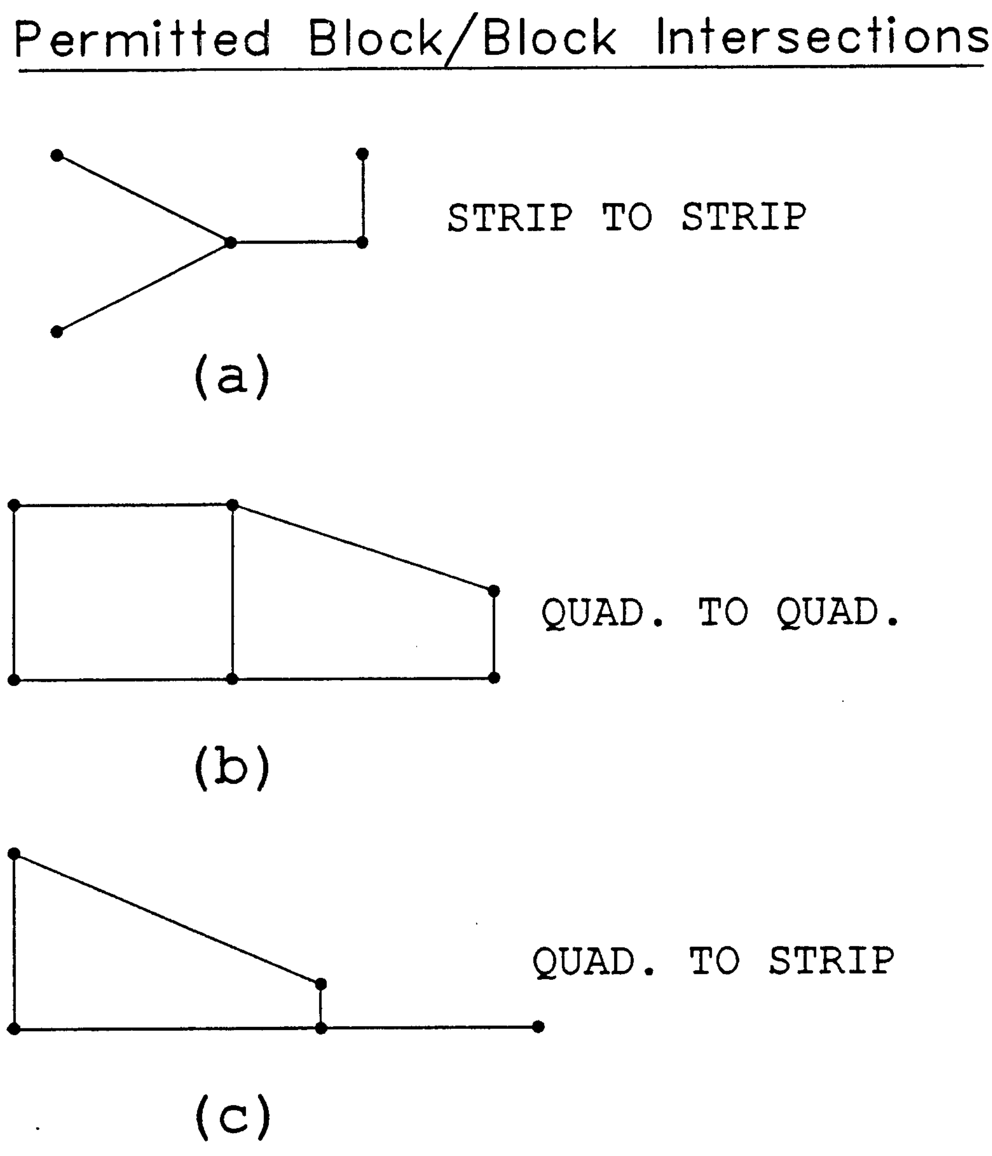

Figure 2.3: The allowed intersections between impedance strips and quadrilateral material cylinders are (a) two or more strips which intersect at their endpoints, (b) two quadrilaterals whose sides abut, and (c) the endpoint of a strip coinciding with the corner of a quadrilateral.

Figure 2.3b, two sides may abut with one another. The sheet impedance strips defined above may not contact the quadrilateral material cylinders in any way, except that the edge of a strip may coincide with the corner of a quadrilateral, as illustrated in Figure 2.3c. Impedance strips which abut a side of a quadrilateral material cylinder must be modeled with the coated impedance strips shown in Figures 2.2c,d as described below.

Building Blocks 3 and 4

Impedance strips which abut a side of a quadrilateral material cylinder can be modeled with the coated impedance strips shown in Figure 2.2c, and are referred to as building blocks Types 3 and 4. The location of the impedance strip is defined by the (x, y) coordinates of points 1 and 2. A quadrilateral material cylinder, with material parameters (μ, ϵ), is located in the region defined by the points 1,2,3,4. Building block Type 3 involves the impedance strip 1,2 and quadrilateral material cylinder 1,2,3,4. Building block Type 4 involves the impedance strip 1,2, the quadrilateral material cylinder 1,2,3,4, and in addition, a second quadrilateral material cylinder with parameters (μ', ϵ') located in the region defined by the points $1, 2, 3', 4'$. This region is shown by the dashed line in Figure 2.2c. Building block Type 3 is intended for use in describing a material cylinder which is coated on one side by a perfectly conducting or a sheet impedance surface. Building block Type 4 is intended for use when a perfectly conducting or a sheet impedance surface penetrates a material cylinder.

Building Block 5

Building block Type 5 is shown in Figure 2.2d and consists of a quadrilateral material cylinder with sheet impedance strips located on any side desired. Thus, the quadrilateral region may be a pure material cylinder like a Type 2 building block, a coated strip like a Type 3 building block, or any other combination of sheet impedance strips in edge contact with the material cylinder. Building block Type 5 is intended for use when a material cylinder is coated on more than one side by perfectly conducting or sheet impedance surfaces. A particular geometry may contain several of the material coated impedance strips of Figures 2.2c,d.

The rules as to how coated impedance strips may contact other building blocks of the general cylinder are the same as for simple impedance sheets and quadrilateral material cylinders, i.e.,

- two strips may only contact at their endpoints (Figure 2.3a),
- two quadrilateral material cylinders may not overlap, but may have their sides abut (Figure 2.3b),
- a simple strip may not penetrate or abut a quadrilateral material cylinder, except that a strip endpoint may coincide with a quadrilateral corner (Figure 2.3c.)

In summary, GCYL constructs a general cylinder from a combination of the building blocks shown in Figure 2.2a-d. In particular, the five types of building blocks are:

1. Type 1: a simple sheet impedance strip as seen in Figure 2.2a
2. Type 2: a quadrilateral material cylinder as seen in Figure 2.2b
3. Type 3: a sheet impedance strip coated on one side by a quadrilateral material cylinder as seen by the solid lines in Figure 2.2c

4. Type 4: a sheet impedance strip coated on both sides by a quadrilateral material cylinder as seen by the solid plus dashed lines in Figure 2.2c

5. Type 5: a quadrilateral material cylinder coated on any side(s) by sheet impedance strips as seen in Figure 2.2d.

It is important to distinguish between the building blocks defined by the user, and the MM expansion modes defined by GCYL. The building blocks are physical matter which are arranged to approximate the geometry of the actual cylinder. There is no limitation on their size. For example, it is legitimate to define a sheet impedance strip 100λ in width. GCYL segments the building blocks into the MM modes, whose maximum dimension is typically 0.1 to 0.25λ. Thus, a particular problem may involve a relatively few building blocks, defined by the user, but thousands of MM modes, defined by GCYL. In this way, the user is concerned only with the physical modeling of the cylinder, and not with the more numerous and complicated MM expansion modes. Also, from the user's standpoint, the definition of the building blocks is frequency independent since GCYL will automatically segment the building blocks into more (fewer) modes as the frequency is increased (decreased).

Chapter 3

Command Inputs

In order to compute the scattering from a general cylinder it is necessary to define the cylinder geometry (in terms of the five building blocks shown in Figure 2.2) plus other information such as the type of pattern desired, the frequency, the polarization (TM or TE), etc. This information is specified to GCYL by 17 command inputs. A typical command has the form:

CMD: COMMAND DESCRIPTION
Parameter List 1
Parameter List 2

where CMD is the command. All commands are three character strings in length. Following the command is a colon (:) and then a brief description of the command. The colon and the description are ignored by the code. They are included if the user wishes to make the input file easier to read. Some commands have a number of associated input parameters. In these cases, one to five lines of these parameters are listed immediately following the command. The commands and their associated parameter lists are read on logical unit 5 from a file normally called INF.DAT. All commands are input in subroutine INPUTS.

Not all commands need be executed on a given run. The only command which must be executed is the END command, which indicates the end of the command inputs. Some input parameters have default values. The default value is the value a parameter is assigned if the command which defines that parameter is not executed. The default value, if any, is shown in parentheses following the parameter list. For example, if a parameter list is shown as

P1 P2 P3
(0.0) (1.0) (-1.0) (Defaults)

then parameter P1 has a default value of 0.0, parameter P2 has a default value 1.0, and P3 has a default value of -1.0.

Below is a list of the GCYL commands. They are presented in alphabetical order. However, unless specifically indicated they can be executed in any order.

3.1 COMMAND ACU: ACCURACY PARAMETERS

Command ACU sets the values of four parameters which control the accuracy of the numerical integrations and summations in the code.

Form of the command:

ACU: ACCURACY PARAMETERS

INTM INT SEGM SEGC

(16) (6) (.15) (.15)   (Defaults)

INTM = the number of integration points per quadrilateral side for self-impedance elements.

INT = the number of integration segments per conductor segment.

SEGM = the maximum length of a quadrilateral side (in material wavelengths).

SEGC = the maximum length of a conductor segment (in free space wavelengths).

As INTM and INT are increased, and SEGM and SEGC are decreased, the accuracy of the solution increases, although at a cost of increased CPU time. In addition, the storage requirements increase as SEGM and SEGC decrease, since this will increase the number of MM modes.

3.2 COMMAND BT1: BLOCK TYPE 1

Command BT1 sets the values of eight parameters which determine the geometry and sheet impedance of a Type 1 building block. The definition of the geometry and sheet impedance for a Type 1 building block is given in Figure 2.2. The BT1 command may be used several times in an input file, i.e., once for each Type 1 building block.

Form of the command:

BT1: BLOCK TYPE 1

X1 Y1 X2 Y2

IZSHTR IZSHTI ZSHT1 ZSHT2

X1,Y1 = (x, y) coordinates of point 1 of the impedance strip (meters).

X2,Y2 = (x, y) coordinates of point 2 of the sheet impedance strip (meters).

IZSHTR = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 ($\Omega/\Box$)

ZSHT2 = the complex value of the sheet impedance at point 2 ($\Omega/\Box$)

GCYL allows for independent tapering of the real and imaginary parts of the sheet impedance. This would be useful in modeling a tapered resistive strip (the real part of Z_s) on a lossless dielectric substrate (the imaginary part of Z_s). Note that ZSHT1 and ZSHT2 are complex numbers.

3.3 COMMAND BT2: BLOCK TYPE 2

Command BT2 sets the values of 12 parameters which determine the geometry and material composition of a Type 2 building block. The geometry and the material parameters for a Type 2 block is described in Figure 2.2. The BT2 command may be used several times in a given input file, i.e., once for each Type 2 building block.

Form of the command:

BT2: BLOCK TYPE 2
X1 Y1 X2 Y2 X3 Y3 X4 Y4
ER TDE UR TDM

XN,YN = (x, y) coordinates of point N of the quadrilateral region (meters).

ER = relative permittivity of material.

TDE = electric loss tangent.

UR = relative permeability of material.

TDM = magnetic loss tangent.

3.4 COMMAND BT3: BLOCK TYPE 3

BT3 sets the values of 16 parameters which determine the geometry, material composition and sheet impedance of a Type 3 building block. The description of a Type 3 building block is given in Figure 2.2. The BT3 command may be used several times in a given input file, i.e., once for each Type 3 building block.

Form of the command:

BT3: BLOCK TYPE 3
X1 Y1 X2 Y2 X3 Y3 X4 Y4
ER TDE UR TDM
IZSHTR IZSHTI ZSHT1 ZSHT2

XN,YN = (x, y) coordinates of point N of the quadrilateral region 1,2,3,4 (meters).

ER = relative permittivity of material.

TDE = electric loss tangent.

UR = relative permeability of material.

TDM = magnetic loss tangent.

IZSHTR = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 $(\Omega/\Box)$

ZSHT2 = the complex value of the sheet impedance at point 2 $(\Omega/\Box)$

3.5 COMMAND BT4: BLOCK TYPE 4

BT4 sets the values of 24 parameters which determine the geometry, material composition and sheet impedance of a Type 4 building block. The description of a Type 4 building block is given in Figure 2.2. The BT4 command may be used several times in a given input file, i.e., once for each Type 4 building block.

Form of the command:

```
BT4: BLOCK TYPE 4
X1 Y1 X2 Y2 X3 Y3 X4 Y4
ER TDE UR TDM
X3P Y3P X4P Y4P
ERP TDEP URP TDMP
IZSHTR IZSHTI ZSHT1 ZSHT2
```

XN,YN = (x, y) coordinates of point N of the quadrilateral region I (meters).

ER = relative permittivity of quadrilateral region I.

TDE = electric loss tangent of quadrilateral region I.

UR = relative permeability of quadrilateral region I.

TDM = magnetic loss tangent of quadrilateral region I.

XNP,YNP = (x, y) coordinates of point N = $3'$ or $4'$ of quadrilateral region II.

ERP = relative permittivity of quadrilateral region II.

TDEP = electric loss tangent of quadrilateral region II.

URP = relative permeability of quadrilateral region II.

TDMP = magnetic loss tangent of quadrilateral region II.

IZSHTR = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 ($\Omega/\square$)

ZSHT2 = the complex value of the sheet impedance at point 2 ($\Omega/\square$)

Referring to Figure 2.2, region I is the quadrilateral cylinder 1,2,3,4, while region II is the quadrilateral cylinder $1, 2, 3', 4'$.

3.6 COMMAND BT5: BLOCK TYPE 5

BT5 sets the values of 18 parameters which determine the geometry, material composition and sheet impedance of a Type 5 building block. The description of a Type 5 building block is given in Figure 2.2. The BT5 command may be used several times in a given input file, i.e., once for each Type 5 building block.

Form of the command:

BT5: BLOCK TYPE 5

X1 Y1 X2 Y2 X3 Y3 X4 Y4

ER TDE UR TDM

IZSHTR IZSHTI ZSHT1 ZSHT2 ZSHT3 ZSHT4

IZ12 IZ23 IZ34 IZ41

XN,YN = (x, y) coordinates of point N of the quadrilateral region (meters).

ER = relative permittivity of material.

TDE = electric loss tangent.

UR = relative permeability of material.

TDM = magnetic loss tangent.

IZSHTR = indicator for the taper type of the real part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

IZSHTI = indicator for the taper type of the imaginary part of the sheet impedance.

= 1 implies a linear taper.

= 2 implies an exponential taper.

ZSHT1 = the complex value of the sheet impedance at point 1 ($\Omega/\square$)

ZSHT2 = the complex value of the sheet impedance at point 2 ($\Omega/\square$)

ZSHT3 = the complex value of the sheet impedance at point 3 ($\Omega/\Box$)

ZSHT4 = the complex value of the sheet impedance at point 4 ($\Omega/\Box$)

IZ12 = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

IZ23 = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

IZ34 = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

IZ41 = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

3.7 COMMAND COM: COMMENT COMMAND

Command COM allows the user to make a comment near the top of the output file which is descriptive of the problem being run. Thus, if the user was running a dielectric coated circular cylinder, then a comment such as 'DIELECTRIC COATED CIRCULAR CYLINDER' may be an appropriate title to describe the output file.

Form of the command:

COM: COM COMMAND
DESCRIPTION OF RUN

3.8 COMMAND END: END OF DATA COMMAND

Command END indicates the end of the input data file. The last line in the input file must always be the END command.

Form of the command:

END: END COMMAND

3.9 COMMAND FMZ: FREQUENCY IN MEGAHERTZ

Command FMZ sets the frequency of the incident wave in Mhz.

Form of the command:

FMZ: FREQUENCY
FMZ
(300.0) (Default)

FMZ = frequency in megahertz

Note that if the FMZ command is not executed, the default frequency is 300 Mhz, i.e., $\lambda = 1$ meter.

3.10 COMMAND INF: INTERNAL FIELDS

The INF command causes GCYL to compute and print a list of the internal fields at the centroid of the quadrilateral cells which comprise the MM expansion modes for the dielectric/ferrite cylinders. The INF command can only be executed if a bistatic pattern is specified in the SCP command (IPAT = 1). The excitation is by a wave incident from ϕ = PHID degrees, with PHID defined in the SCP command.

Form of the command:

INF: INTERNAL FIELDS

Once the equivalent volume polarization currents have been determined, the volume equivalence theorems [2] can be used to compute the internal fields. This computation is extremely straight-forward, and requires practically no CPU time. Thus, the user should not hesitate to use the INF command if there is an interest in the internal fields. Note that GCYL can not compute the internal magnetic fields of a pure dielectric material ($\mu = \mu_0$) or the internal electric fields of a pure magnetic material ($\epsilon = \epsilon_0$). In these cases, the internal fields are shown as zero.

3.11 COMMAND MDG: MODE GEOMETRY

GCYL always outputs the geometry of the building blocks defined by the user. GCYL then segments the building blocks into the MM modes. The detailed mode geometry is only printed if the MDG command is executed. Note that this can result in a fairly large output if the cylinder is electrically large.

Form of the command:

MDG: MODE GEOMETRY

3.12 COMMAND POL: POLARIZATION

Command POL determines whether the incident plane wave is a transverse electric (i.e. H_z) wave or a transverse magnetic (i.e. E_z) wave.

Form of the command:

POL: POLARIZATION

NPOL

(0) (Default)

NPOL = indicator for polarization type.

0 for TM problem.

1 for TE problem.

Note that if the NPOL command is not executed the default polarization is TM.

3.13 COMMAND PRC: PRINT COMMANDS

GCYL always provides a printout summarizing the problem geometry and other input parameters. However, there are cases where a user wishes a direct echoing of the exact input parameters for each command. If the PRC command is executed, GCYL will print the inputs corresponding to each command, *immediately following that command.* Only commands following the PRC command will be printed. Thus, if the PRC command is used, normally it will be the first command of the input file.

Form of the command:

PRC: PRINT COMMANDS

3.14 COMMAND RUN: RUN COMMAND

MM codes, such as GCYL, often require long and complicated input files, and also large amounts of CPU time to perform the MM computations. When running GCYL on a complicated geometry, it is expected that the user may need several runs just to get the input file correct. It is extremely wasteful to perform the expensive MM computations if one is not sure that the input file is correct. If the RUN command *is not* executed, then GCYL will simply read the input file, print out a description of the problem, and then stop, i.e., no MM computations will be made. These runs typically require only about a second of CPU time. When the user is confident that the input file is correct, then the RUN command is added to the input file and GCYL will proceed to make the desired MM computations.

Form of the command:

RUN: RUN COMMAND

3.15 COMMAND SCP: SCATTERING PATTERN

Command SCP defines the parameters of the plane wave scattering pattern. GCYL can compute either a back or bistatic scattering pattern. In a backscatter pattern the angle of the incident wave is identical to that of the scattered wave. A pattern is obtained by varying the angle from 0 to 360 degrees. In a bistatic pattern the angle of the incident wave is fixed, and the angle of the scattered wave is varied from 0 to 360 degrees.

Form of the command:

SCP: SCATTERING PATTERN
IPAT PHID STEP
(1) (0.0) (5.0) (Defaults)

IPAT = indicator for pattern type.

0 for backscatter pattern.

1 for bistatic pattern.

PHID = for a bistatic pattern, the cylindrical ϕ angle between the positive x axis and the opposite direction of the incident wave; for backscatter patterns this parameter is ignored (degrees).

STEP = incremental angle between scattering observations. (degrees)

Note that all patterns go from 0 to 360 degrees.

3.16 COMMAND SUB: SUBROUTINE GENERATED INPUT

In many problems, the longest and most complicated part of the input file is the definition of the building blocks which approximate the actual cylinder geometry. Some cylinder geometries may require hundreds of building blocks, which in turn would require hundreds of the BT1-BT5 commands. If the cylinder geometry has a reasonably simple geometric description, in these cases, the user should consider writing an external driver code, whose output would be a file containing the BT1-BT5 commands. An alternate method for defining the building block geometry is provided by the SUB command. If the SUB command is executed, then the building block geomtry is to be generated by a Fortran subroutine CGEOM written by the user. The window of subroutine CGEOM is fixed and is described in Appendix A. If the SUB command is used, then the commands BT1-BT5 can not used, although all other commands of subroutine INPUT must be used to specify other parameters of the problem.

Form of the command:

SUB: SUBROUTINE GENERATED INPUT

In summary, if the SUB command is executed, then the building block geometry is to be generated by the user written Fortran subroutine, CGEOM rather than by the BT1-BT5 commands. Subroutine CGEOM is described in Section 3.18.

3.17 COMMAND WRI: WRITE INDICATORS

Command WRI is used to obtain printouts of the currents, right hand side vector, and impedance matrix.

Form of the command:

WRI: WRITE INDICATORS
IZWR ICWR
(0) (0) (Defaults)

IZWR = indicator to print out impedance matrix.

0 do not print out impedance matrix.

1 print out impedance matrix.

ICWR = indicator to print out right hand side vector and currents.

0 do not print current or solution vector

1 print current or solution vector.

Caution should be exercised in using the WRI command. Setting IZWR to 1 will result in N^2 lines of output, where N is the number of unknowns in the MM solution. Setting ICWR to 1 will result in $2N$ lines of output for every angle in a backscatter pattern.

3.18 Subroutine CGEOM

This section will describe the user generated Fortran subroutine CGEOM. If the SUB command is evoked in the INF.DAT file, then the building blocks comprising the cylinder geometry are defined in subroutine CGEOM. However, the user must specify all other non-building block information in the INF.DAT input file. The window parameters of subroutine CGEOM always have the exact form as shown in Appendix A. A user may have several subroutine CGEOM's for defining various cylinder geometries. All are called CGEOM and all have the window parameters shown in Appendix A. A particular subroutine CGEOM is selected by linking that subroutine CGEOM with GCYL.

When GCYL is linked to form an executable program, a subroutine CGEOM must be included or a link error stating that module CGEOM can not be found will be generated. Thus, a user who does not wish to employ the subroutine CGEOM must either comment out (by placing a C in column one) the call to CGEOM in the GCYL main program, or include a dummy subroutine CGEOM such as the one shown in Appendix A.

3.18.1 CGEOM Window Inputs and Outputs

Referring to Appendix A, window parameters FMHZ, SEGM, and SEGC are inputs to CGEOM and are specified by commands FMZ and ACU respectively, while the remaining parameters are outputs and must be defined in subroutine CGEOM. All of the window parameters in CGEOM have been defined in Section 3.18, however, for convenience they will also briefly be defined here. The reader is referred to Figure 2.2 for the geometry of the five types of building blocks.

Inputs to Subroutine CGEOM

FMHZ = frequency in Megahertz.

SEGM = maximum side length in material wavelengths for segmenting the material building blocks into the MM expansion functions.

SEGC = maximum segment size in free space wavelengths for segmenting the TYPE 1 building blocks into the MM expansion functions.

Outputs from Subroutine CGEOM

NGEN = the number of building blocks.

ITYP(I) = the block type for building block I.

= 1 implies a sheet impedance strip from points 1 to 2.

= 2 implies a quadrilateral material cylinder in the region 1,2,3,4.

= 3 implies a sheet impedance strip from points 1 to 2 coated with a material in the quadrilateral region 1,2,3,4.

= 4 implies a sheet impedance strip from points 1 to 2 coated with a material in the quadrilateral region 1,2,3,4 and in the quadrilateral region $1, 2, 3', 4'$.

= 5 implies a quadrilateral material cylinder in the region 1,2,3,4 coated on any side(s) by sheet impedance strips.

X1(I), Y1(I) = (x, y) coordinates in meters of point 1 of building block I.

X2(I), Y2(I) = (x, y) coordinates in meters of point 2 of building block I.

X3(I), Y3(I) = (x, y) coordinates in meters of point 3 of building block I.

X4(I), Y4(I) = (x, y) coordinates in meters of point 4 of building block I.

X3P(I), Y3P(I) = (x, y) coordinates in meters of point $3'$ of building block I.

X4P(I), Y4P(I) = (x, y) coordinates in meters of point $4'$ of building block I.

IZSHTR(I) = indicator for the type of taper of the real part of sheet impedance in building block I.

= 1 implies a real part of sheet impedance which tapers linearly from ZSHT1(I) $\Omega/\square$ at point 1 to ZSHT2(I) $\Omega/\square$ at point 2, and similarly on any strip m,n.

= 2 implies a real part of sheet impedance which tapers exponentially from ZSHT1(I) $\Omega/\square$ at point 1 to ZSHT2(I) $\Omega/\square$ at point 2, and similarly on any strip m,n.

IZSHTI(I) = indicator for the type of taper of the imaginary part of sheet impedance in building block I.

= 1 implies an imaginary part of sheet impedance which tapers linearly from ZSHT1(I) $\Omega/\square$ at point 1 to ZSHT2(I) $\Omega/\square$ at point 2, and similarly on any strip m,n.

= 2 implies an imaginary part of sheet impedance which tapers exponentially from ZSHT1(I) $\Omega/\square$ at point 1 to ZSHT2(I) $\Omega/\square$ at point 2, and similarly on any strip m,n.

ZSHT1(I) = the complex sheet impedance in $\Omega/\Box$ at point 1 in building block I.

ZSHT2(I) = the complex sheet impedance in $\Omega/\Box$ at point 2 of building block I.

ZSHT3(I) = the complex sheet impedance in $\Omega/\Box$ at point 3 of building block I.

ZSHT4(I) = the complex sheet impedance in $\Omega/\Box$ at point 4 of building block I.

IZ12(I) = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4 of building block I.

= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4 of building block I.

IZ23(I) = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4 of building block I.

= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4 of building block I.

IZ34(I) = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4 of building block I.

= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4 of building block I.

IZ41(I) = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4 building block I.

= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4 building block I.

ER(I) the relative dielectric constant of the material in the quadrilateral region 1,2,3,4 of building block I.

TDE(I) the electric loss tangent of the material in the quadrilateral region 1,2,3,4 of building block I.

UR(I) the relative permeability of the material in the quadrilateral region 1,2,3,4 of building block I.

TDM(I) the magnetic loss tangent of the material in the quadrilateral region 1,2,3,4 of building block I.

ERP(I) the relative dielectric constant of the material in the quadrilateral region $1, 2, 3', 4'$ of building block I.

TDEP(I) the electric loss tangent of the material in the quadrilateral region $1, 2, 3', 4'$ of building block I.

URP(I) the relative permeability of the material in the quadrilateral region $1, 2, 3', 4'$ of building block I.

TDMP(I) the magnetic loss tangent of the material in the quadrilateral region $1, 2, 3', 4'$ of building block I.

IDIE indicator for dielectric material.

IFER indicator for ferrite material.

If an element in one of the above arrays is meaningless, then it does not have to be defined. For example, if ITYP(J) $= 1$, then building block J is a simple impedance strip, and X3(J), Y3(J), X4(J), Y4(J), ER(J), TDE(J), etc., need not be defined. If the parameter would not be input, then it need not be defined in CGEOM.

3.18.2 CGEOM Example - A Coated Circular Cylinder

The writing of subroutine CGEOM will now be illustrated by the example of the coated perfectly conducting circular cylinder shown in Figure 3.1a. The perfectly conducting circular cylinder is of radius A, while the coating has inner radius A and outer radius B. The coating material is homogeneous with parameters (μ, ϵ). Below we will describe a subroutine CGEOM which defines a number of building blocks that approximate the coated circular cylinder.

The GCYL model of the coated circular cylinder is shown in Figure 3.1b. For purposes of illustration, the circular cylinders of radius A and B are approximated by 12 sided regular polygons. As described below, the actual number of sides for a specific cylinder will be a function of the outer radius, B, the wavelength in the material coating, and SEGM. By connecting the corners of the inner and outer polygons, a number (i.e., NGEN = 12) of quadrilateral regions are created which will be the building blocks representing the coated cylinder. The building blocks are numbered counterclockwise from the x axis. The four corners of the N^{th} building block are shown. The building blocks will be of Type 3, i.e., coated on one side only, with a zero sheet impedance from points 1 to 2.

Appendix A shows a subroutine CGEOM which defines the building blocks representing the coated cylinder geometry. Lines 62,63 define the inner and outer radii of the cylinder, while the relative permittivity, permeability, and loss tangents of the coating are specified in lines 65-70. Although here we define the geometry of the cylinder via Fortran statements, the above parameters could easily be read from an input file.

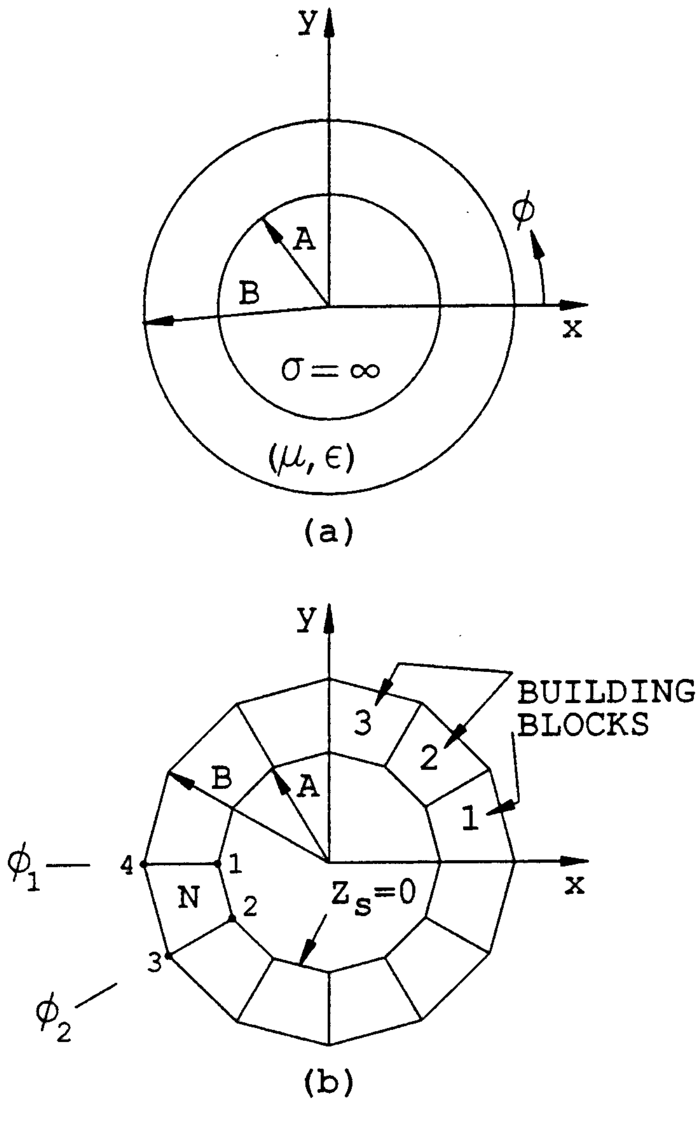

Figure 3.1: (a) Geometry for a material coated perfectly conducting circular cylinder, and (b) the cylinder model by NGEN = 12 building blocks of Type 3.

We wish to approximate the circular cross section cylinder by regular polygons such that the side length of the outer polygon does not exceed SEGM material wavelengths at the frequency f = FMHZ megahertz. Line 73 computes the wavelength in the coating material, and line 75 computes SMAX = the maximum side length of the outer polygon. Line 79 computes the angular sector, DPHI, for a side of length SMAX of a regular polygon of radius B. Since the entire polygon spans 2π radians, NSIDES = the number of sides in the polygon will be the first integer larger than 2π/DPHI. NSIDES is computed in line 82-84. Lines 83,84 insure that NSIDES is an even number greater than or equal to 4. Line 85 recomputes DPHI = the angular sector of one side of the NSIDES sided regular polygon. As seen in Line 96, NGEN = the total number of building blocks = NSIDES.

The geometry of the NGEN building blocks is defined in the DO 100 loop from lines 97 to 121. Referring to Figure 3.1b, building block N goes from $\phi_1 \leq \phi \leq \phi_2$. Lines 99,100 compute PHI1 = ϕ_1 and PHI2 = ϕ_2. Lines 102-109 then compute the (x, y) coordinates in meters of corners 1,2,3,4 for building block N. Line 112 indicates that the building blocks are of type 3, i.e., a sheet impedance strip from point 1 to 2, plus a quadrilateral material cylinder in the region 1,2,3,4. Line 113,114 sets IZSHTR(N) = 1 and IZSHTI(N) = 1 , which indicates a linear taper of both the real and imaginary parts of sheet impedance. Lines 115 and 116 define ZSHT1(N) and ZSHT2(N), the values of the sheet impedance at point 1 and point 2, respectively, as complex 0 $\Omega/\Box$, i.e., a perfectly conducting strip. Finally, lines 117-120 define the material parameters of the quadrilateral cylinder.

The advantage of writing a subroutine CGEOM is the ease of changing the parameters of the cylinder. For example, if we wish to change the cylinder radii, it is only necessary to change A and B in lines 62,63 and then CGEOM will automatically create the new geometry. By contrast, if the cylinder geometry were specified by INF.DAT, an entirely new input file would need to be created. It is hoped that the user can see that by changing a few lines, the above CGEOM could be modified to describe a coated elliptic, ogival, or rectangular cylinder.

Chapter 4

Example Runs

This section will present five example runs which illustrate the use of GCYL to compute the echo width of various cylinders. All data runs were made on the Ohio State University ElectroScience Laboratory VAX 8550 computer, using the GCYL code as it existed in June 1990. The Vax 8550 is about five times faster than the VAX 11/780.

4.1 Example 1: A Perfectly Conducting Strip

Example 1 will be to compute the backscatter echo width of a 1.0 meter wide perfectly conducting strip at $f = 300$ Mhz. An end view of the strip is shown in Figure 4.1.

The input file for Example 1 is shown in Figure 4.2. Here, we have invoked the COM command to describe the run. The PRC command is used so that a listing of the input file will be printed in the output file. The RUN command indicates that the parameters of the problem have been checked and verified by the user, and thus the electromagnetic calculation portion of GCYL is ready to be executed. If the run for Example 1 was executed without the RUN command, then the program would divide the conducting strip into mode size, provide in the output file a summary of the geometry and all other parameters of the input file, and then stop execution. The MDG command causes the program to print out all mode information in the output file. Without the MDG command, only general building block information is provided in the output file. Four parameters are set under the ACU command. These parameters are: INTM = 16 segment self-element numerical integrations in the material MM cells (not used in this example), INT = 6 segment numerical integrations on the strip MM modes, a maximum mode material side length of SEGM = 0.15 λ (not used), and a maximum conductor mode length of SEGC = .15 λ . The FMZ command defines the frequency as FMHZ = 300.0 Mhz, and the POL command shows that NPOL = 0, indicating TM polarization. The SCP command defines the parameters that specify the desired pattern. In this case, IPAT = 0 means that the pattern will be a backscatter pattern; PHID, the angle between the positive x axis and the opposite propagation direction of the incident wave for a bistatic pattern, is set to ninety (however, it is not used in this run since we are doing a backscatter pattern); and STEP = 10 means that the step size for the pattern angle is 10 degrees. Command BT1 specifies that the general cylinder geometry will be described with an ITYP(1) = 1 building block, i.e., a sheet impedance strip. The first line of data defines the (x, y) coordinates in meters of points 1 and 2, i.e., the endpoints of the strip. In the second line we set IZSHTR(1) = 1 and IZSHTI(1) = 1, indicating that both the real and imaginary parts of the sheet impedance taper from the endpoints in a linear manner. The values of sheet impedance at the endpoints are given by ZSHT1(1) = (0.0,0.0) $\Omega/\square$ and ZSHT2(1) = (0.0,0.0) $\Omega/\square$, which means that the strip is a perfectly conducting one.

The output file for Example 1 is shown in Appendix D. The first block of output summarizes the commands of the input file. The next block of output summarizes the various run control parameters. The next block of data summarizes the parameters of the NGEN building blocks. In this case there is one building block. It is shown as a Type 1 building block (a simple sheet impedance strip) from (x_1, y_1) = (-0.5,0.0) to (x_2, y_2) = (0.5,0.0) meters, with a linear taper of both the real and imaginary parts of the sheet impedance, and a sheet impedance of $0.0 + j0.0\ \Omega/\square$ at each endpoint (a perfectly conducting strip). For the purpose of the MM solution the strip is segmented into 7 smaller strips, corresponding to the MM modes. The next two groups of output show the detailed geometry of these seven MM strip modes. For example, mode 3 goes from point IA(3) = 3 to point IB(3) = 4, is of length 0.143 meters, and has zero sheet impedance. In command ACU the maximum MM segment size was specified as SEGC = 0.15 wavelengths. In this case, the wavelength is a *free space wavelength* since the problem contains no material cylinders. At $f = 300$ Mhz the free space wavelength is 1 meter, and thus our segment size is a maximum of 0.15 meters. Note that if the number of MM modes is reduced to 6, then the segment size would be 0.167 meters, which is larger than SEGC. The final group of output shows the backscatter echo width pattern. The echo width is shown in meters and in dB over a meter. Also shown is the magnitude and phase of the far zone scattered electric field. The backscatter pattern is plotted in Figure 4.3. The CPU time for Example 1 was about 0.23 seconds.

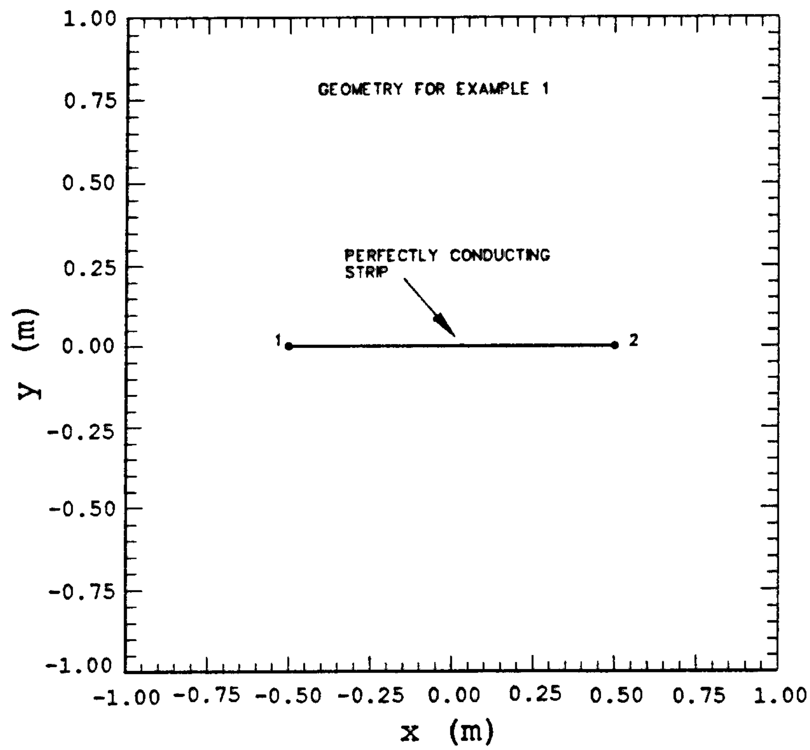

Figure 4.1: The cylinder geometry for Example 1 is a 1.0 meter wide perfectly conducting strip

```
COM
        ****EXAMPLE 1****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
POL
0
SCP
0 90.0 10.
BT1
-.5 0.0 0.5 0.
1 1 (0.0,0.0) (0.0,0.0)
END
```

Figure 4.2: The input file for Example 1

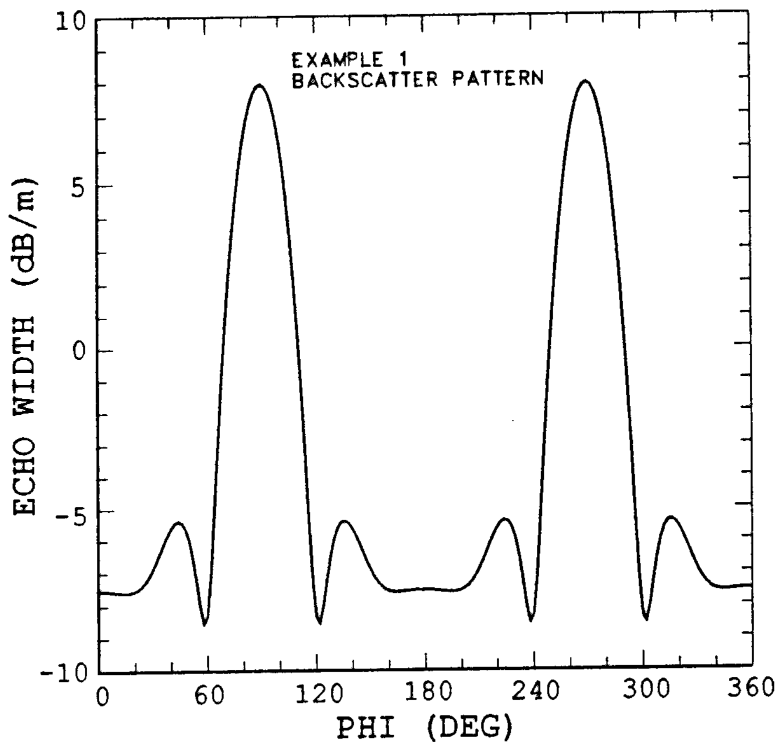

Figure 4.3: The backscatter echo width of the perfectly conducting strip in Example 1

4.2 Example 2: A Linear Tapered Sheet Impedance Strip

Example 2 will be to find the backscatter echo width for a tapered sheet impedance strip 1.0 meter wide at $f = 300.0$ Mhz. The geometry of the strip is shown in Figure 4.4. Example 2 is identical to Example 1 in all respects except that Example 2 has a non-zero value of sheet impedance. Essentially, the strip is a Type 1 building block with a sheet impedance of $Z_s = (1.0, 10.0)\Omega/\Box$ at point 1 and a sheet impedance of $Z_s = (100.0, 10.0)\Omega/\Box$ at point 2.

The input file for Example 2 is shown in Figure 4.5.

The output from Example 2 is shown in Appendix E. After the commands and the run control parameters, the output shows the geometry of the one building block. It is shown as a Type 1 building block, with a linear tapered sheet impedance strip from point 1 to 2. The sheet impedance at point 1 is $Z_s = (1.0, 10.)\Omega/\Box$ and at point 2 it is $Z_s = (100.0, 10.)\Omega/\Box$. It is indicated that the perfectly conducting strip is segmented into 7 strip modes. The detailed mode coordinates are shown next. The final output is the backscatter echo width pattern. The backscatter pattern is plotted in Figure 4.6.

The CPU time for this run was .44 seconds.

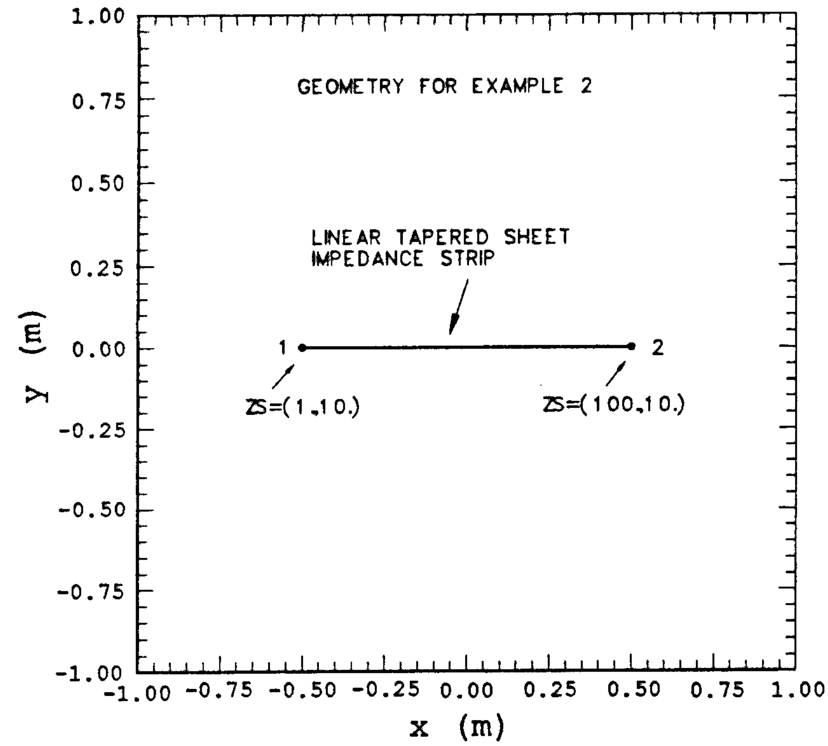

Figure 4.4: The geometry of the sheet impedance strip of Example 2

```
COM
      ****EXAMPLE 2****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
0 0
POL
1
SCP
0 90.0 10.
BT1
-.5 0.0 0.5 0.
1 1 (1.0,10.) (100.0,10.0)
END
```

Figure 4.5: The input file for Example 2

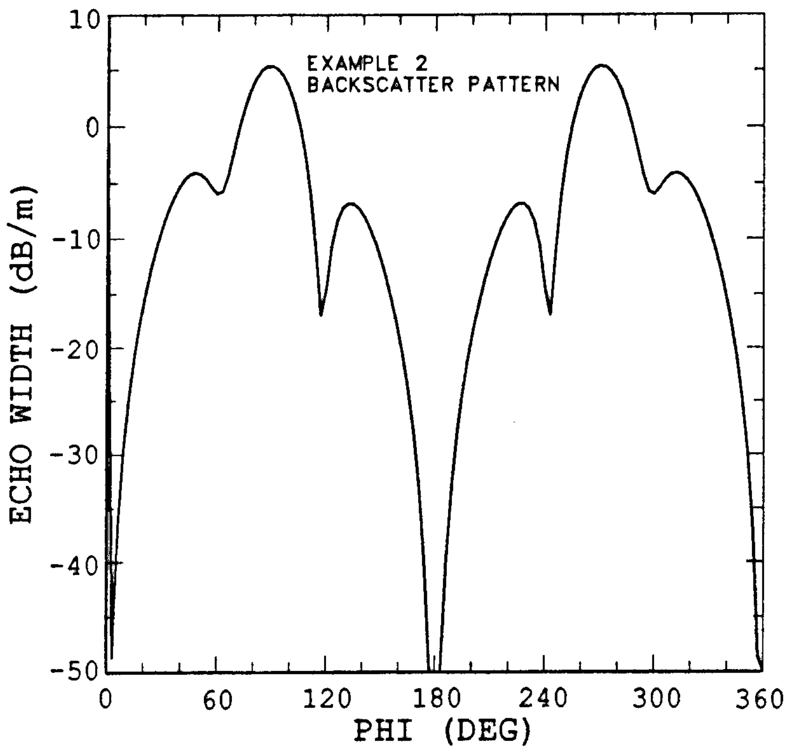

Figure 4.6: The backscatter echo width of the sheet impedance strip in Example 2

4.3 Example 3: A Material Coated Perfectly Conducting Strip

Example 3 will be to find the bistatic echo width for a 0.25 meter perfectly conducting strip coated with a 0.05 meter thick material coating on its surface at 300. Mhz. The permittivity and permeability of the coating are:

$$\epsilon_r = 1.5 \qquad \tan\delta_e = 0.1$$

$$\mu_r = 2.0 \qquad \tan\delta_m = 0.0.$$

The geometry of the coated strip is shown in Figure 4.7. Essentially, it is a Type 3 building block with a $Z_s = 0 \ \Omega/\square$ sheet impedance from point 1 to point 2. The dashed lines in Figure 4.7 show the segmentation of the rectangular cross section section material cylinder into 3 smaller rectangular cells for the purposes of the MM solution. The size of these cells should not exceed SEGM = 0.15 wavelength in the material coating.

In general GCYL will segment a quadrilateral material cylinder into a number of smaller quadrilateral cells, corresponding to the MM expansion modes in the material cylinder [1]. Figure 4.8 shows a typical quadrilateral cell, defined by the (x, y) coordinates of its four corners. Side 1 of the quadrilateral cell goes from point 1 to point 2, side 2 goes from point 2 to point 3, etc. As described below, each quadrilateral cell in general corresponds to three MM expansion modes.

If the material has a permittivity different from free space, then in the TM case each cell contains an expansion mode consisting of a uniform cylinder of $\hat{z}$ polarized electric current, shown as J_z in Figure 4.8. If the material has a permeability different from free space, then each cell contains

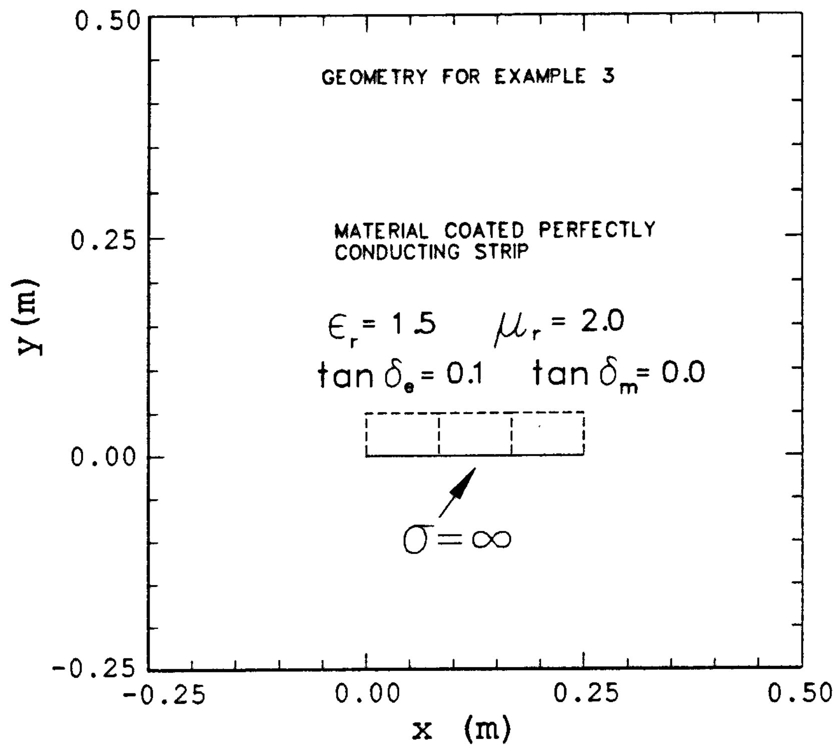

Figure 4.7: The cylinder geometry for Example 3 is a 0.25 meter wide perfectly conducting strip with a 0.05 meter thick material coating

two uniform expansion modes consisting of transverse polarized magnetic currents. One of the transverse polarized magnetic currents, denoted M_{13} in Figure 4.8, is polarized in the direction from the center of side 1 to the center of side 3. The other, denoted M_{42}, is polarized in the direction from the center of side 4 to the center of side 2. The modes are numbered so that the first are the strip modes on the conducting or sheet impedance surfaces, the next are the J_z modes in the dielectric, the next are the M_{13} modes in the ferrite, and the last are the M_{42} modes in the ferrite. In the TE case, each MM material cell which has a permittivity different from free space will have two expansion modes of electric current given by J_{13} and J_{42}, where the polarization convention is the same as for the M_{13} and M_{42} currents in the TM case. If the permeability of the material in the TE case is different from free space, then there will be a $\hat{z}$ polarized magnetic current expansion mode given by M_z.

The input file for Example 3 is shown in Figure 4.9. The COM command describes the input file. The PRC command prints the contents of the input file in the output file. The RUN command indicates that the geometry is correct and that electromagnetic calculations are ready to be performed. The MDG command causes mode information to be printed in the output file. The ACU command specifies the accuracy parameters for the run. In this case, INTM=16 means that for self-impedance material elements, a 16 by 16 integration grid will be employed; INT=6 means that 6 integration points are used for the self-elements of conducting modes, SEGM=.15 sets the maximum length of a side of a material mode at .15 material wavelengths; and SEGC=.15 sets the maximum length of a conductor mode at .15 free space wavelengths. In the present example, SEGC is ignored since the conductor part is in contact with the material part.

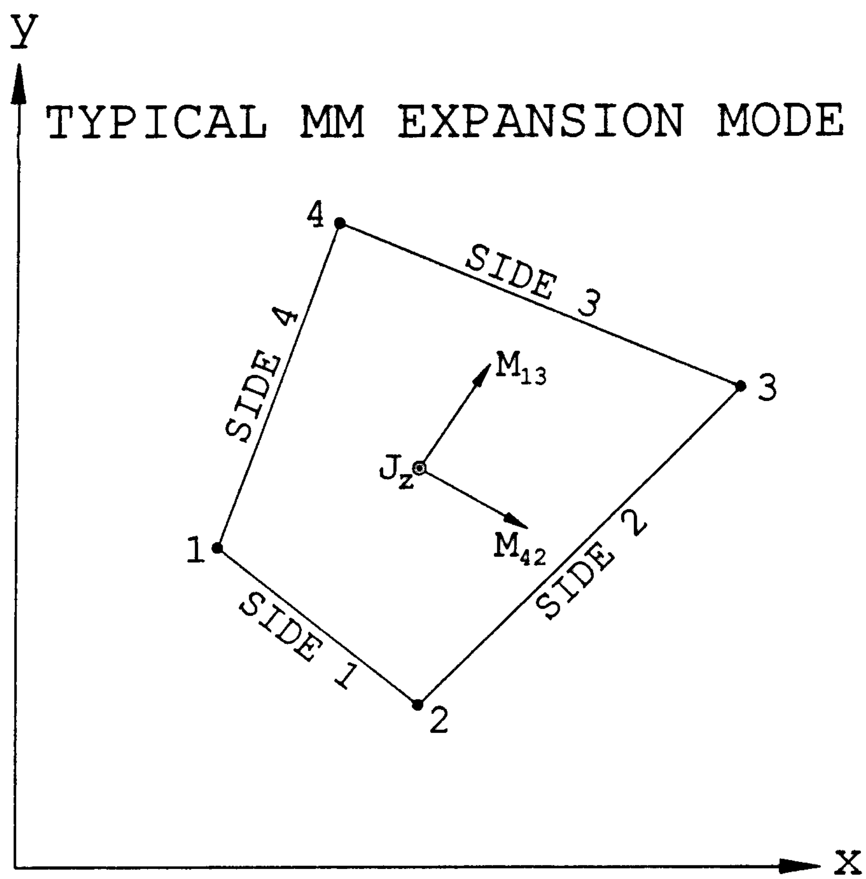

Figure 4.8: In general each quadrilateral material cell contains J_z, M_{13}, and M_{42} MM expansion modes.

SEGC is only used if the conductor is not in edge contact with a material. The FMZ command shows that the frequency in megahertz is FMHZ=300. The WRI command indicates that IZWR=1 and ICWR=1, meaning the impedance matrix, voltage vector, and current vector are to be printed in the output file. The POL command sets NPOL=0, which indicates TM polarization. The SCP command sets IPAT=1, which means a bistatic pattern is to be calculated, PHID=90.0, which sets the angle of the incident wave at 90.0 degrees, and STEP=10.0, which indicates that a pattern calculation is to be made every 10.0 degrees. The BT3 command means that we have a type 3 building block; i.e., a coated sheet impedance strip. Points 1 and 2 are given on the first data line, while points 3 and 4 are given on the second data line. The permittivity and permeability are given on the next line, and the final data line indicates a perfectly conducting strip. The END command indicates the end of the data file.

The output from Example 3 is shown in Appendix F. After the listing of the input file, run control parameters, and the frequency, the output shows the geometry of the one building block. It is shown as a Type 3 building block, with a perfectly conducting strip from point 1 to 2. The permittivity and permeability of the quadrilateral cylinder 1,2,3,4 are printed. It is indicated that the perfectly conducting strip is segmented into 3 strip modes, and the material cylinder into 3 cells. This will result in 3 conductor modes, 3 dielectric modes, and 6 ferrite modes. The detailed mode coordinates are shown next. The next output is the nine blocks of the MM impedance matrix [1]. Here M and N are row and column indices of the $[Z]$ matrix, while ML and NL are local row and column indices for the particular block of the $[Z]$ matrix. The next two outputs are the voltage and current vector for a wave incident from ϕ_i = PHID = 90°. The first 3 elements in these

```
COM
        ****EXAMPLE 3****
PRC
RUN
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
1 1
POL
0
SCP
1 90.0 10.
BT3
0.0 0.0 0.25 0.
.25 .05 0. .05
1.5 .01 2. 0.0
1 1 (0.0,0.0) (0.0,0.0)
END
```

Figure 4.9: The input file for Example 3

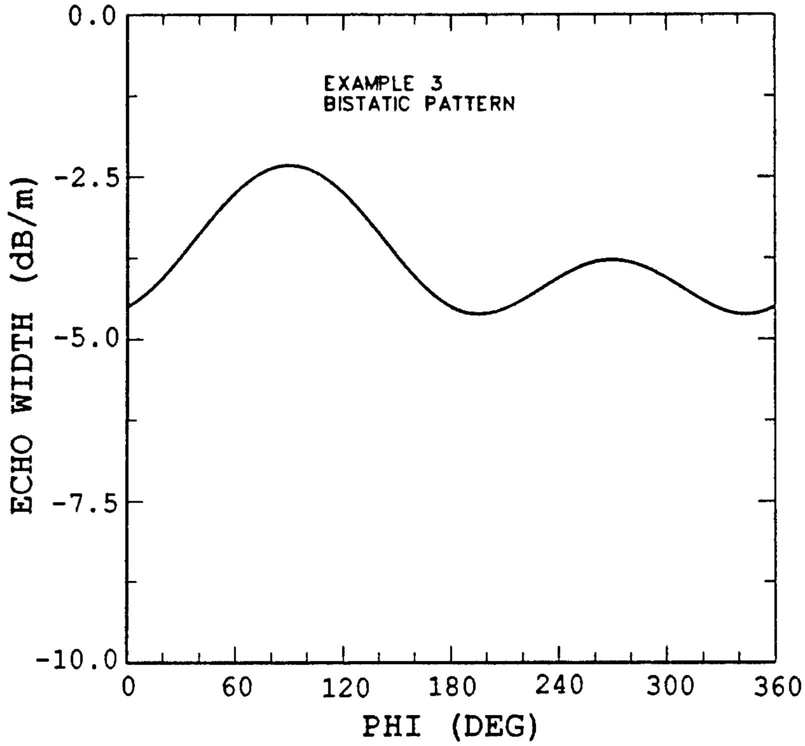

Figure 4.10: The bistatic echo width of the coated perfectly conducting strip in Example 3

vectors refer to the conductor modes, the next 3 to the J_z modes in the material cylinder, the next 3 to the M_{13} modes in the material cylinder, and the last 3 to the M_{42} modes in the material cylinder. The final output is the bistatic echo width pattern. Figure 4.10 shows a plot of the bistatic echo width. The CPU time for this run was about 2. seconds.

4.4 Example 4: A Corner Reflector

Example 4 will be to compute the bistatic echo width of a corner reflector for TE polarization at $f = 300$ Mhz. The corner reflector geometry is shown in Figure 4.11. The corner reflector consists of two perfectly conducting strips joined at a right angle and coated by a material with a permittivity of

$$\epsilon_r = 3.0 \qquad \tan\delta_e = 0.1$$

and a permeability of

$$\mu_r = 1.0 \qquad \tan\delta_m = 0.0.$$

The input file for Example 4 is shown in Figure 4.12. The COM command describes the input file. The PRC command prints the contents of the input file in the output file. The RUN command indicates that the geometry is correct and that electromagnetic calculations are ready to be performed. The MDG command causes mode information to be printed in the output file. The ACU command specifies the accuracy parameters for the run. In this case, INTM=16 means that for self-impedance material elements, a 16 by 16 integration grid will be employed; INT=6 means that 6 integration points are used for the self-elements of conducting modes, SEGM=.15 sets the maximum length of a side of a material mode at .15 material wavelengths; and SEGC=.15 sets the maximum length of a conductor mode at .15 free space wavelengths. In the present example, SEGC is ignored since the conductor part is in edge contact with the material part. The FMZ command sets the frequency at FMZ = 300.0 Mhz, and the parameters under the WRI command indicate that the voltage vector and current vector are to be printed out (ICWR=1), but not the impedance matrix (IZWR=0). The POL command is used to indicate TE polarization (NPOL=1). The parameters under the SCP command show that a bistatic pattern is desired (IPAT=1), with a pattern step of 5. degrees (STEP=5.), and the incidence angle is 45. degrees (PHID=45.). The BT3 command

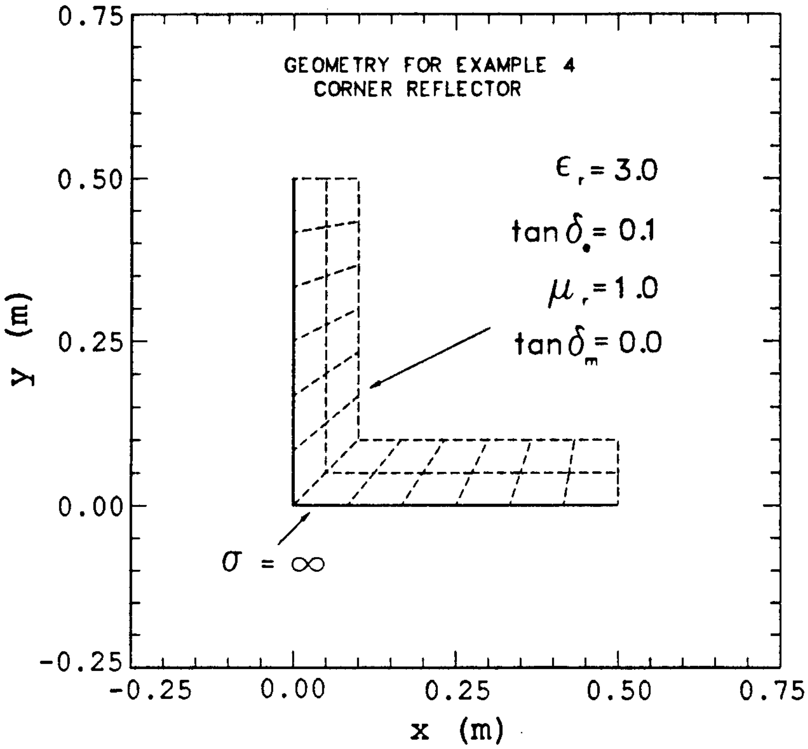

Figure 4.11: The geometry of the material coated corner reflector of Example 4

means that we have a type 3 building block; i.e., a coated sheet impedance strip. Points 1 and 2 are given on the first data line, while points 3 and 4 are given on the second data line. The permittivity and permeability are given on the next line, and the final data line indicates a perfectly conducting strip. Using two BT3 building blocks, the corner reflector of Figure 4.11 is constructed. The END command indicates the end of the data file.

The output for Example 4 is shown in Appendix G. After a summary of the input file and the run control parameters, there is a listing of the 2 building blocks. It is seen that they are type 3 building blocks (i.e.

```
COM
        ****EXAMPLE 4****
RUN
PRC
MDG
ACU
16 6 .15 .15
FMZ
300.
WRI
0 1
POL
1
SCP
1 45.0 5.
BT3
0.0 0.0 0.0 0.5
.1 .5 .1 .1
3. .1 1.0001 0.
1 1 (0.0,0.0) (0.0,0.0)
BT3
0.0 0.0 0.5 0.0
.5 .1 .1 .1
3. .1 1.00001 0.
1 1 (0.0,0.0) (0.0,0.0)
END
```

Figure 4.12: The input file for Example 4

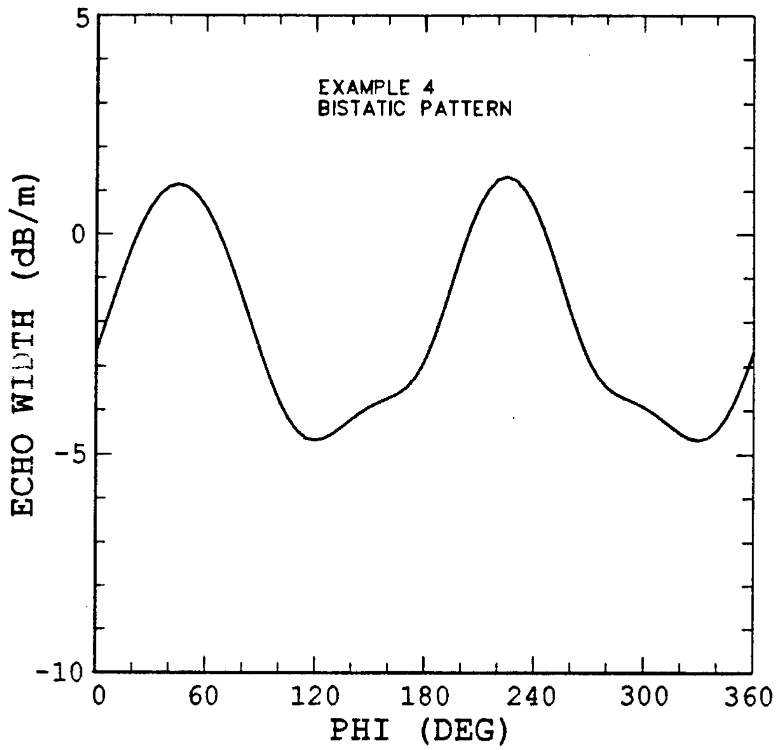

Figure 4.13: The bistatic echo width of the coated corner reflector of Example 4

coated strips), with the conducting strips extending from point 1 to point 2, whereas the dielectric material is confined by the quadrilateral regions defined by points 1,2,3, and 4. Since the building blocks are the same in physical extent and composition, they are divided in the same manner: 6 conductor segments and 12 material cells. Next is a summary of mode information. Note that although there are a total of 12 conducting segments, there are only 11 conducting modes. This is because the sinusoidal expansion functions of the TE solution extend over two segments. As a result, this particular geometry dictates the need for only 11 conductor expansion modes. There are in general 3 modes per material cell in a dielectric and ferrite material. In the TE case there are 2 dielectric modes per cell (J_{13} and J_{42}), and 1 ferrite mode per cell (M_z). As a consequence, from 24 material cells we have 48 dielectric modes and 24 ferrite modes. In the present state of the GCYL code, TE material examples always include ferrite modes in the solution, whether or not the permeability is the free space permeability or some other one. The next output is a summary of the mode information. Following the mode information is a listing of the voltage vector and the current vector. Next is the output for the bistatic pattern. The bistatic pattern is plotted in Figure 4.13. The run time was about 97 seconds.

4.5 Example 5: A Material Coated Perfectly Conducting Cylinder

Example 5 will be to compute the bistatic echo width of a coated perfectly conducting circular cylinder at $f = 300$ Mhz. The cylinder geometry is shown in Figure 4.14. The radius of the perfectly conducting cylinder is 0.15 meters, while the outer radius of the material coating is 0.25 meters.

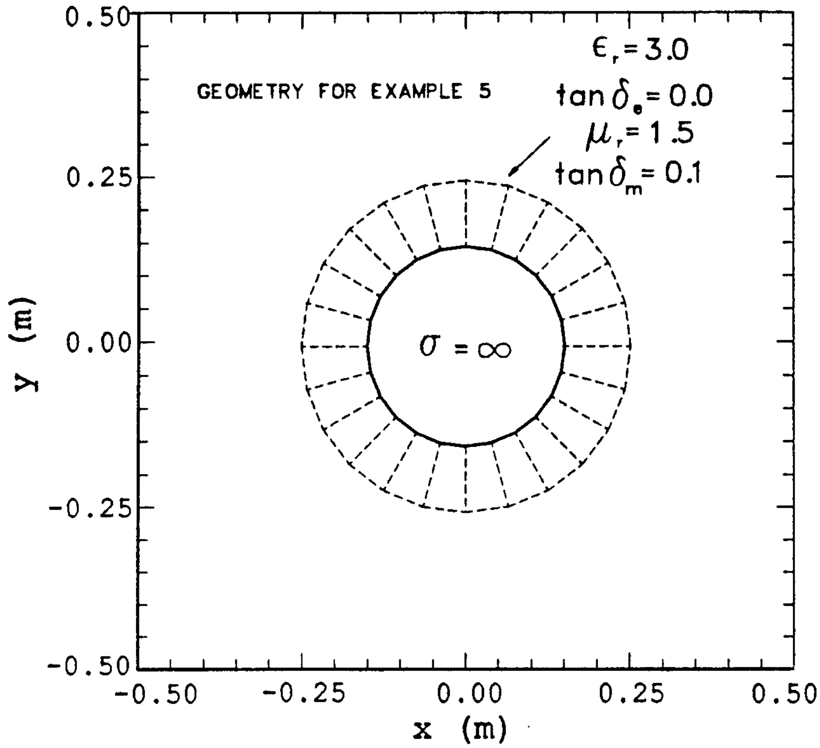

Figure 4.14: The geometry of Example 5 consists of a material coated perfectly circular cylinder.

The parameters of the material coating are:

$$\epsilon_r = 3.0 \qquad \tan\delta_e = 0.0$$

$$\mu_r = 1.5 \qquad \tan\delta_m = 0.1.$$

This coated cylinder geometry is defined by the subroutine CGEOM shown in Appendix A, and which is described in Section 3.18.2.

The input file for Example 5 is shown in Figure 4.15. This input file has basically the same form as Examples 1-4, with the one major difference being the addition of the SUB command, which implies that building block information is to be input via the subroutine CGEOM in Appendix A. Notice that there are no building block commands in the input file. From the input file, we see that the run will be made at $f = 300.0$ Mhz, the polarization is TE, and that the pattern will be bistatic, with the angle of incidence being 0.0 degrees, and a pattern step of 5. degrees.

The output file for Example 5 is shown in Appendix H. Note that in the listing of commands and inputs the SUB command has been invoked, indicating that the building block information for the run has been generated from subroutine CGEOM as listed in Appendix A. The next output is the summary of run control parameters. Following that is the building block information generated by subroutine CGEOM. It is seen that the 24 building blocks approximate a dielectric/ferrite coating of a circular conducting cylinder. The outer radius of the conducting circular cylinder is .15 meters, while the outer radius of the coating is .25 meters. The parameters of the material coating are:

$$\epsilon_r = 3.0 \qquad \tan\delta_e = 0.0$$

$$\mu_r = 1.5 \qquad \tan\delta_m = 0.1.$$

Next, a summary of modes is given, including detailed mode geometry information. Finally the bistatic pattern is output. This pattern is shown in Figure 4.16, where it is compared to an exact eigenfunction solution [7]. The CPU time for Example 5 was 316 seconds.

```
COM
        ****EXAMPLE 5****
RUN
PRC
MDG
SUB
ACU
16 6 .15 .15
FMZ
300.
WRI
0 0
POL
1
SCP
1 0.0 5.
END
```

Figure 4.15: The input file for Example 5.

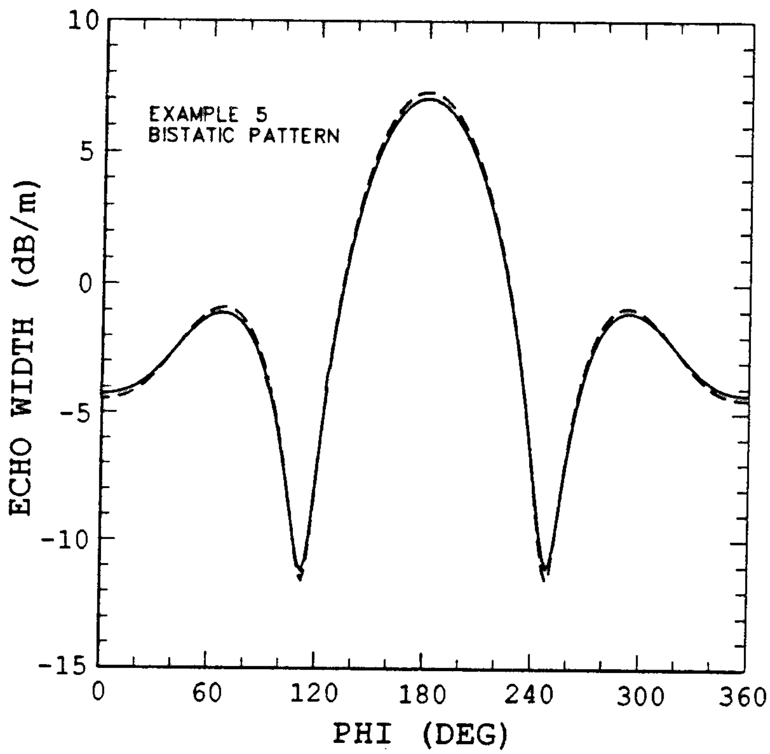

Figure 4.16: The bistatic scattering pattern of Example 5 is compared to an exact eigenfunction solution.

Chapter 5

Array Dimensions and Output Files

5.1 Array Dimensions

GCYL contains many arrays which hold the general cylinder geometry, as well as matrices and vectors used in the MM solution. The required size of these arrays is dependent upon the number of modes in the MM solution. All arrays in GCYL are dimensioned according to the two dimension indicators, IDMM and IDM, specified by PARAMETER statements at the top of the main program. A user may need to increase these dimension indicators in order to run a larger problem, or he may need to decrease them in order to "fit" GCYL on a machine with limited core storage.

The dimension indicators are defined as follows:

IDMM = maximum number of MM strip segments + maximum number of material cells (typically set to 550).

IDM = maximum number of MM modes

= maximum number of MM strip segment modes plus three times the maximum number of material cells (typically set to 1300).

Most of the core storage is in the complex array Z(IDM,IDM) which holds the MM impedance matrix (see Equation (1.1)).

5.2 Data for Geometry Plots

The output files shown in Appendices D-H provide block as well as modal descriptions of the input geometry. However, one is often interested in obtaining a visual plot of both building block data and modal data to verify that the correct geometry has been input. To aid the user in obtaining a visual image of the geometry, GCYL outputs a disk file, referred to as GPLOT, on logical unit 9. In addition, a listing of a fortran code called GEOMP is provided in Appendix B. GEOMP reads the data from file GPLOT and calls a GKS plotting subroutine named PLOTTER as well as subroutine IPOINT to generate a plot of the problem geometry. GEOMP generates a plot of either the building block geometry or the mode geometry or both.

GPLOT contains both building block geometry data and mode geometry data. It can be read with free format. In the building block part of GPLOT, the first line of GPLOT lists:

NGEN

NGEN = total number of general building blocks

The remaining lines of the building block part of GPLOT provide a tabular listing of the building block information. For a complete discussion of the different types of general building blocks available to the user, refer to Chapter 2 of this manual. Each building block line begins with the building block type:

ITYP

ITYP = 1 means a sheet impedance strip

2 means a material quadrilateral region

3 means a strip coated by a material quadrilateral region

4 means a strip coated on each side by material quadrilateral regions

5 means a quadrilateral region with strips adjacent to none, some, or all sides.

Only geometrical information is listed for a given building block type. This is because once we know what type of building block we have (BT1-BT5), only geometrical information about the block is needed to generate a plot of that block. The description for the output of each type of block follows. For a type 1 block:

X1 Y1 X2 Y2

X1,Y1 = (x, y) coordinates of point 1 of the impedance strip (meters).

X2,Y2 = (x, y) coordinates of point 2 of the sheet impedance strip (meters).

For a type 2 block:

X1 Y1 X2 Y2

X3 Y3 X4 Y4

XN,YN = (x, y) coordinates of point N of the quadrilateral region (meters).

For a type 3 block:

X1 Y1 X2 Y2

X3 Y3 X4 Y4

XN,YN = (x, y) coordinates of point N of the quadrilateral region 1,2,3,4 (meters). (note: in a type 3 block the strip lies on side 1,2 of the quadrilateral)

For a type 4 block:

X1 Y1 X2 Y2

X3 Y3 X4 Y4

X3P Y3P X4P Y4P

XN,YN = (x, y) coordinates of point N of the quadrilateral region I (meters).

XNP,YNP = (x, y) coordinates of point N = $3'$ or $4'$ of quadrilateral region II.

For a type 5 block:

X1 Y1 X2 Y2 X3 Y3 X4 Y4

IZ12 IZ23 IZ34 IZ41

XN,YN = (x, y) coordinates of point N of the quadrilateral region (meters).

IZ12 = 0 if there is no sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side12 of quadrilateral region 1,2,3,4.

IZ23 = 0 if there is no sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side23 of quadrilateral region 1,2,3,4.

IZ34 = 0 if there is no sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side34 of quadrilateral region 1,2,3,4.

IZ41 = 0 if there is no sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

= 1 if there is a sheet impedance strip on side41 of quadrilateral region 1,2,3,4.

The remaining lines of GPLOT provide mode geometry information The first line of mode information is:

LMD NM

LMD = total number of material quadrilateral cells.

NM = total number of strip segment modes.

The next NM line are a tabular listing of the strip segment modes. Each line defines:

X1 Y1 X2 Y2

X1,Y1 = (x, y) coordinates of point 1 of the impedance strip (meters).

X2,Y2 = (x, y) coordinates of point 2 of the sheet impedance strip (meters).

The next 4*LMD lines define:

X1 Y1

X2 Y2

X3 Y3

X4 Y4

XN,YN = (x, y) coordinates of point N of the quadrilateral region (meters).

5.3 Data for Pattern Plots

The output files shown in Appendices D-H provide tabular listings of the echo width patterns. However, often one desires a plot of these patterns. To aid a user who wishes to obtain a pattern plot, GCYL outputs a disk file on logical unit 7. This file will be referred to as PPLOT.

PPLOT contains ISTEP + 1 lines of output. It can be read with free format. The first line of PPLOT lists:

FMHZ = frequency in Mhz.

IPAT = indicator for type of pattern

= 0 implies a backscatter pattern = 1 implies a bistatic scatter pattern.

ISTEP = the number of pattern points going from $0 \leq \phi_s \leq 360^o$.

PHID = the angle of the incident wave in degrees for bistatic patterns.

NTOTT = the total number of MM modes.

The remaining NSTEP lines of PPLOT provide a tabular listing of the pattern. Each line defines:

PHISD = angle of the scattered wave in degrees.

WDBM = echo width in dB over a meter.

PESCTD = phase of the far zone scattered electric field in degrees.

Chapter 6

Summary

This report serves as a user's manual for a computer code (GCYL) which can compute the TM/TE scattering from a general cylinder. A general cylinder is composed of:

1. perfectly conducting cylinders of arbitrary cross section
2. lossy and inhomogeneous dielectric and/or ferrite material cylinders of arbitrary cross section
3. electrically thin dielectric strips modeled by a sheet impedance (including tapered sheet impedances).

The general cylinder geometry is constructed from a number of building blocks which are perfectly conducting or sheet impedance strips (constant or tapered) and quadrilateral cross section dielectric/ferrite cylinders. In this way, a cylinder of essentially arbitrary cross section, and with essentially arbitrary lossy and inhomogeneous material composition, can be constructed. This manual describes the basic use of GCYL, including code inputs and outputs.

Bibliography

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[4] N.N. Wang, "Reaction Formulation for Radiation and Scattering from Plates, Corner Reflectors, and Dielectric-Coated Cylinders", PhD dissertation, The Ohio State University, Dept. of Electrical Engineering, April 1974.

[5] J.H. Richmond, "An Integral-Equation Solution for TE Scattering from Conducting Cylinders", Ohio State University, Department of Electrical Engineering, Technical Report 2902-7, October, 1972.

[6] E.H. Newman and J.L. Blanchard, "TM Scattering by an Impedance Sheet Extension of a Parabolic Cylinder", IEEE Trans. on Antennas and Propagation, vol. AP-36, April 1988, pp. 527-534.

[7] Eigenfunction solution for the material coated perfectly conducting circular cylinder supplied by Prof. J.H. Richmond of the Ohio State University ElectroScience Lab.

Appendix A

Subroutine CGEOM for a Coated Circular Cylinder

```
                                                             31-Oct-1989
16:19:40 VAX FORTRAN V5.1-10                     Page    1
                                                             31-Oct-1989
16:19:32 USER2:[ROSEM.GTM]CGEOM.FOR;19

              SUBROUTINE CGEOM(FMHZ,SEGM,SEGC,NGEN,ITYP,X1,Y1,X2,Y2,X3,Y3,
         2    X4,Y4,X3P,Y3P,X4P,Y4P,IZSHTR,IZSHTI,ZSHT1,ZSHT2,ZSHT3,ZSHT4,
         3    ER,TDE,UR,TDM,ERP,TDEP,URP,TDMP,IDIE,IFER)
      C
      C       CGEOM DEFINES GENERAL BUILDING BLOCKS FOR A MATERIAL
      C       COATED PERFECTLY CONDUCTING CIRCULAR CYLINDER COATED
      C       WITH FERRITE/DIELECTRIC MATERIAL.
      C
      C INPUTS:
      C
      C       FMHZ = FREQUENCY IN MEGAHERTZ
      C       SEGM = MAX. LENGTH OF A CELL OR SEGMENT LENGTH(IN MATERIAL
      C                                                     SPACE
WV'S)
      C       SEGC = MAX. LENGTH OF A CONDUCTOR SEGMENT (IN FREE SPACE
WV'S)
      C
      C       OUTPUTS:
      C
      C       NGEN=NO. OF BUILDING BLOCKS
```

```
C       ITYP(I)=1 IMPLIES A SHEET IMPEDANCE STRIP
C              =2 IMPLIES A MATERIAL QUAD.
C              =3 IMPLIES A SHEET IMPEDANCE WITH MATERIAL COAT
ON
C                  ONE SIDE
C              =4 IMPLIES A SHEET IMPEDANCE WITH MATERIAL COATING
C                  ON BOTH SIDES
C              =5 IMPLIES A MATERIAL QUAD. COATED WITH A SHEET
C                 IMPEDANCE ON BOTH SIDES
C                   ARRAYS:
C       X1,X2,X3,X4 = X COORDINATES OF PTS. 1,2,3,4 OF QUAD.
REGION
C Y1,Y2,Y3,Y4 = Y COORDINATES OF PTS. 1,2,3,4 '    '        '
C       X3P,X4P     = X COORDINATES OF PTS. 3,4 OF 2nd COAT
C       Y3P,Y4P     = Y COORDINATES OF PTS. 3,4 OF 2nd COAT
C       IZSHTR(NG)=1 IMPLIES A LINEAR TAPERED REAL PART SHEET
IMPEDANCE
C                 =2 IMPLIES AN EXPONENTIALLY REAL
C                         PART TAPERED SHEET IMPEDANCE
C       IZSHTI(NG)=1 IMPLIES A LINEAR TAPERED
C                     IMAGINARY PART OF THE SHEET IMPEDANCE
C                =2 IMPLIES AN EXPONENTIALLY TAPERED
C                     IMAGINARY PART OF THE SHEET IMPEDANCE
C       ZSHTN(I) =FOUR ARRAYS HOLDING THE SHEET IMPEDANCE AT
THE Nth pt.
C
C
C       ER(I)  = RELATIVE PERMITTIVITY OF THE Ith BLOCK
C       TDE(I) = ELECTRIC LOSS TANGENT OF THE Ith    '     '
C       UR(I)  = RELATIVE PERMEABILITY '   '   '   '       '
C       TDM(I) = MAGNETIC LOSS TANGENT '   '   '   '       '.
C       ERP(I) = RELATIVE PERMITTIVITY OF THE 2nd COAT OF THE
Ith BLOCK
C       TDEP(I)= ELECTRIC LOSS TANGENT '  '   '   '   '   '
'  '
C       URP(I) = RELATIVE PERMEABILITY '   '   '   '   '   '
'  '
C       TDMP(I)= MAGNETIC LOSS TANGENT '   '   '   '   '   '
'  '
C       IDIE = INDICATOR FOR DIELECTRIC
C       IFER = INDICATOR FOR FERRITE
C
        DIMENSION X1(1),Y1(1),X2(1),Y2(1),X3(1),Y3(1),X4(1),Y4(1),
     2  X3P(1),Y3P(1),X4P(1),Y4P(1),IZSHTR(1),IZSHTI(1)
```

```
            DIMENSION ITYP(1),ER(1),TDE(1),UR(1),TDM(1),
     2      ERP(1),TDEP(1),URP(1),TDMP(1)
CGEOM                                                          31-Oct-1989
16:19:40 VAX FORTRAN V5.1-10                  Page   2
                                                               31-Oct-1989
16:19:32 USER2:[ROSEM.GTM]CGEOM.FOR;19

            COMPLEX ZSHT1(1),ZSHT2(1),ZSHT3(1),ZSHT4(1)
C           DEFINE PI
            DATA PI /3.141593/
C           SPECIFY A = INNER RADIUS AND B = OUTER RADIUS
            AA=.25
            BB=0.15
C           SPECIFY THE MATERIAL PARAMETERS OF THE COATING
            ERC=3.000
            TDEC=0.
            IDIE=1
            URC=1.5
            TDMC=0.1
            IFER=1
C           COMPUTE THE WAVELENGTH IN AIR AND IN THE COATING
            WVO=300.0/FMHZ
            WVC=WVO/SQRT(ERC*URC)
C           COMPUTE THE MAXIMUM SEGMENT SIZE FOR THE MM MODES
            SMAX=SEGM*WVC
C           IF THIS WAS A PURELY CONDUCTING CYLINDER, THEN ONE
C           WOULD USE SMAX=SEGC*WVC.
C           COMPUTE THE ANGULAR DPHI OF EACH SIDE OF THE POLYGON
            DPHI=2.0*ASIN(SMAX/(2.0*BB))
C           COMPUTE THE NUMBER OF SIDES IN THE POLYGON, INSURING
C           THAT IT IS AN EVEN NUMBER. ALSO RESET DPHI
            NSIDES=IFIX(0.99+(2.0*PI/DPHI))
            NSIDES=2*((NSIDES+1)/2)
            IF(NSIDES.LT.4)NSIDES=4
            DPHI=2.0*PI/NSIDES
C
C ADJUST THE RADII FOR EQUAL AREA
C
      FAC=SQRT(PI/(NSIDES*COS(0.5*DPHI)*SIN(0.5*DPHI)))
      A=AA*FAC
      B=BB*FAC
      TYPE*,'AA,BB = ',AA,BB
      TYPE*,'A,B = ',A,B
C           DEFINE THE NGEN = NSIDES GENERAL BUILDING BLOCKS
```

```
C     REPRESENTING THE COATED PERFECTLY CONDUCTING CYLINDER.
      NGEN=NSIDES
      DO100N=1,NGEN
C     GENERAL BUILDING BLOCK N GOES FROM PHI1 TO PHI2
      PHI1=(N-1)*DPHI
      PHI2=PHI1+DPHI
C     COMPUTE THE X,Y COORDINATES OF POINTS 1,2,3,4.
      X1(N)=A*COS(PHI1)
      Y1(N)=A*SIN(PHI1)
      X2(N)=A*COS(PHI2)
      Y2(N)=A*SIN(PHI2)
      X3(N)=B*COS(PHI2)
      Y3(N)=B*SIN(PHI2)
      X4(N)=B*COS(PHI1)
      Y4(N)=B*SIN(PHI1)
C     DEFINE THE BLOCK TYPE, SHEET IMPEDANCE, AND
C     MATERIAL PARAMETERS OF THE GENERAL BUILDING BLOCKS.
      ITYP(N)=3
      IZSHTR(N)=1
      IZSHTI(N)=1
```



```
      ZSHT1(N)=(0.0,0.0)
      ZSHT2(N)=(0.0,0.0)
      ER(N)=ERC
      TDE(N)=TDEC
      UR(N)=URC
      TDM(N)=TDMC
  100 CONTINUE
      RETURN
      END
```

Appendix B

Subroutine GEOMP for Generating Block and Mode Geometry Plots

```
C
C       PROGRAM GEOMP ACCEPTS BLOCK COORDINATE AND
C       MODE COORDINATE INFORMATION
C       AND PRODUCES A PLOT OF THE GEOMETRY
C
C
C       DECLARING VARIABLES
C
 DIMENSION X(2),Y(2),XN1(5),YN1(5),XC(1000),YC(1000)
        INTEGER LMD,NM,NT,NGEN
        NT=0
C
C       IGEOM = 0 IF ONLY THE GENERAL BULIDING BLOCK GEOMETRY
IS TO BE PLOTTED
C               1 IF ONLY THE MODE GEOMETRY IS TO BE PLOTTED
C               2 IF BOTH PLOTS ARE TO BE PLOTTED
C
        TYPE*,'SELECT GEOMETRY TO BE PLOTTED: 0=BLOCK 1=MODE
2=BOTH'
        ACCEPT*,IGEOM
C
C       READ: NGEN = NUMBER OF BUILDING BLOCKS
```

```
C
          READ(9,*)NGEN

          DO 5 I=1,NGEN
C
C         READ: ITP = TYPE OF BUILDING BLOCK: 1=BT1 2=BT2 3=BT3
4=BT4 5=BT5
C
      READ(9,*)ITP
C
C         READ: X1,Y1,X2,Y2 = POINT 1 AND POINT 2 OF BLOCK
C
           READ(9,*)X(1),Y(1),X(2),Y(2)
C
C         PLOTTING SHEET IMPEDANCE PART FOR BT1-BT4
C
          IF(ITP.NE.2.AND.ITP.NE.5.AND.IGEOM.NE.1)THEN
           NT=NT+1
           IF(NT.EQ.99)NT=NT+1
C
C          IN PLOTTER 0 INDICATES A SINGLE PLOT
C
           IF(I.EQ.NGEN.AND.NGEN.EQ.1.AND.ITP.EQ.1)NT=0
           CALL PLOTTER(X,Y,2,-90,0,1,NT)
          ENDIF

           IF(ITP.GT.1)THEN
C
C          READ: X3,Y3,X4,Y4 = POINT 3 AND POINT 4 OF BLOCK
C
           READ(9,*)XN1(3),YN1(3),XN1(4),YN1(4)
           XN1(1)=X(1)
           YN1(1)=Y(1)
           XN1(2)=X(2)
           YN1(2)=Y(2)
           ENDIF
           IF(ITP.EQ.5)THEN
C
C          READ: I12,I23,I34,I41 = 0 FOR NO SHEET IMPEDANCE ON
SIDE12(23)(34)(41)
C                                  1 FOR A SHEET IMPEDANCE ON SIDE12(23)(34)(4
C
           READ(9,*)I12,I23,I34,I41
C
```

```
C          PLOTTING THE SHEET IMPEDANCE PART OF A BT5 BLOCK
C
          IF(IGEOM.NE.1)THEN
           IF(I12.EQ.1)THEN
           NT=NT+1
           IF(NT.EQ.99)NT=NT+1
           CALL PLOTTER(X,Y,2,-90,0,1,NT)
           ENDIF
           IF(I23.EQ.1)THEN
           NT=NT+1
           X(1)=XN1(2)
           Y(1)=YN1(2)
   X(2)=XN1(3)
           Y(2)=YN1(3)
           IF(NT.EQ.99)NT=NT+1
           CALL PLOTTER(X,Y,2,-90,0,1,NT)
           ENDIF
           IF(I34.EQ.1)THEN
           X(1)=XN1(3)
           Y(1)=YN1(3)
   X(2)=XN1(4)
           Y(2)=YN1(4)
           NT=NT+1
           IF(NT.EQ.99)NT=NT+1
           CALL PLOTTER(X,Y,2,-90,0,1,NT)
           ENDIF
           IF(I41.EQ.1)THEN
           NT=NT+1
           X(1)=XN1(4)
           Y(1)=YN1(4)
   X(2)=XN1(1)
           Y(2)=YN1(1)
           IF(NT.EQ.99)NT=NT+1
           CALL PLOTTER(X,Y,2,-90,0,1,NT)
           ENDIF
          ENDIF
          ENDIF
C
C          PLOTTING QUADRILATERAL INFORMATION FOR BT2-BT5
C
           IF(ITP.NE.1)THEN
            IF(IGEOM.NE.1)THEN
            X(1)=XN1(1)
            Y(1)=YN1(1)
```

```
      X(2)=XN1(2)
      Y(2)=YN1(2)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(2)
      Y(1)=YN1(2)
      X(2)=XN1(3)
      Y(2)=YN1(3)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(3)
      Y(1)=YN1(3)
      X(2)=XN1(4)
      Y(2)=YN1(4)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(4)
      Y(1)=YN1(4)
      X(2)=XN1(1)
      Y(2)=YN1(1)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      ENDIF
       IF(ITP.EQ.4)THEN
C
C    READ: X3P,Y3P,X4P,Y4P = POINT 3' AND 4' OF BT4 BLOCK
C
       READ(9,*)XN1(3),YN1(3),XN1(4),YN1(4)
```

```
         IF(IGEOM.NE.1)THEN
        X(1)=XN1(1)
        Y(1)=YN1(1)
        X(2)=XN1(2)
        Y(2)=YN1(2)
        NT=NT+1
        IF(NT.EQ.99)NT=NT+1
        CALL IPOINT(XC,YC,X,Y,NT,IND)
        IF(IND.EQ.0)THEN
        CALL PLOTTER(X,Y,2,-90,0,2,NT)
        ENDIF
        X(1)=XN1(2)
        Y(1)=YN1(2)
        X(2)=XN1(3)
        Y(2)=YN1(3)
        NT=NT+1
        IF(NT.EQ.99)NT=NT+1
        CALL IPOINT(XC,YC,X,Y,NT,IND)
        IF(IND.EQ.0)THEN
        CALL PLOTTER(X,Y,2,-90,0,2,NT)
        ENDIF
        X(1)=XN1(3)
        Y(1)=YN1(3)
        X(2)=XN1(4)
        Y(2)=YN1(4)
        NT=NT+1
        IF(NT.EQ.99)NT=NT+1
        CALL IPOINT(XC,YC,X,Y,NT,IND)
        IF(IND.EQ.0)THEN
        CALL PLOTTER(X,Y,2,-90,0,2,NT)
        ENDIF
        X(1)=XN1(4)
        Y(1)=YN1(4)
        X(2)=XN1(1)
        Y(2)=YN1(1)
        NT=NT+1
        IF(NT.EQ.99)NT=NT+1
        CALL IPOINT(XC,YC,X,Y,NT,IND)
        IF(IND.EQ.0)THEN
        CALL PLOTTER(X,Y,2,-90,0,2,NT)
        ENDIF
         ENDIF
         ENDIF
       ENDIF
```

```
    5   CONTINUE
C
C        IN PLOTTER 99 INDICATES LAST PLOT
C
        IF(IGEOM.NE.1)THEN
        NT=99
        X(1)=0.0
        Y(1)=0.0
        Y(2)=0.00001
        X(2)=0.00001
        CALL PLOTTER(X,Y,2,-90,0,3,NT)
        ENDIF
C
C       MODE INFORMATION PART
C
C       READ: LMD = NUMBER OF QUADRILATERAL CELLS
C             NM = NUMBER OF SHEET IMPEDANCE SEGMENTS
C
        READ(9,*)LMD,NM
C
C       INITIALIZE PLOT NUMBER
C
         NT=0
C
C       PLOT SEGMENTS
C
        IF(IGEOM.NE.0)THEN
        DO 21 J1=1,NM
C
C       READ: X(1),Y(1),X(2),Y(2) = POINT 1 AND POINT 2 OF SEGMENT
C
         READ(9,*)X(1),Y(1),X(2),Y(2)
         IF(NM.NE.1)NT=NT+1
         IF(NT.EQ.99)NT=NT+1
         IF(NM.EQ.1.AND.LMD.EQ.0)NT=0
         CALL PLOTTER(X,Y,2,-90,0,1,NT)
   21   CONTINUE
C
C       PLOT QUADRILATERAL CELLS
C
        DO 20 J=1,LMD
         DO 30 I=1,4
           READ(9,*)XN1(I),YN1(I)
   30    CONTINUE
```

```
      X(1)=XN1(1)
      Y(1)=YN1(1)
      X(2)=XN1(2)
      Y(2)=YN1(2)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(2)
      Y(1)=YN1(2)
      X(2)=XN1(3)
      Y(2)=YN1(3)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(3)
      Y(1)=YN1(3)
      X(2)=XN1(4)
      Y(2)=YN1(4)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
      X(1)=XN1(4)
      Y(1)=YN1(4)
      X(2)=XN1(1)
      Y(2)=YN1(1)
      NT=NT+1
      IF(NT.EQ.99)NT=NT+1
      CALL IPOINT(XC,YC,X,Y,NT,IND)
      IF(IND.EQ.0)THEN
      CALL PLOTTER(X,Y,2,-90,0,2,NT)
      ENDIF
   20 CONTINUE
     IF(IGEOM.NE.0)THEN
C
C    IN PLOTTER 99 INDICATES LAST PLOT
```

```
C
      NT=99
      X(1)=0.0
      Y(1)=0.0
      Y(2)=0.00001
      X(2)=0.00001
      CALL PLOTTER(X,Y,2,-90,0,3,NT)
      ENDIF
      ENDIF
      STOP
      END
```

Appendix C

Subroutine PATP for Generating Pattern Plots

```
C       PROGRAM PATP GENERATES A PATTERN PLOT (i.e. ECHO WIDTH
C                 VS. PATTERN ANGLE)
C
DIMENSION WM(361),PH(361),PHS(361)
C
C       READ: FMHZ = FREQUENCY IN MEGAHERTZ
C             IPAT = 0 FOR BACKSCATTER PLOTS
C                    1 FOR BISTATIC PLOTS
C             ISTEP = NO. OF PATTERN POINTS GOING FROM 0 TO 360
C             PHID  = THE ANGLE OF THE INCIDENT WAVE IN DEGREES
C                            FOR BISTATIC PATTERNS
C             NTOTT = THE TOTAL NO. OF MM MODES
C
        READ(7,*)FMHZ,IPAT,ISTEP,PHID,NTOTT
DO100I=1,ISTEP
C
C       READ: PH(I) = ANGLE OF SCATTERED WAVE IN DEGREES
C             WM(I) =ECHO WIDTH IN dB OVER A METER
C             PHS(I) = PHASE IN DEGREES OF SCATTERED FIELD
C
READ(7,*)PH(I),WM(I),PHS(I)
  100 CONTINUE
CALLPLOTTER(PH,WM,NSTEP,-90,0,1,0)
STOP
END
```

Appendix D

Output for Example 1

```
      ******THE OHIO STATE UNIVERSITY******
   PLANE WAVE SCATTERING BY A GENERAL CYLINDER
       ****EXAMPLE 1****


  COMMAND PRC: PRINT COMMANDS
    **** LISTING OF COMMANDS AND INPUTS ****

  COMMAND RUN: RUN DATA

  COMMAND MDG: MODE GEOMETRY

  COMMAND ACU: ACCURACY PARAMETERS
  INTM =16   INT = 6   SEGM =.150   SEGC =.150

  COMMAND FMZ: FREQUENCY
  FMHZ =   300.0000

  COMMAND POL: POLARIZATION TYPE
  NPOL =0

  COMMAND SCP: SCATTERING PATTERN
  IPAT = 0   PHID =  90.00   STEP =  10.00

  COMMAND BT1: BLOCK TYPE 1
  X1 = -0.500   Y1 =  0.000   X2 =  0.500   Y2 =  0.000
```

```
  IZSHTR = 1   IZSHTI = 1
  ZSHT1 =(0.0E+00,0.0E+00)   ZSHT2 =(0.0E+00,0.0E+00)

  COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1
NPOL; INDICATOR FOR POLARIZATION TYPE = 0
IPAT; INDICATOR FOR PATTERN TYPE = 0
PHID; DIRECTION OF INCIDENT WAVE IN DEG. =  90.0
STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0
INF; INDICATOR FOR INTERNAL FIELDS = 0
INT; CONDUCTOR INTEGRATION SEGMENTATIONS =  6
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16
IZWR; INDICATOR TO WRITE Z-MATRIX = 0
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0
IRDG; INDICATOR FOR INPUT TYPE = 1
IDIE; INDICATOR FOR DIELECTRIC = 0
IFER; INDICATOR FOR FERRITE = 0
FHMZ; FREQUENCY IN MHZ =   300.0000
WV; WAVELENGTH IN METERS =   1.0000
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE   1 BUILDING BLOCKS:
    (LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK   1
BLOCK TYPE = 1
  PT.     X           Y
  1    -0.5000     0.0000
  2     0.5000     0.0000
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY PART SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
NO. SHEET IMPEDANCE SEGMENTS =    7

SUMMARY OF MODES:
NO. SHEET IMPEDANCE OR CONDUCTOR MODES =    7
NO. DIELECTRIC MODES =    0
NO. FERRITE MODES =    0
TOTAL NO. MODES =    7
```

CONDUCTOR ENDPOINT COORDINATES :

N = POINT NO.	X(N)	Y(N)
1	-0.5000	0.0000
2	-0.3571	0.0000
3	-0.2143	0.0000
4	-0.0714	0.0000
5	0.0714	0.0000
6	0.2143	0.0000
7	0.3571	0.0000
8	0.5000	0.0000

CONDUCTOR MODE STRIP SEGMENTS:

I	IA(I)	IB(I)	D(I)	ZSH1(I)	ZSH2(I)
1	1	2	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
2	2	3	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
3	3	4	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
4	4	5	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
5	5	6	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
6	6	7	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)
7	7	8	0.143	(0.000E+00,0.000E+00)	(0.000E+00,0.000E+00)

CPU TO GET Z-MATRIX = 0.06 SEC

BACKSCATTER PATTERN: PHI INCIDENT = PHI SCAT.

PHI S(DEG)	ECHO WIDTH(M)	ECHO WIDTH(DB/M)	|FIELD|	PHASE(DEG)
0.00	0.1764	-7.5358	0.168	124.12
10.00	0.1747	-7.5765	0.167	118.55
20.00	0.1756	-7.5544	0.167	101.17
30.00	0.2043	-6.8971	0.180	73.12
40.00	0.2736	-5.6286	0.209	42.71
50.00	0.2528	-5.9730	0.201	11.77
60.00	0.1463	-8.3469	0.153	-61.26
70.00	1.1391	0.5656	0.426	-126.36
80.00	4.1944	6.2267	0.817	-141.04
90.00	6.2232	7.9402	0.995	-144.38
100.00	4.1944	6.2267	0.817	-141.04
110.00	1.1391	0.5656	0.426	-126.36
120.00	0.1463	-8.3469	0.153	-61.26

130.00	0.2528	-5.9730	0.201	11.77
140.00	0.2736	-5.6286	0.209	42.71
150.00	0.2043	-6.8971	0.180	73.12
160.00	0.1756	-7.5544	0.167	101.17
170.00	0.1747	-7.5765	0.167	118.55
180.00	0.1764	-7.5358	0.168	124.12
190.00	0.1747	-7.5765	0.167	118.55
200.00	0.1756	-7.5544	0.167	101.17
210.00	0.2043	-6.8971	0.180	73.12
220.00	0.2736	-5.6286	0.209	42.71
230.00	0.2528	-5.9730	0.201	11.77
240.00	0.1463	-8.3469	0.153	-61.26
250.00	1.1391	0.5656	0.426	-126.36
260.00	4.1944	6.2267	0.817	-141.04
270.00	6.2232	7.9402	0.995	-144.38
280.00	4.1944	6.2267	0.817	-141.04
290.00	1.1391	0.5656	0.426	-126.36
300.00	0.1463	-8.3469	0.153	-61.26
310.00	0.2528	-5.9730	0.201	11.77
320.00	0.2736	-5.6286	0.209	42.71
330.00	0.2043	-6.8971	0.180	73.12
340.00	0.1756	-7.5545	0.167	101.17
350.00	0.1747	-7.5765	0.167	118.55
360.00	0.1764	-7.5358	0.168	124.12

CPU TIME TO SOLVE CURRENTS AND E.W. = 0.19 SEC

TOTAL CPU TIME= 0.25 SEC

Appendix E

Output for Example 2

```
      ******THE OHIO STATE UNIVERSITY******
   PLANE WAVE SCATTERING BY A GENERAL CYLINDER
       ****EXAMPLE 2****


 COMMAND PRC: PRINT COMMANDS
   **** LISTING OF COMMANDS AND INPUTS ****

 COMMAND RUN: RUN DATA

 COMMAND MDG: MODE GEOMETRY

 COMMAND ACU: ACCURACY PARAMETERS
 INTM =16    INT = 6    SEGM =.150    SEGC =.150

 COMMAND FMZ: FREQUENCY
 FMHZ =    300.0000

 COMMAND WRI: WRITE INDICATORS
 IZWR = 0    ICWR = 0

 COMMAND POL: POLARIZATION TYPE
 NPOL =1

 COMMAND SCP: SCATTERING PATTERN
```

```
   IPAT = 0   PHID =  90.00   STEP =  10.00

   COMMAND BT1: BLOCK TYPE 1
   X1 = -0.500   Y1 =  0.000   X2 =  0.500   Y2 =  0.000
   IZSHTR = 1   IZSHTI = 1
   ZSHT1 =(0.1E+01,0.1E+02)   ZSHT2 =(0.1E+03,0.1E+02)

   COMMAND END: END OF INPUT DATA

 SUMMARY OF RUN CONTROL PARAMETERS:

 NGO; PARAMETER TO CONTINUE RUN = 1
 NPOL; INDICATOR FOR POLARIZATION TYPE = 1
 IPAT; INDICATOR FOR PATTERN TYPE = 0
 PHID; DIRECTION OF INCIDENT WAVE IN DEG. =  90.0
 STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0
 INF; INDICATOR FOR INTERNAL FIELDS = 0
 INT; CONDUCTOR INTEGRATION SEGMENTATIONS =  6
 INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16
 IZWR; INDICATOR TO WRITE Z-MATRIX = 0
 ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0
 IRDG; INDICATOR FOR INPUT TYPE = 1
 IDIE; INDICATOR FOR DIELECTRIC = 0
 IFER; INDICATOR FOR FERRITE = 0
 FHMZ; FREQUENCY IN MHZ =   300.0000
 WV; WAVELENGTH IN METERS =   1.0000
 SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150
 SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150
 IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

 GEOMETRY FOR THE   1 BUILDING BLOCKS:
     (LINEAR DIMENSIONS IN METERS)

 GEOMETRY FOR BUILDING BLOCK   1
 BLOCK TYPE = 1
   PT.    X          Y
   1    -0.5000    0.0000
   2     0.5000    0.0000
 REAL PART SHEET IMPEDANCE TAPER TYPE = 1
 IMAGINARY PART SHEET IMPEDANCE TAPER TYPE = 1
 ZSHT1 =(.10E+01,.10E+02)  ZSHT2 =(.10E+03,.10E+02)
 NO. SHEET IMPEDANCE SEGMENTS =    7

 SUMMARY OF MODES:
```

NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 6
NO. DIELECTRIC MODES = 0
NO. FERRITE MODES = 0
TOTAL NO. MODES = 6

CONDUCTOR ENDPOINT COORDINATES :

N = POINT NO.	X(N)	Y(N)
1	-0.5000	0.0000
2	-0.3571	0.0000
3	-0.2143	0.0000
4	-0.0714	0.0000
5	0.0714	0.0000
6	0.2143	0.0000
7	0.3571	0.0000
8	0.5000	0.0000

CONDUCTOR MODE STRIP SEGMENTS:

I	IA(I)	IB(I)	D(I)	ZSH1(I)	ZSH2(I)
1	1	2	0.143	(0.100E+01,0.100E+02)	(0.151E+02,0.100E+02)
2	2	3	0.143	(0.151E+02,0.100E+02)	(0.293E+02,0.100E+02)
3	3	4	0.143	(0.293E+02,0.100E+02)	(0.434E+02,0.100E+02)
4	4	5	0.143	(0.434E+02,0.100E+02)	(0.576E+02,0.100E+02)
5	5	6	0.143	(0.576E+02,0.100E+02)	(0.717E+02,0.100E+02)
6	6	7	0.143	(0.717E+02,0.100E+02)	(0.859E+02,0.100E+02)
7	7	8	0.143	(0.859E+02,0.100E+02)	(0.100E+03,0.100E+02)

CONDUCTOR MODE NUMBERS:

I = MODE	I1(I)	I2(I)	I3(I)
1	1	2	3
2	2	3	4
3	3	4	5
4	4	5	6
5	5	6	7
6	6	7	8

CPU TO GET Z-MATRIX = 0.04 SEC

BACKSCATTER PATTERN: PHI INCIDENT = PHI SCAT.
PHI S(DEG) ECHO WIDTH(M) ECHO WIDTH(DB/M) |FIELD| PHASE(DEG)

0.00	0.0000	0.0000	0.000	0.00
10.00	0.0017	-27.7156	0.016	-140.48
20.00	0.0268	-15.7247	0.065	-134.67
30.00	0.1250	-9.0296	0.141	-125.77
40.00	0.3028	-5.1886	0.220	-113.97
50.00	0.3819	-4.1803	0.247	-96.03
60.00	0.2517	-5.9905	0.200	-51.66
70.00	0.7070	-1.5060	0.335	17.15
80.00	2.4317	3.8591	0.622	40.86
90.00	3.4343	5.3584	0.739	48.50
100.00	2.0274	3.0693	0.568	49.47
110.00	0.3493	-4.5684	0.236	40.91
120.00	0.0354	-14.5043	0.075	-83.09
130.00	0.1961	-7.0745	0.177	-118.50
140.00	0.1649	-7.8279	0.162	-129.00
150.00	0.0637	-11.9571	0.101	-138.43
160.00	0.0127	-18.9604	0.045	-147.24
170.00	0.0008	-31.1412	0.011	-153.70
180.00	0.0000	-99.9900	0.000	-156.08
190.00	0.0008	-31.1412	0.011	-153.70
200.00	0.0127	-18.9604	0.045	-147.24
210.00	0.0637	-11.9571	0.101	-138.43
220.00	0.1649	-7.8279	0.162	-129.00
230.00	0.1961	-7.0745	0.177	-118.50
240.00	0.0354	-14.5043	0.075	-83.09
250.00	0.3493	-4.5684	0.236	40.91
260.00	2.0274	3.0693	0.568	49.47
270.00	3.4343	5.3584	0.739	48.50
280.00	2.4317	3.8591	0.622	40.86
290.00	0.7070	-1.5060	0.335	17.15
300.00	0.2517	-5.9905	0.200	-51.66
310.00	0.3819	-4.1803	0.247	-96.03
320.00	0.3028	-5.1886	0.220	-113.97
330.00	0.1250	-9.0296	0.141	-125.77
340.00	0.0268	-15.7247	0.065	-134.67
350.00	0.0017	-27.7155	0.016	-140.48
360.00	0.0000	-99.9900	0.000	-142.52

CPU TIME TO SOLVE CURRENTS AND E.W. = 0.32 SEC

TOTAL CPU TIME= 0.36 SEC

Appendix F

Output for Example 3

```
    ******THE OHIO STATE UNIVERSITY******
  PLANE WAVE SCATTERING BY A GENERAL CYLINDER
     ****EXAMPLE 3****


COMMAND PRC: PRINT COMMANDS
  **** LISTING OF COMMANDS AND INPUTS ****

COMMAND RUN: RUN DATA

COMMAND MDG: MODE GEOMETRY

COMMAND ACU: ACCURACY PARAMETERS
INTM =16   INT = 6   SEGM =.150   SEGC =.150

COMMAND FMZ: FREQUENCY
FMHZ =   300.0000

COMMAND WRI: WRITE INDICATORS
IZWR = 1   ICWR = 1

COMMAND POL: POLARIZATION TYPE
NPOL =0

COMMAND SCP: SCATTERING PATTERN
IPAT = 1   PHID =  90.00   STEP =  10.00
```

```
  COMMAND BT3: BLOCK TYPE 3
  X1 =  0.000   Y1 =  0.000   X2 =  0.250   Y2 =  0.000
  X3 =  0.250   Y3 =  0.050   X4 =  0.000   Y4 =  0.050
  ER =   1.500 TDE =0.1E-01 UR =   2.000 TDM =0.0E+00
  IZSHTR = 1   IZSHTI = 1
  ZSHT1 =(0.0E+00,0.0E+00) ZSHT2 =(0.0E+00,0.0E+00)

  COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1
NPOL; INDICATOR FOR POLARIZATION TYPE = 0
IPAT; INDICATOR FOR PATTERN TYPE = 1
PHID; DIRECTION OF INCIDENT WAVE IN DEG. =  90.0
STEP; INCREMENT OF PATTERN ANGLE IN DEG. = 10.0
INF; INDICATOR FOR INTERNAL FIELDS = 0
INT; CONDUCTOR INTEGRATION SEGMENTATIONS =  6
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16
IZWR; INDICATOR TO WRITE Z-MATRIX = 1
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 1
IRDG; INDICATOR FOR INPUT TYPE = 1
IDIE; INDICATOR FOR DIELECTRIC = 1
IFER; INDICATOR FOR FERRITE = 1
FHMZ; FREQUENCY IN MHZ =   300.0000
WV; WAVELENGTH IN METERS =   1.0000
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE   1 BUILDING BLOCKS:
    (LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK   1
BLOCK TYPE = 3
  PT.    X          Y
  1     0.0000     0.0000
  2     0.2500     0.0000
  3     0.2500     0.0500
  4     0.0000     0.0500
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
```

```
ER =  1.500   TDE =.1E-01   UR =  2.000   TDM =.0E+00
NO. OF MATERIAL CELLS =   3
NO. SHEET IMPEDANCE SEGMENTS =    3

SUMMARY OF MODES:
NO. SHEET IMPEDANCE OR CONDUCTOR MODES =    3
NO. DIELECTRIC MODES =    3
NO. FERRITE MODES =    6
TOTAL NO. MODES =   12

CONDUCTOR ENDPOINT COORDINATES :
N = POINT NO.       X(N)      Y(N)

  1              0.0000       0.0000
  2              0.0833       0.0000
  3              0.1667       0.0000
  4              0.2500       0.0000

CONDUCTOR MODE STRIP SEGMENTS:
  I   IA(I)   IB(I)  D(I)     ZSH1(I)         ZSH2(I)

  1     1       2   0.083 (.0E+00,.0E+00) (.0E+00, .0E+00)
  2     2       3   0.083 (.0E+00,.0E+00) (.0E+00, .0E+00)
  3     3       4   0.083 (.0E+00,.0E+00) (.0E+00, .0E+00)

  MATERIAL CELL ENDPOINT COORDINATES :
CELL    XD1     YD1     XD2     YD2     XD3     YD3     XD4     YD4

  1   0.000   0.000   0.083   0.000   0.083   0.050   0.000   0.050
  2   0.083   0.000   0.167   0.000   0.167   0.050   0.083   0.050
  3   0.167   0.000   0.250   0.000   0.250   0.050   0.167   0.050


  ELEMENTS OF THE IMPEDANCE MATRIX BY BLOCKS:
   SZ = CONDUCTOR Z-POL CURRENTS
   JZ = DIELECTRIC Z-POL CURRENTS
   M13 = FERRITE SIDE 1 TO 3-POL CURRENTS
   M42 = FERRITE SIDE 4 TO 2-POL CURRENTS
SZ/SZ BLOCK

  M     N     ML     NL             Z(M,N)

  1     1     1     1    (  0.58546E+03,  0.84309E+03)
  1     2     1     2    (  0.54602E+03,  0.28595E+03)
```

1	3	1	3	(0.43613E+03, -0.61353E+02)
2	1	2	1	(0.54602E+03, 0.28595E+03)
2	2	2	2	(0.58546E+03, 0.84309E+03)
2	3	2	3	(0.54602E+03, 0.28595E+03)
3	1	3	1	(0.43613E+03, -0.61353E+02)
3	2	3	2	(0.54602E+03, 0.28595E+03)
3	3	3	3	(0.58546E+03, 0.84309E+03)

SZ/JZ BLOCK

M	N	ML	NL	Z(M,N)
1	4	1	1	(0.57968E+03, 0.58690E+03)
1	5	1	2	(0.53722E+03, 0.21855E+03)
1	6	1	3	(0.42669E+03, -0.64074E+02)
2	4	2	1	(0.53722E+03, 0.21855E+03)
2	5	2	2	(0.57968E+03, 0.58690E+03)
2	6	2	3	(0.53722E+03, 0.21855E+03)
3	4	3	1	(0.42694E+03, -0.61044E+02)
3	5	3	2	(0.53722E+03, 0.21855E+03)
3	6	3	3	(0.57968E+03, 0.58690E+03)

SZ/M BLOCKS
SZ/M13

M	N	ML	NL	Z(M,N)
1	7	1	1	(0.83447E-06, -0.47684E-06)
1	8	1	2	(0.15191E+01, -0.14522E+01)
1	9	1	3	(0.11506E+01, -0.69977E+00)
2	7	2	1	(-0.15191E+01, 0.14522E+01)
2	8	2	2	(0.83447E-06, -0.47684E-06)
2	9	2	3	(0.15191E+01, -0.14522E+01)
3	7	3	1	(-0.11506E+01, 0.69977E+00)
3	8	3	2	(-0.15191E+01, 0.14522E+01)
3	9	3	3	(0.71526E-06, 0.71526E-06)

SZ/M42

M	N	ML	NL	Z(M,N)
1	10	1	1	(-0.38107E+01, 0.12191E+00)
1	11	1	2	(-0.87895E+00, 0.11598E+00)
1	12	1	3	(-0.18724E+00, 0.10600E+00)

2	10	2	1	(-0.87895E+00, 0.11598E+00)
2	11	2	2	(-0.38107E+01, 0.12191E+00)
2	12	2	3	(-0.87895E+00, 0.11598E+00)
3	10	3	1	(-0.17289E+00, 0.11010E+00)
3	11	3	2	(-0.87895E+00, 0.11598E+00)
3	12	3	3	(-0.38107E+01, 0.12191E+00)

JZ/SZ BLOCK

M	N	ML	NL	Z(M,N)
4	1	1	1	(0.58485E+03, 0.62297E+03)
4	2	1	2	(0.54546E+03, 0.23606E+03)
4	3	1	3	(0.43506E+03, -0.72866E+02)
5	1	2	1	(0.54546E+03, 0.23606E+03)
5	2	2	2	(0.58485E+03, 0.62297E+03)
5	3	2	3	(0.54546E+03, 0.23606E+03)
6	1	3	1	(0.43506E+03, -0.72866E+02)
6	2	3	2	(0.54546E+03, 0.23606E+03)
6	3	3	3	(0.58485E+03, 0.62297E+03)

M/SZ BLOCK
M13/SZ

M	N	ML	NL	Z(M,N)
7	1	1	1	(0.14901E-07, 0.27940E-08)
7	2	1	2	(0.21273E+01, -0.39269E+00)
7	3	1	3	(0.11478E+01, -0.70601E+00)
8	1	2	1	(-0.21273E+01, 0.39269E+00)
8	2	2	2	(0.25332E-06, -0.19558E-07)
8	3	2	3	(0.21273E+01, -0.39269E+00)
9	1	3	1	(-0.11478E+01, 0.70601E+00)
9	2	3	2	(-0.21273E+01, 0.39269E+00)
9	3	3	3	(-0.73016E-06, 0.21420E-07)

M42/SZ

M	N	ML	NL	Z(M,N)
10	1	1	1	(0.41039E+01, -0.12264E+00)
10	2	1	2	(0.74932E+00, -0.11849E+00)
10	3	1	3	(0.18053E+00, -0.10655E+00)
11	1	2	1	(0.74932E+00, -0.11849E+00)

11	2	2	2	(0.41039E+01, -0.12264E+00)
11	3	2	3	(0.74932E+00, -0.11849E+00)
12	1	3	1	(0.18053E+00, -0.10655E+00)
12	2	3	2	(0.74932E+00, -0.11849E+00)
12	3	3	3	(0.41040E+01, -0.12264E+00)

JZ/JZ BLOCK

M	N	ML	NL	Z(M,N)
4	4	1	1	(0.14497E+04, -0.27986E+05)
4	5	1	2	(0.54760E+03, 0.25165E+03)
4	6	1	3	(0.43661E+03, -0.69206E+02)
5	4	2	1	(0.54760E+03, 0.25165E+03)
5	5	2	2	(0.14497E+04, -0.27986E+05)
5	6	2	3	(0.54760E+03, 0.25165E+03)
6	4	3	1	(0.43661E+03, -0.69206E+02)
6	5	3	2	(0.54760E+03, 0.25165E+03)
6	6	3	3	(0.14497E+04, -0.27986E+05)

JZ/M BLOCKS
JZ/M13

M	N	ML	NL	Z(M,N)
4	7	1	1	(0.71054E-13, -0.35527E-13)
4	8	1	2	(0.22985E+01, -0.39331E+00)
4	9	1	3	(0.11571E+01, -0.71054E+00)
5	7	2	1	(-0.22985E+01, 0.39331E+00)
5	8	2	2	(0.47684E-06, -0.35527E-13)
5	9	2	3	(0.22985E+01, -0.39331E+00)
6	7	3	1	(-0.11571E+01, 0.71054E+00)
6	8	3	2	(-0.22985E+01, 0.39331E+00)
6	9	3	3	(-0.47684E-06, 0.00000E+00)

JZ/M42

M	N	ML	NL	Z(M,N)
4	10	1	1	(-0.95367E-06, 0.47684E-06)
4	11	1	2	(-0.65828E-07, 0.40651E-06)
4	12	1	3	(-0.91123E-07, 0.58820E-06)
5	10	2	1	(-0.53382E-07, -0.40651E-06)
5	11	2	2	(0.85265E-13, 0.47684E-06)

5	12	2	3	(0.29180E-06, -0.70329E-07)
6	10	3	1	(0.31518E-07, -0.34978E-06)
6	11	3	2	(-0.53382E-07, 0.70329E-07)
6	12	3	3	(0.47684E-06, 0.00000E+00)

M/JZ BLOCKS

M13/JZ

7	4	1	1	(-0.39977E-06, 0.44238E-08)
7	5	1	2	(0.23035E+01, -0.39363E+00)
7	6	1	3	(0.11674E+01, -0.70715E+00)
8	4	2	1	(-0.23035E+01, 0.39363E+00)
8	5	2	2	(-0.11912E-05, -0.11365E-07)
8	6	2	3	(0.23035E+01, -0.39363E+00)
9	4	3	1	(-0.11674E+01, 0.70714E+00)
9	5	3	2	(-0.23035E+01, 0.39363E+00)
9	6	3	3	(0.24168E-06, 0.22046E-07)

M42/JZ

M	N	ML	NL	Z(M,N)
10	4	1	1	(0.16275E-06, -0.30923E-08)
10	5	1	2	(-0.39649E-02, 0.21394E-04)
10	6	1	3	(-0.20880E-02, 0.16314E-03)
11	4	2	1	(0.39649E-02, -0.21397E-04)
11	5	2	2	(0.43865E-06, -0.62864E-08)
11	6	2	3	(-0.39649E-02, 0.21393E-04)
12	4	3	1	(0.20880E-02, -0.16314E-03)
12	5	3	2	(0.39649E-02, -0.21399E-04)
12	6	3	3	(0.43935E-06, -0.63883E-08)

M/M BLOCKS

M13/M13

M	N	ML	NL	Z(M,N)
7	7	1	1	(0.20633E-02, -0.16527E+00)
7	8	1	2	(0.18551E-02, -0.10846E-01)
7	9	1	3	(0.12637E-02, -0.35197E-02)
8	7	2	1	(0.18551E-02, -0.10846E-01)
8	8	2	2	(0.20633E-02, -0.16527E+00)
8	9	2	3	(0.18551E-02, -0.10846E-01)
9	7	3	1	(0.12637E-02, -0.35197E-02)
9	8	3	2	(0.18551E-02, -0.10846E-01)

9	9	3	3	(0.20633E-02, -0.16527E+00)

M42/M13

M	N	ML	NL	Z(M,N)
10	7	1	1	(0.20490E-09, -0.25141E-08)
10	8	1	2	(0.21319E-09, 0.78991E-09)
10	9	1	3	(0.18348E-09, 0.32728E-09)
11	7	2	1	(0.22026E-09, 0.16386E-08)
11	8	2	2	(0.20019E-09, -0.22878E-08)
11	9	2	3	(0.22026E-09, 0.75219E-09)
12	7	3	1	(0.15990E-09, 0.28956E-09)
12	8	3	2	(0.22969E-09, 0.21290E-08)
12	9	3	3	(0.20019E-09, -0.23632E-08)

M13/M42

M	N	ML	NL	Z(M,N)
7	10	1	1	(0.10291E-10, -0.18782E-09)
7	11	1	2	(-0.18114E-10, -0.22820E-08)
7	12	1	3	(-0.88652E-10, -0.22924E-09)
8	10	2	1	(0.21472E-09, -0.22820E-08)
8	11	2	2	(-0.21142E-10, -0.18782E-09)
8	12	2	3	(-0.18114E-10, -0.41939E-09)
9	10	3	1	(0.37701E-09, 0.70208E-09)
9	11	3	2	(0.21472E-09, -0.41939E-09)
9	12	3	3	(-0.54252E-11, 0.94377E-09)

M42/M42

M	N	ML	NL	Z(M,N)
10	10	1	1	(0.20709E-02, -0.13336E+00)
10	11	1	2	(0.20008E-02, 0.12613E-01)
10	12	1	3	(0.17994E-02, 0.30381E-02)
11	10	2	1	(0.20008E-02, 0.12613E-01)
11	11	2	2	(0.20709E-02, -0.13336E+00)
11	12	2	3	(0.20008E-02, 0.12613E-01)
12	10	3	1	(0.17994E-02, 0.30381E-02)
12	11	3	2	(0.20008E-02, 0.12613E-01)
12	12	3	3	(0.20709E-02, -0.13336E+00)

RHS OR VOLTAGE VECTOR

I	V-MAG	PHASE(DEG)
1	1.000000	0.00
2	1.000000	0.00
3	1.000000	0.00
4	1.000000	9.00
5	1.000000	9.00
6	1.000000	9.00
7	0.000000	-171.00
8	0.000000	-171.00
9	0.000000	-171.00
10	0.002653	-171.00
11	0.002653	-171.00
12	0.002653	-171.00

CURRENT OR SOLUTION VECTOR

M	I-MAG	PHASE(DEG)
1	0.000630	-49.91
2	0.000223	-25.41
3	0.000630	-49.87
4	0.000017	154.02
5	0.000015	159.97
6	0.000017	154.01
7	0.007326	-156.70
8	0.000008	-100.13
9	0.007322	23.29
10	0.040133	-114.74
11	0.037343	-107.10
12	0.040147	-114.73

BISTATIC PATTERN: PHI INCIDENT (DEG) = 90.00

PHI S(DEG)	ECHO WIDTH(M)	ECHO WIDTH(DB/M)	|FIELD|	PHASE(DEG)
0.00	0.3548	-4.5003	0.238	-136.84
10.00	0.3707	-4.3096	0.243	-139.52
20.00	0.3942	-4.0428	0.250	-143.36
30.00	0.4243	-3.7235	0.260	-148.26
40.00	0.4591	-3.3812	0.270	-154.09
50.00	0.4958	-3.0473	0.281	-160.70
60.00	0.5306	-2.7520	0.291	-167.94
70.00	0.5596	-2.5211	0.298	-175.61
80.00	0.5789	-2.3742	0.304	176.48

90.00	0.5856	-2.3237	0.305	168.55
100.00	0.5789	-2.3736	0.304	160.85
110.00	0.5598	-2.5200	0.298	153.60
120.00	0.5308	-2.7504	0.291	147.06
130.00	0.4960	-3.0452	0.281	141.44
140.00	0.4593	-3.3786	0.270	136.96
150.00	0.4246	-3.7206	0.260	133.78
160.00	0.3945	-4.0396	0.251	132.05
170.00	0.3710	-4.3063	0.243	131.83
180.00	0.3551	-4.4970	0.238	133.14
190.00	0.3469	-4.5976	0.235	135.93
200.00	0.3463	-4.6058	0.235	140.08
210.00	0.3522	-4.5318	0.237	145.45
220.00	0.3634	-4.3965	0.240	151.82
230.00	0.3778	-4.2279	0.245	158.98
240.00	0.3930	-4.0564	0.250	166.72
250.00	0.4064	-3.9106	0.254	174.78
260.00	0.4156	-3.8133	0.257	-177.06
270.00	0.4189	-3.7793	0.258	-169.05
280.00	0.4156	-3.8137	0.257	-161.43
290.00	0.4063	-3.9114	0.254	-154.43
300.00	0.3929	-4.0577	0.250	-148.27
310.00	0.3776	-4.2296	0.245	-143.15
320.00	0.3632	-4.3987	0.240	-139.22
330.00	0.3520	-4.5343	0.237	-136.59
340.00	0.3460	-4.6086	0.235	-135.32
350.00	0.3467	-4.6007	0.235	-135.42
360.00	0.3548	-4.5003	0.238	-136.84

TOTAL CPU TIME=   2.02 SEC

Appendix G

Output for Example 4

```
     ******THE OHIO STATE UNIVERSITY******
   PLANE WAVE SCATTERING BY A GENERAL CYLINDER
       ****EXAMPLE 4****


 COMMAND PRC: PRINT COMMANDS
   **** LISTING OF COMMANDS AND INPUTS ****

 COMMAND MDG: MODE GEOMETRY

 COMMAND ACU: ACCURACY PARAMETERS
 INTM =16   INT = 6   SEGM =.150   SEGC =.150

 COMMAND FMZ: FREQUENCY
 FMHZ =   300.0000

 COMMAND WRI: WRITE INDICATORS
 IZWR = 0   ICWR = 1

 COMMAND POL: POLARIZATION TYPE
 NPOL =1

 COMMAND SCP: SCATTERING PATTERN
 IPAT = 1   PHID =  45.00   STEP =    5.00

 COMMAND BT3: BLOCK TYPE 3
```

```
  X1 =  0.000   Y1 =  0.000   X2 =  0.000   Y2 =  0.500
  X3 =  0.100   Y3 =  0.500   X4 =  0.100   Y4 =  0.100
  ER =   3.000 TDE =0.1E+00 UR =   1.000 TDM =0.0E+00
  IZSHTR = 1   IZSHTI = 1
  ZSHT1 =(0.0E+00,0.0E+00) ZSHT2 =(0.0E+00,0.0E+00)

  COMMAND BT3: BLOCK TYPE 3
  X1 =  0.000   Y1 =  0.000   X2 =  0.500   Y2 =  0.000
  X3 =  0.500   Y3 =  0.100   X4 =  0.100   Y4 =  0.100
  ER =   3.000 TDE =0.1E+00 UR =   1.000 TDM =0.0E+00
  IZSHTR = 1   IZSHTI = 1
  ZSHT1 =(0.0E+00,0.0E+00) ZSHT2 =(0.0E+00,0.0E+00)

  COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1
NPOL; INDICATOR FOR POLARIZATION TYPE = 1
IPAT; INDICATOR FOR PATTERN TYPE = 1
PHID; DIRECTION OF INCIDENT WAVE IN DEG. =  45.0
STEP; INCREMENT OF PATTERN ANGLE IN DEG. =  5.0
INF; INDICATOR FOR INTERNAL FIELDS = 0
INT; CONDUCTOR INTEGRATION SEGMENTATIONS =  6
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16
IZWR; INDICATOR TO WRITE Z-MATRIX = 0
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 1
IRDG; INDICATOR FOR INPUT TYPE = 1
IDIE; INDICATOR FOR DIELECTRIC = 1
IFER; INDICATOR FOR FERRITE = 1
FHMZ; FREQUENCY IN MHZ =   300.0000
WV; WAVELENGTH IN METERS =   1.0000
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE   2 BUILDING BLOCKS:
    (LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK   1
BLOCK TYPE = 3
  PT.     X          Y
  1     0.0000     0.0000
  2     0.0000     0.5000
```

```
  3     0.1000      0.5000
  4     0.1000      0.1000
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.1E+00   UR =  1.000   TDM =.0E+00
NO. OF MATERIAL CELLS =  12
NO. SHEET IMPEDANCE SEGMENTS =    6

GEOMETRY FOR BUILDING BLOCK   2
BLOCK TYPE = 3
  PT.    X           Y
  1     0.0000      0.0000
  2     0.5000      0.0000
  3     0.5000      0.1000
  4     0.1000      0.1000
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.1E+00   UR =  1.000   TDM =.0E+00
NO. OF MATERIAL CELLS =  12
NO. SHEET IMPEDANCE SEGMENTS =    6

SUMMARY OF MODES:
NO. SHEET IMPEDANCE OR CONDUCTOR MODES =   11
NO. DIELECTRIC MODES =   48
NO. FERRITE MODES =   24
TOTAL NO. MODES =   83

CONDUCTOR ENDPOINT COORDINATES :
N = POINT NO.       X(N)      Y(N)

  1              0.0000      0.0000
  2              0.0000      0.0833
  3              0.0000      0.1667
  4              0.0000      0.2500
  5              0.0000      0.3333
  6              0.0000      0.4167
  7              0.0000      0.5000
  8              0.0833      0.0000
  9              0.1667      0.0000
 10              0.2500      0.0000
 11              0.3333      0.0000
 12              0.4167      0.0000
```

13		0.5000	0.0000

CONDUCTOR MODE STRIP SEGMENTS:

I	IA(I)	IB(I)	D(I)	ZSH1(I)	ZSH2(I)
1	1	2	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
2	2	3	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
3	3	4	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
4	4	5	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
5	5	6	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
6	6	7	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
7	1	8	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
8	8	9	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
9	9	10	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
10	10	11	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
11	11	12	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)
12	12	13	0.083	(.0E+00,.0E+00)	(.0E+00, .0E+00)

CONDUCTOR MODE NUMBERS:

I = MODE	I1(I)	I2(I)	I3(I)
1	2	1	8
2	1	2	3
3	2	3	4
4	3	4	5
5	4	5	6
6	5	6	7
7	1	8	9
8	8	9	10
9	9	10	11
10	10	11	12
11	11	12	13

MATERIAL CELL ENDPOINT COORDINATES :

CELL	XD1	YD1	XD2	YD2	XD3	YD3	XD4	YD4
1	0.000	0.000	0.000	0.083	0.050	0.125	0.050	0.050
2	0.000	0.083	0.000	0.167	0.050	0.200	0.050	0.125
3	0.000	0.167	0.000	0.250	0.050	0.275	0.050	0.200
4	0.000	0.250	0.000	0.333	0.050	0.350	0.050	0.275
5	0.000	0.333	0.000	0.417	0.050	0.425	0.050	0.350
6	0.000	0.417	0.000	0.500	0.050	0.500	0.050	0.425
7	0.050	0.050	0.050	0.125	0.100	0.167	0.100	0.100
8	0.050	0.125	0.050	0.200	0.100	0.233	0.100	0.167

9	0.050	0.200	0.050	0.275	0.100	0.300	0.100	0.233
10	0.050	0.275	0.050	0.350	0.100	0.367	0.100	0.300
11	0.050	0.350	0.050	0.425	0.100	0.433	0.100	0.367
12	0.050	0.425	0.050	0.500	0.100	0.500	0.100	0.433
13	0.000	0.000	0.083	0.000	0.125	0.050	0.050	0.050
14	0.083	0.000	0.167	0.000	0.200	0.050	0.125	0.050
15	0.167	0.000	0.250	0.000	0.275	0.050	0.200	0.050
16	0.250	0.000	0.333	0.000	0.350	0.050	0.275	0.050
17	0.333	0.000	0.417	0.000	0.425	0.050	0.350	0.050
18	0.417	0.000	0.500	0.000	0.500	0.050	0.425	0.050
19	0.050	0.050	0.125	0.050	0.167	0.100	0.100	0.100
20	0.125	0.050	0.200	0.050	0.233	0.100	0.167	0.100
21	0.200	0.050	0.275	0.050	0.300	0.100	0.233	0.100
22	0.275	0.050	0.350	0.050	0.367	0.100	0.300	0.100
23	0.350	0.050	0.425	0.050	0.433	0.100	0.367	0.100
24	0.425	0.050	0.500	0.050	0.500	0.100	0.433	0.100

RHS OR VOLTAGE VECTOR

I	V-MAG	PHASE(DEG)
1	22.649950	7.13
2	22.474653	-158.79
3	22.474655	-137.57
4	22.474655	-116.36
5	22.474651	-95.15
6	22.474665	-73.93
7	22.474651	21.21
8	22.474659	42.43
9	22.474651	63.64
10	22.474651	84.85
11	22.474653	106.07
12	1.000000	22.80
13	1.000000	42.96
14	1.000000	63.11
15	1.000000	83.26
16	1.000000	103.41
17	1.000000	123.57
18	1.000000	47.20
19	1.000000	65.23
20	1.000000	83.26
21	1.000000	101.29
22	1.000000	119.32
23	1.000000	137.36
24	1.000000	22.80

25	1.000000	42.96
26	1.000000	63.11
27	1.000000	83.26
28	1.000000	103.41
29	1.000000	123.57
30	1.000000	47.20
31	1.000000	65.23
32	1.000000	83.26
33	1.000000	101.29
34	1.000000	119.32
35	1.000000	137.36
36	16.375847	22.80
37	53.315880	42.96
38	95.944054	63.11
39	143.542801	83.26
40	193.965149	103.41
41	243.520264	123.57
42	16.375803	47.20
43	53.315742	65.23
44	95.943878	83.26
45	143.542603	101.29
46	193.964767	119.32
47	243.520096	137.36
48	16.375847	-157.20
49	53.315880	-137.04
50	95.944054	-116.89
51	143.542801	-96.74
52	193.965149	-76.59
53	243.520264	-56.43
54	16.375803	-132.80
55	53.315742	-114.77
56	95.943878	-96.74
57	143.542603	-78.71
58	193.964767	-60.68
59	243.520096	-42.64
60	266.579254	-157.20
61	266.579254	-137.04
62	266.579254	-116.89
63	266.579254	-96.74
64	266.579254	-76.59
65	266.579254	-56.43
66	266.579254	-132.80
67	266.579254	-114.77
68	266.579254	-96.74

69	266.579224	-78.71
70	266.579224	-60.68
71	266.579285	-42.64
72	266.579254	22.80
73	266.579254	42.96
74	266.579254	63.11
75	266.579254	83.26
76	266.579254	103.41
77	266.579254	123.57
78	266.579254	47.20
79	266.579254	65.23
80	266.579254	83.26
81	266.579224	101.29
82	266.579224	119.32
83	266.579285	137.36

CURRENT OR SOLUTION VECTOR

M	I-MAG	PHASE(DEG)
1	4.770626	6.62
2	4.082648	-174.77
3	2.446153	-176.98
4	0.524794	165.98
5	1.120826	17.35
6	1.755641	14.77
7	4.082999	5.23
8	2.445320	3.02
9	0.524887	-14.02
10	1.120720	-162.65
11	1.755550	-165.23
12	0.000432	87.94
13	0.000326	88.71
14	0.000168	92.56
15	0.000026	176.16
16	0.000130	-109.64
17	0.000155	-114.04
18	0.000285	89.17
19	0.000193	90.33
20	0.000080	96.50
21	0.000037	-119.41
22	0.000118	-103.50
23	0.000144	-104.40
24	0.000432	87.94
25	0.000326	88.71

26	0.000168	92.56
27	0.000026	176.15
28	0.000130	-109.64
29	0.000155	-114.04
30	0.000285	89.17
31	0.000193	90.33
32	0.000080	96.50
33	0.000037	-119.41
34	0.000118	-103.50
35	0.000144	-104.40
36	0.018956	173.81
37	0.050330	172.60
38	0.066084	172.06
39	0.061204	171.17
40	0.034657	168.03
41	0.024388	20.34
42	0.011347	171.00
43	0.030743	171.14
44	0.042148	170.76
45	0.040444	169.85
46	0.024730	166.79
47	0.004968	43.50
48	0.018950	-6.20
49	0.050353	-7.39
50	0.066068	-7.95
51	0.061202	-8.83
52	0.034657	-11.97
53	0.024386	-159.66
54	0.011348	-9.00
55	0.030749	-8.86
56	0.042144	-9.24
57	0.040443	-10.15
58	0.024730	-13.21
59	0.004968	-136.49
60	0.022231	-10.26
61	0.023491	-9.36
62	0.017623	-6.52
63	0.008627	6.08
64	0.003633	77.73
65	0.017044	34.16
66	0.060393	-9.94
67	0.053673	-8.51
68	0.036524	-4.06
69	0.016693	14.19

70	0.010137	83.42
71	0.014583	74.51
72	0.022238	169.75
73	0.023484	170.64
74	0.017617	173.48
75	0.008630	-173.92
76	0.003633	-102.29
77	0.017044	-145.84
78	0.060394	170.06
79	0.053668	171.49
80	0.036522	175.94
81	0.016694	-165.81
82	0.010137	-96.59
83	0.014583	-105.49

BISTATIC PATTERN: PHI INCIDENT (DEG) = 45.00

PHI S(DEG)	ECHO WIDTH(M)	ECHO WIDTH(DB/M)	|FIELD|	PHASE(DEG)
0.00	0.5388	-2.6860	0.293	4.27
5.00	0.6216	-2.0647	0.315	10.23
10.00	0.7188	-1.4340	0.338	15.50
15.00	0.8270	-0.8249	0.363	20.07
20.00	0.9408	-0.2650	0.387	23.97
25.00	1.0526	0.2228	0.409	27.18
30.00	1.1535	0.6201	0.428	29.69
35.00	1.2340	0.9132	0.443	31.49
40.00	1.2861	1.0927	0.452	32.57
45.00	1.3041	1.1532	0.456	32.94
50.00	1.2861	1.0927	0.452	32.57
55.00	1.2340	0.9132	0.443	31.49
60.00	1.1535	0.6200	0.428	29.69
65.00	1.0526	0.2227	0.409	27.18
70.00	0.9408	-0.2650	0.387	23.97
75.00	0.8270	-0.8250	0.363	20.07
80.00	0.7188	-1.4341	0.338	15.50
85.00	0.6216	-2.0648	0.315	10.23
90.00	0.5388	-2.6861	0.293	4.27
95.00	0.4715	-3.2652	0.274	-2.39
100.00	0.4197	-3.7706	0.258	-9.74
105.00	0.3823	-4.1761	0.247	-17.74
110.00	0.3577	-4.4644	0.239	-26.30
115.00	0.3443	-4.6303	0.234	-35.29
120.00	0.3403	-4.6817	0.233	-44.55
125.00	0.3437	-4.6378	0.234	-53.86

130.00	0.3528	-4.5251	0.237	-63.04
135.00	0.3653	-4.3729	0.241	-71.87
140.00	0.3794	-4.2088	0.246	-80.18
145.00	0.3931	-4.0548	0.250	-87.79
150.00	0.4051	-3.9244	0.254	-94.51
155.00	0.4149	-3.8202	0.257	-100.16
160.00	0.4235	-3.7318	0.260	-104.58
165.00	0.4331	-3.6336	0.263	-107.64
170.00	0.4480	-3.4872	0.267	-109.31
175.00	0.4733	-3.2486	0.274	-109.73
180.00	0.5147	-2.8841	0.286	-109.20
185.00	0.5772	-2.3865	0.303	-108.15
190.00	0.6635	-1.7818	0.325	-106.99
195.00	0.7725	-1.1212	0.351	-106.02
200.00	0.8987	-0.4638	0.378	-105.38
205.00	1.0321	0.1370	0.405	-105.04
210.00	1.1588	0.6402	0.429	-104.93
215.00	1.2639	1.0170	0.448	-104.94
220.00	1.3334	1.2496	0.461	-104.98
225.00	1.3577	1.3281	0.465	-105.01
230.00	1.3334	1.2496	0.461	-104.98
235.00	1.2639	1.0170	0.448	-104.94
240.00	1.1588	0.6402	0.429	-104.93
245.00	1.0321	0.1370	0.405	-105.04
250.00	0.8987	-0.4638	0.378	-105.38
255.00	0.7725	-1.1212	0.351	-106.02
260.00	0.6635	-1.7818	0.325	-106.99
265.00	0.5772	-2.3865	0.303	-108.15
270.00	0.5147	-2.8842	0.286	-109.20
275.00	0.4733	-3.2487	0.274	-109.73
280.00	0.4480	-3.4873	0.267	-109.31
285.00	0.4331	-3.6337	0.263	-107.64
290.00	0.4235	-3.7319	0.260	-104.58
295.00	0.4149	-3.8204	0.257	-100.16
300.00	0.4051	-3.9245	0.254	-94.51
305.00	0.3931	-4.0549	0.250	-87.79
310.00	0.3794	-4.2090	0.246	-80.18
315.00	0.3653	-4.3730	0.241	-71.87
320.00	0.3528	-4.5252	0.237	-63.03
325.00	0.3437	-4.6378	0.234	-53.86
330.00	0.3403	-4.6817	0.233	-44.54
335.00	0.3443	-4.6303	0.234	-35.29
340.00	0.3577	-4.4643	0.239	-26.30
345.00	0.3823	-4.1760	0.247	-17.74

350.00	0.4197	-3.7705	0.258	-9.74
355.00	0.4715	-3.2651	0.274	-2.39
360.00	0.5388	-2.6860	0.293	4.27

TOTAL CPU TIME= 94.66 SEC

Appendix H

Output for Example 5

```
      ******THE OHIO STATE UNIVERSITY******
    PLANE WAVE SCATTERING BY A GENERAL CYLINDER
        ****EXAMPLE 5****


  COMMAND PRC: PRINT COMMANDS
    **** LISTING OF COMMANDS AND INPUTS ****

  COMMAND MDG: MODE GEOMETRY

  COMMAND SUB: SUBROUTINE GENERATED GEOMETRY
  IRDG = 0

  COMMAND ACU: ACCURACY PARAMETERS
  INTM =16   INT = 6   SEGM =.150   SEGC =.150

  COMMAND FMZ: FREQUENCY
  FMHZ =   300.0000

  COMMAND WRI: WRITE INDICATORS
  IZWR = 0   ICWR = 0

  COMMAND POL: POLARIZATION TYPE
  NPOL =1

  COMMAND SCP: SCATTERING PATTERN
```

```
  IPAT = 1   PHID =   0.00   STEP =   5.00

  COMMAND END: END OF INPUT DATA

SUMMARY OF RUN CONTROL PARAMETERS:

NGO; PARAMETER TO CONTINUE RUN = 1
NPOL; INDICATOR FOR POLARIZATION TYPE = 1
IPAT; INDICATOR FOR PATTERN TYPE = 1
PHID; DIRECTION OF INCIDENT WAVE IN DEG. =   0.0
STEP; INCREMENT OF PATTERN ANGLE IN DEG. =  5.0
INF; INDICATOR FOR INTERNAL FIELDS = 0
INT; CONDUCTOR INTEGRATION SEGMENTATIONS =  6
INTM; MATERIAL SELF-ELEMENT INTEGRATION SEGMENTATIONS = 16
IZWR; INDICATOR TO WRITE Z-MATRIX = 0
ICWR; INDICATOR TO WRITE CURRENTS AND RHS VECTOR = 0
IRDG; INDICATOR FOR INPUT TYPE = 0
IDIE; INDICATOR FOR DIELECTRIC = 1
IFER; INDICATOR FOR FERRITE = 1
FHMZ; FREQUENCY IN MHZ =   300.0000
WV; WAVELENGTH IN METERS =   1.0000
SEGM; MAXIMUM SEGMENT SIZE IN MAT. WV = 0.150
SEGC; MAXIMUM SEGMENT SIZE OF CONDUCTOR MODES = 0.150
IMODE; INDICATOR TO PRINT MODE INFORMATION = 1

GEOMETRY FOR THE  24 BUILDING BLOCKS:
    (LINEAR DIMENSIONS IN METERS)

GEOMETRY FOR BUILDING BLOCK   1
BLOCK TYPE = 3
  PT.     X          Y
  1     0.1509     0.0000
  2     0.1457     0.0390
  3     0.2429     0.0651
  4     0.2514     0.0000
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   2
BLOCK TYPE = 3
```

```
  PT.    X          Y
  1    0.1457     0.0390
  2    0.1306     0.0754
  3    0.2177     0.1257
  4    0.2429     0.0651
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   3
BLOCK TYPE = 3
  PT.    X          Y
  1    0.1306     0.0754
  2    0.1067     0.1067
  3    0.1778     0.1778
  4    0.2177     0.1257
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   4
BLOCK TYPE = 3
  PT.    X          Y
  1    0.1067     0.1067
  2    0.0754     0.1306
  3    0.1257     0.2177
  4    0.1778     0.1778
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   5
BLOCK TYPE = 3
  PT.    X          Y
  1    0.0754     0.1306
```

```
  2     0.0390      0.1457
  3     0.0651      0.2429
  4     0.1257      0.2177
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000    TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   6
BLOCK TYPE = 3
 PT.     X           Y
  1     0.0390      0.1457
  2     0.0000      0.1509
  3     0.0000      0.2514
  4     0.0651      0.2429
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000    TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   7
BLOCK TYPE = 3
 PT.     X           Y
  1     0.0000      0.1509
  2    -0.0390      0.1457
  3    -0.0651      0.2429
  4     0.0000      0.2514
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000    TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   8
BLOCK TYPE = 3
 PT.     X           Y
  1    -0.0390      0.1457
  2    -0.0754      0.1306
  3    -0.1257      0.2177
```

```
  4    -0.0651      0.2429
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK   9
BLOCK TYPE = 3
  PT.     X            Y
  1    -0.0754      0.1306
  2    -0.1067      0.1067
  3    -0.1778      0.1778
  4    -0.1257      0.2177
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  10
BLOCK TYPE = 3
  PT.     X            Y
  1    -0.1067      0.1067
  2    -0.1306      0.0754
  3    -0.2177      0.1257
  4    -0.1778      0.1778
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  11
BLOCK TYPE = 3
  PT.     X            Y
  1    -0.1306      0.0754
  2    -0.1457      0.0390
  3    -0.2429      0.0651
  4    -0.2177      0.1257
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
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IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =   3.000    TDE =.0E+00    UR =   1.500    TDM =.1E+00
NO. OF MATERIAL CELLS =    2
NO. SHEET IMPEDANCE SEGMENTS =     1

GEOMETRY FOR BUILDING BLOCK  12
BLOCK TYPE = 3
  PT.     X           Y
  1     -0.1457     0.0390
  2     -0.1509     0.0000
  3     -0.2514     0.0000
  4     -0.2429     0.0651
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =   3.000    TDE =.0E+00    UR =   1.500    TDM =.1E+00
NO. OF MATERIAL CELLS =    2
NO. SHEET IMPEDANCE SEGMENTS =     1

GEOMETRY FOR BUILDING BLOCK  13
BLOCK TYPE = 3
  PT.     X           Y
  1     -0.1509     0.0000
  2     -0.1457    -0.0390
  3     -0.2429    -0.0651
  4     -0.2514     0.0000
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =   3.000    TDE =.0E+00    UR =   1.500    TDM =.1E+00
NO. OF MATERIAL CELLS =    2
NO. SHEET IMPEDANCE SEGMENTS =     1

GEOMETRY FOR BUILDING BLOCK  14
BLOCK TYPE = 3
  PT.     X           Y
  1     -0.1457    -0.0390
  2     -0.1306    -0.0754
  3     -0.2177    -0.1257
  4     -0.2429    -0.0651
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
```

```
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  15
BLOCK TYPE = 3
  PT.    X          Y
  1    -0.1306    -0.0754
  2    -0.1067    -0.1067
  3    -0.1778    -0.1778
  4    -0.2177    -0.1257
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  16
BLOCK TYPE = 3
  PT.    X          Y
  1    -0.1067    -0.1067
  2    -0.0754    -0.1306
  3    -0.1257    -0.2177
  4    -0.1778    -0.1778
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  17
BLOCK TYPE = 3
  PT.    X          Y
  1    -0.0754    -0.1306
  2    -0.0390    -0.1457
  3    -0.0651    -0.2429
  4    -0.1257    -0.2177
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
```

NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 18
BLOCK TYPE = 3

PT.	X	Y
1	-0.0390	-0.1457
2	0.0000	-0.1509
3	0.0000	-0.2514
4	-0.0651	-0.2429

REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00) ZSHT2 =(.00E+00,.00E+00)
ER = 3.000 TDE =.0E+00 UR = 1.500 TDM =.1E+00
NO. OF MATERIAL CELLS = 2
NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 19
BLOCK TYPE = 3

PT.	X	Y
1	0.0000	-0.1509
2	0.0390	-0.1457
3	0.0651	-0.2429
4	0.0000	-0.2514

REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00) ZSHT2 =(.00E+00,.00E+00)
ER = 3.000 TDE =.0E+00 UR = 1.500 TDM =.1E+00
NO. OF MATERIAL CELLS = 2
NO. SHEET IMPEDANCE SEGMENTS = 1

GEOMETRY FOR BUILDING BLOCK 20
BLOCK TYPE = 3

PT.	X	Y
1	0.0390	-0.1457
2	0.0754	-0.1306
3	0.1257	-0.2177
4	0.0651	-0.2429

REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00) ZSHT2 =(.00E+00,.00E+00)
ER = 3.000 TDE =.0E+00 UR = 1.500 TDM =.1E+00
NO. OF MATERIAL CELLS = 2
NO. SHEET IMPEDANCE SEGMENTS = 1

```
GEOMETRY FOR BUILDING BLOCK  21
BLOCK TYPE = 3
  PT.    X          Y
  1      0.0754    -0.1306
  2      0.1067    -0.1067
  3      0.1778    -0.1778
  4      0.1257    -0.2177
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  22
BLOCK TYPE = 3
  PT.    X          Y
  1      0.1067    -0.1067
  2      0.1306    -0.0754
  3      0.2177    -0.1257
  4      0.1778    -0.1778
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  23
BLOCK TYPE = 3
  PT.    X          Y
  1      0.1306    -0.0754
  2      0.1457    -0.0390
  3      0.2429    -0.0651
  4      0.2177    -0.1257
REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00)  ZSHT2 =(.00E+00,.00E+00)
ER =  3.000   TDE =.0E+00   UR =  1.500   TDM =.1E+00
NO. OF MATERIAL CELLS =   2
NO. SHEET IMPEDANCE SEGMENTS =    1

GEOMETRY FOR BUILDING BLOCK  24
BLOCK TYPE = 3
```

PT.	X	Y
1	0.1457	-0.0390
2	0.1509	0.0000
3	0.2514	0.0000
4	0.2429	-0.0651

REAL PART SHEET IMPEDANCE TAPER TYPE = 1
IMAGINARY SHEET IMPEDANCE TAPER TYPE = 1
ZSHT1 =(.00E+00,.00E+00) ZSHT2 =(.00E+00,.00E+00)
ER = 3.000 TDE =.0E+00 UR = 1.500 TDM =.1E+00
NO. OF MATERIAL CELLS = 2
NO. SHEET IMPEDANCE SEGMENTS = 1

SUMMARY OF MODES:
NO. SHEET IMPEDANCE OR CONDUCTOR MODES = 24
NO. DIELECTRIC MODES = 96
NO. FERRITE MODES = 48
TOTAL NO. MODES = 168

CONDUCTOR ENDPOINT COORDINATES :

N = POINT NO.	X(N)	Y(N)
1	0.1509	0.0000
2	0.1457	0.0390
3	0.1306	0.0754
4	0.1067	0.1067
5	0.0754	0.1306
6	0.0390	0.1457
7	0.0000	0.1509
8	-0.0390	0.1457
9	-0.0754	0.1306
10	-0.1067	0.1067
11	-0.1306	0.0754
12	-0.1457	0.0390
13	-0.1509	0.0000
14	-0.1457	-0.0390
15	-0.1306	-0.0754
16	-0.1067	-0.1067
17	-0.0754	-0.1306
18	-0.0390	-0.1457
19	0.0000	-0.1509
20	0.0390	-0.1457
21	0.0754	-0.1306
22	0.1067	-0.1067
23	0.1306	-0.0754

24	0.1457	-0.0390

CONDUCTOR MODE STRIP SEGMENTS:

I	IA(I)	IB(I)	D(I)	ZSH1(I)	ZSH2(I)
1	1	2	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
2	2	3	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
3	3	4	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
4	4	5	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
5	5	6	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
6	6	7	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
7	7	8	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
8	8	9	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
9	9	10	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
10	10	11	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
11	11	12	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
12	12	13	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
13	13	14	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
14	14	15	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
15	15	16	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
16	16	17	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
17	17	18	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
18	18	19	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
19	19	20	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
20	20	21	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
21	21	22	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
22	22	23	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
23	23	24	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)
24	24	1	0.039	(.0E+00,.0E+00)	(.0E+00, .0E+00)

CONDUCTOR MODE NUMBERS:

I = MODE	I1(I)	I2(I)	I3(I)
1	2	1	24
2	1	2	3
3	2	3	4
4	3	4	5
5	4	5	6
6	5	6	7
7	6	7	8
8	7	8	9
9	8	9	10
10	9	10	11
11	10	11	12

12	11	12	13
13	12	13	14
14	13	14	15
15	14	15	16
16	15	16	17
17	16	17	18
18	17	18	19
19	18	19	20
20	19	20	21
21	20	21	22
22	21	22	23
23	22	23	24
24	23	24	1

MATERIAL CELL ENDPOINT COORDINATES :

CELL	XD1	YD1	XD2	YD2	XD3	YD3	XD4	YD4
1	0.151	0.000	0.146	0.039	0.194	0.052	0.201	0.000
2	0.201	0.000	0.194	0.052	0.243	0.065	0.251	0.000
3	0.146	0.039	0.131	0.075	0.174	0.101	0.194	0.052
4	0.194	0.052	0.174	0.101	0.218	0.126	0.243	0.065
5	0.131	0.075	0.107	0.107	0.142	0.142	0.174	0.101
6	0.174	0.101	0.142	0.142	0.178	0.178	0.218	0.126
7	0.107	0.107	0.075	0.131	0.101	0.174	0.142	0.142
8	0.142	0.142	0.101	0.174	0.126	0.218	0.178	0.178
9	0.075	0.131	0.039	0.146	0.052	0.194	0.101	0.174
10	0.101	0.174	0.052	0.194	0.065	0.243	0.126	0.218
11	0.039	0.146	0.000	0.151	0.000	0.201	0.052	0.194
12	0.052	0.194	0.000	0.201	0.000	0.251	0.065	0.243
13	0.000	0.151	-0.039	0.146	-0.052	0.194	0.000	0.201
14	0.000	0.201	-0.052	0.194	-0.065	0.243	0.000	0.251
15	-0.039	0.146	-0.075	0.131	-0.101	0.174	-0.052	0.194
16	-0.052	0.194	-0.101	0.174	-0.126	0.218	-0.065	0.243
17	-0.075	0.131	-0.107	0.107	-0.142	0.142	-0.101	0.174
18	-0.101	0.174	-0.142	0.142	-0.178	0.178	-0.126	0.218
19	-0.107	0.107	-0.131	0.075	-0.174	0.101	-0.142	0.142
20	-0.142	0.142	-0.174	0.101	-0.218	0.126	-0.178	0.178
21	-0.131	0.075	-0.146	0.039	-0.194	0.052	-0.174	0.101
22	-0.174	0.101	-0.194	0.052	-0.243	0.065	-0.218	0.126
23	-0.146	0.039	-0.151	0.000	-0.201	0.000	-0.194	0.052
24	-0.194	0.052	-0.201	0.000	-0.251	0.000	-0.243	0.065
25	-0.151	0.000	-0.146	-0.039	-0.194	-0.052	-0.201	0.000
26	-0.201	0.000	-0.194	-0.052	-0.243	-0.065	-0.251	0.000
27	-0.146	-0.039	-0.131	-0.075	-0.174	-0.101	-0.194	-0.052

28	-0.194	-0.052	-0.174	-0.101	-0.218	-0.126	-0.243	-0.065
29	-0.131	-0.075	-0.107	-0.107	-0.142	-0.142	-0.174	-0.101
30	-0.174	-0.101	-0.142	-0.142	-0.178	-0.178	-0.218	-0.126
31	-0.107	-0.107	-0.075	-0.131	-0.101	-0.174	-0.142	-0.142
32	-0.142	-0.142	-0.101	-0.174	-0.126	-0.218	-0.178	-0.178
33	-0.075	-0.131	-0.039	-0.146	-0.052	-0.194	-0.101	-0.174
34	-0.101	-0.174	-0.052	-0.194	-0.065	-0.243	-0.126	-0.218
35	-0.039	-0.146	0.000	-0.151	0.000	-0.201	-0.052	-0.194
36	-0.052	-0.194	0.000	-0.201	0.000	-0.251	-0.065	-0.243
37	0.000	-0.151	0.039	-0.146	0.052	-0.194	0.000	-0.201
38	0.000	-0.201	0.052	-0.194	0.065	-0.243	0.000	-0.251
39	0.039	-0.146	0.075	-0.131	0.101	-0.174	0.052	-0.194
40	0.052	-0.194	0.101	-0.174	0.126	-0.218	0.065	-0.243
41	0.075	-0.131	0.107	-0.107	0.142	-0.142	0.101	-0.174
42	0.101	-0.174	0.142	-0.142	0.178	-0.178	0.126	-0.218
43	0.107	-0.107	0.131	-0.075	0.174	-0.101	0.142	-0.142
44	0.142	-0.142	0.174	-0.101	0.218	-0.126	0.178	-0.178
45	0.131	-0.075	0.146	-0.039	0.194	-0.052	0.174	-0.101
46	0.174	-0.101	0.194	-0.052	0.243	-0.065	0.218	-0.126
47	0.146	-0.039	0.151	0.000	0.201	0.000	0.194	-0.052
48	0.194	-0.052	0.201	0.000	0.251	0.000	0.243	-0.065

BISTATIC PATTERN: PHI INCIDENT (DEG) = 0.00

PHI S(DEG)	ECHO WIDTH(M)	ECHO WIDTH(DB/M)	|FIELD|	PHASE(DEG)
0.00	0.3751	-4.2581	0.244	20.77
5.00	0.3767	-4.2403	0.245	21.40
10.00	0.3817	-4.1827	0.246	23.28
15.00	0.3913	-4.0744	0.250	26.30
20.00	0.4072	-3.9024	0.255	30.28
25.00	0.4307	-3.6580	0.262	34.94
30.00	0.4632	-3.3420	0.272	40.02
35.00	0.5049	-2.9682	0.283	45.22
40.00	0.5545	-2.5607	0.297	50.32
45.00	0.6095	-2.1504	0.311	55.18
50.00	0.6653	-1.7696	0.325	59.71
55.00	0.7163	-1.4492	0.338	63.91
60.00	0.7555	-1.2174	0.347	67.82
65.00	0.7762	-1.1001	0.351	71.49
70.00	0.7722	-1.1227	0.351	75.02
75.00	0.7391	-1.3132	0.343	78.52
80.00	0.6754	-1.7045	0.328	82.15
85.00	0.5834	-2.3401	0.305	86.14
90.00	0.4699	-3.2804	0.273	90.87

95.00	0.3458	-4.6114	0.235	97.06
100.00	0.2267	-6.4448	0.190	106.24
105.00	0.1313	-8.8189	0.145	122.00
110.00	0.0799	-10.9752	0.113	151.29
115.00	0.0930	-10.3134	0.122	-169.70
120.00	0.1888	-7.2411	0.173	-143.21
125.00	0.3804	-4.1975	0.246	-129.33
130.00	0.6746	-1.7097	0.328	-121.47
135.00	1.0693	0.2910	0.413	-116.50
140.00	1.5533	1.9125	0.497	-113.10
145.00	2.1057	3.2339	0.579	-110.65
150.00	2.6973	4.3093	0.655	-108.82
155.00	3.2925	5.1753	0.724	-107.45
160.00	3.8524	5.8573	0.783	-106.42
165.00	4.3377	6.3726	0.831	-105.67
170.00	4.7133	6.7332	0.866	-105.16
175.00	4.9509	6.9468	0.888	-104.87
180.00	5.0322	7.0176	0.895	-104.77
185.00	4.9512	6.9471	0.888	-104.88
190.00	4.7140	6.7339	0.866	-105.18
195.00	4.3387	6.3736	0.831	-105.70
200.00	3.8536	5.8586	0.783	-106.46
205.00	3.2939	5.1771	0.724	-107.50
210.00	2.6987	4.3116	0.655	-108.89
215.00	2.1072	3.2370	0.579	-110.74
220.00	1.5548	1.9168	0.497	-113.22
225.00	1.0708	0.2973	0.413	-116.65
230.00	0.6761	-1.6998	0.328	-121.67
235.00	0.3820	-4.1795	0.247	-129.60
240.00	0.1904	-7.2034	0.174	-143.56
245.00	0.0948	-10.2316	0.123	-170.02
250.00	0.0818	-10.8708	0.114	151.35
255.00	0.1334	-8.7479	0.146	122.28
260.00	0.2292	-6.3988	0.191	106.53
265.00	0.3485	-4.5779	0.236	97.32
270.00	0.4728	-3.2533	0.274	91.10
275.00	0.5866	-2.3166	0.306	86.35
280.00	0.6787	-1.6832	0.329	82.35
285.00	0.7425	-1.2932	0.344	78.70
290.00	0.7756	-1.1037	0.351	75.19
295.00	0.7795	-1.0817	0.352	71.66
300.00	0.7586	-1.1997	0.347	67.99
305.00	0.7191	-1.4323	0.338	64.08
310.00	0.6678	-1.7538	0.326	59.88

315.00	0.6115	-2.1358	0.312	55.35
320.00	0.5562	-2.5479	0.298	50.49
325.00	0.5061	-2.9575	0.284	45.39
330.00	0.4641	-3.3337	0.272	40.17
335.00	0.4313	-3.6520	0.262	35.09
340.00	0.4075	-3.8986	0.255	30.40
345.00	0.3915	-4.0723	0.250	26.40
350.00	0.3818	-4.1817	0.247	23.35
355.00	0.3767	-4.2399	0.245	21.43
360.00	0.3751	-4.2581	0.244	20.77

TOTAL CPU TIME=   316.19 SEC