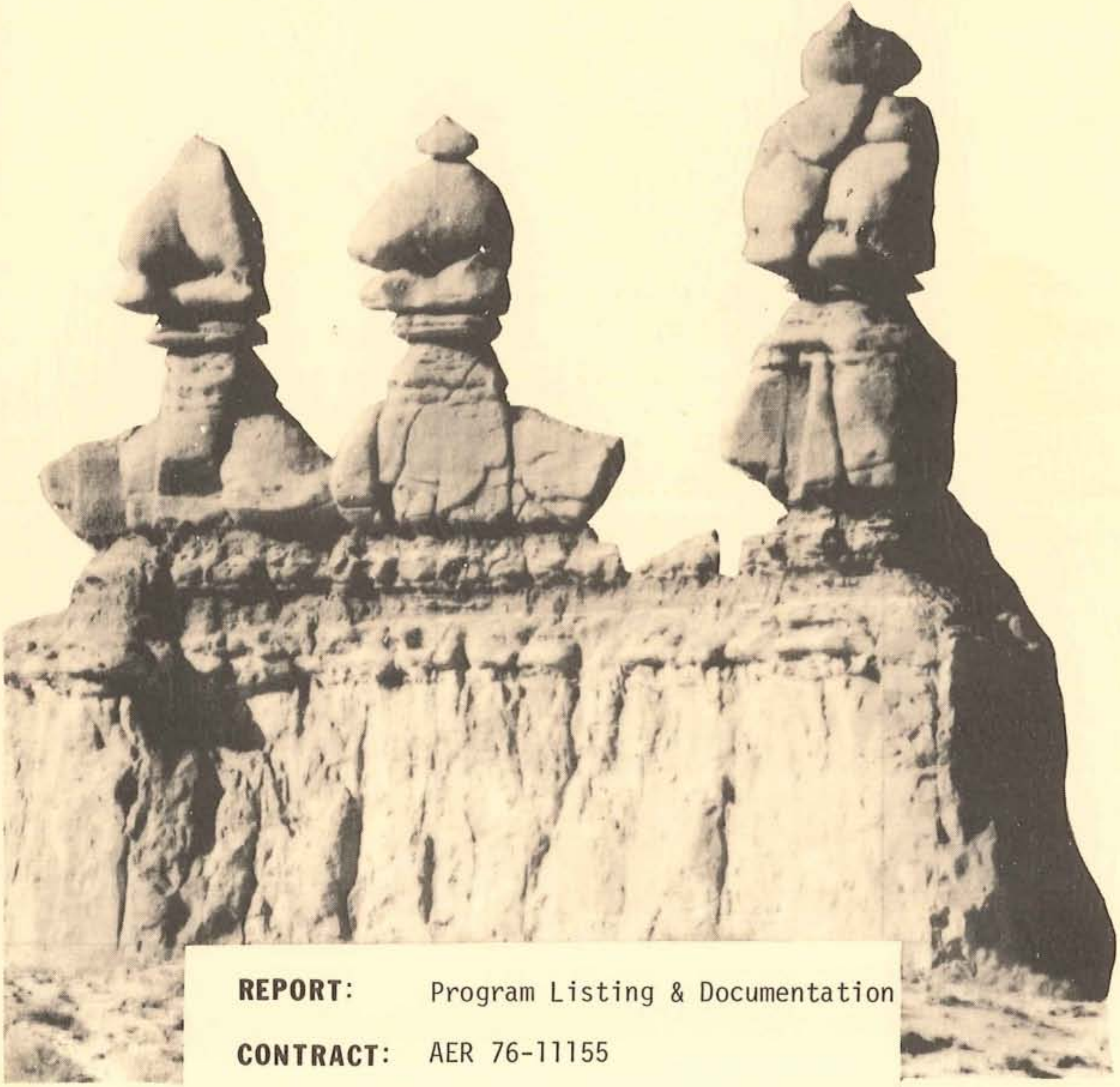
DEPARTMENT OF
GEOLOGY AND GEOPHYSICS



REPORT: Program Listing & Documentation

CONTRACT: AER 76-11155

AGENCY: National Science Foundation

TITLE: Documentation of a Finite Element Program
for Solution of Geophysical Problems Governed
by the Inhomogeneous 2-D Scalar Helmholtz Equation

AUTHORS: John A. Stodt

DATE: July 1978

UNIVERSITY OF UTAH SALT LAKE CITY, UTAH 84112

Documentation of a Finite Element
Program for Solution of Geophysical
Problems Governed by the Inhomogeneous
2-D Scalar Helmholtz Equation

by

John A. Stodt

Acknowledgements

The author was supported from NSF contract No. AER 76-11155 while preparing this documentation.

TABLE OF CONTENTS

List of Figures

List of Tables

I. Introduction

A two dimensional finite element program applicable to the numerical solution of a wide variety of geophysical problems has been developed at the University of Utah. Finite element programs to handle a number of geophysical problems were originally developed by Rijo (Rijo, 1977). Linear interpolation of the unknown field over triangular sub-domains of the region where a solution is sought was used in conjuction with the Galerkin technique to derive a system of linear equations which approximates the governing PDE. The solution of this linear system of equations gives the approximate field values at the nodes of the discretized domain.

These programs have been modified and consolidated by the author into a single program which will handle the two dimensional magnetotelluric TE and TM mode problems, as well as the infinite line source problem. In addition, the element equations obtained from the finite element technique have been re-derived and re-programmed in a sufficiently general form so that any physical problem governed by the two dimensional inhomogeneous scalar Helmholtz equation may be handled with minor modifications to the program.

II. Applications

The finite element formalism developed in part IV of this documentation is applicable to any physical problem governed by the equation

$$1)\qquad \frac{\partial}{\partial x}\left(\frac{1}{k}\frac{\partial f}{\partial x}\right) + \frac{\partial}{\partial x}\left(\frac{1}{k}\frac{\partial f}{\partial z}\right) + pf = S$$

where

k,p ≡ physical property factors which may be functions of position over the domain where a solution is sought

s ≡ source funcion

f ≡ unknown field for which a solution is sought

In practice, f, k, p, and s may be real or complex. Examples of some particular physical problems which are governed by this equation are given in Table 1. In Table 1 we make use of the following parameters:

$\hat{z} = j\omega\mu$

$\hat{y} = \sigma + j\omega\varepsilon$

I = current strength

Problem	f	k	p	S
TE-MT	E_y	$\hat{z}$	$-\hat{y}$	0
TM-MT	H_y	$\hat{y}$	$-\hat{y}$	0
Line Source	E_y	$\hat{z}$	$-\hat{y}$	$I\sigma(x)\delta(z)$

Table 1. Examples of physical problems governed by equation 1.

The program for which this documentation is written solves the examples of Table 1, where f, k, and p are complex quantities. Any or all of σ, μ, and ε may be considered piecewise constant functions of position. The DC resistivity problem, which is also goverened by equation 1 after Fourier transformation of the strike direction, is not incorporated in the same program since only real numbers are required for its solution. It is more efficient computationally to develop a program utilizing only real arithmetic when dealing with problems involving only real quantities. A program based on the theory outlined in part IV of this documentation which solves the DC problem is available at the Department of Geology and Geophysics of the University of Utah as a separate program.

In closing this section, it should be pointed out that an effort was made, through appropriate structuring, to produce a program which could be easily modified to handle other physical problems governed by equation 1 once the user has gained a rudimentary knowledge of both the program and the finite element method. Sufficient theory is hopefully provided in part IV of this documentation, while knowledge of the program itself should be obtained from part III of this report in conjunction with a study of the comment statements in the program itself.

III. Documentation

A. Description of software

A flow diagram of program construction is given in figure 1. This diagram shows the sequence in which subroutines are called to do the various calculations. Also indicated are calls to the Univac 1108 system library routines where they are used. A brief description of the function of the various routines is given in comment statements in the program itself and will not be repeated here. As an aid to the programmer trying to implement the program on a different system, the write-ups on the 1108 system library subroutines are included in Appendix II.

One Univac 1108 system I/O device is used which deserves special mention. The device name is NTRAN and its use is in transferring large amounts of unformatted data from core to Fastrand drum storage and vice versa in an efficient manner. This is necessary in implementing this program on the 1108 because of the relatively limited amount of core storage available. A temporary word addressable data file is assigned in which the coefficient matrix of the linear system to be solved is stored. The Greenfield algorithm (see e.g. Swift, 1967 - Appendix 3) is then used to solve the linear system of equations, with appropriate size blocks of the coefficient matrix being transferred into core and reduced one by one during solution. This data transfer into and out of core is handled by Univac's system device NTRAN. A write up of NTRAN is included in Appendix II as an aid to the user trying to adapt the program to a different system. In this case, a suitable substitution for NTRAN must be found, unless the user's system has a large amount of core memory (150-200K) available so that execution can proceed entirely in core.

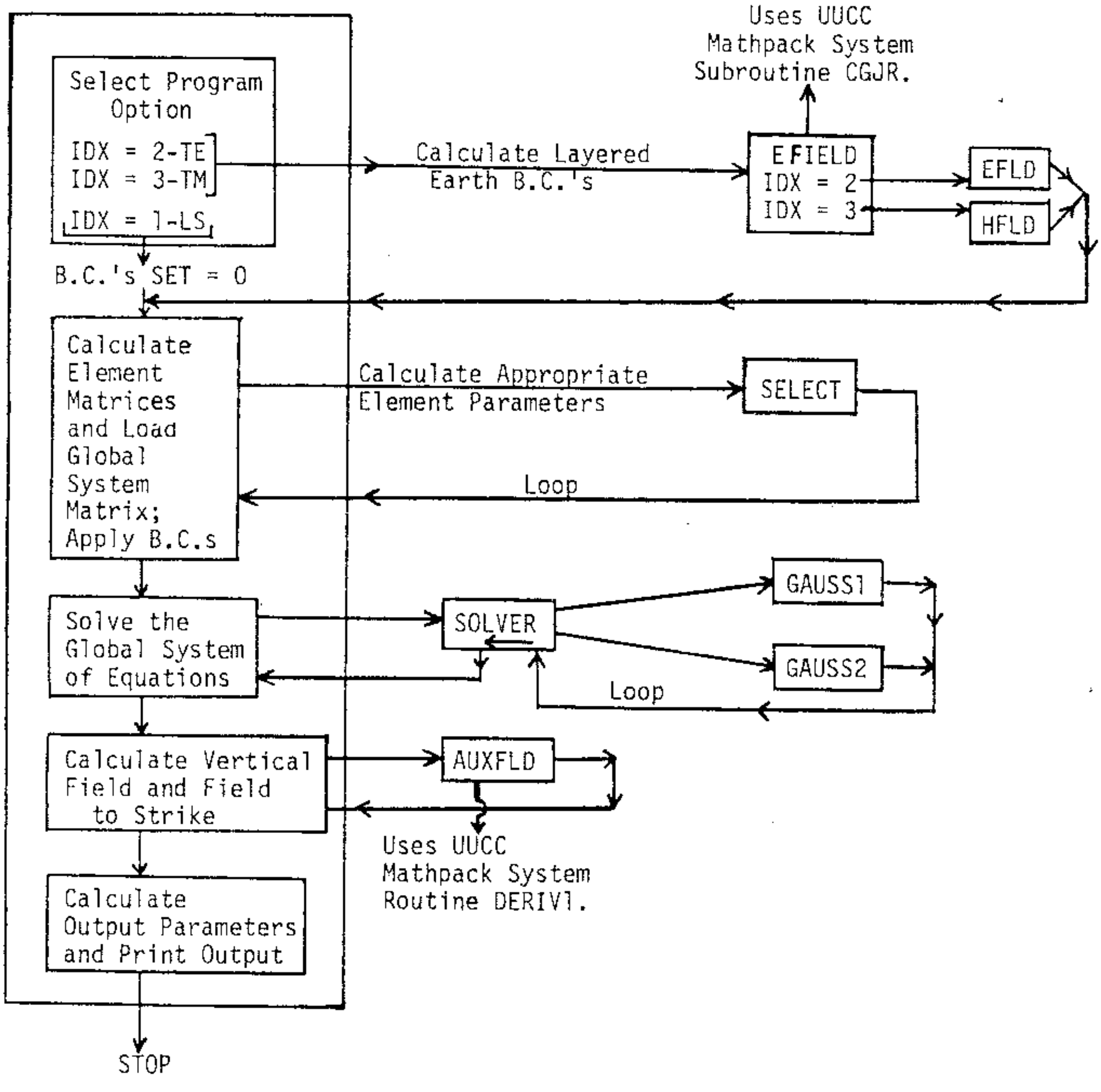


Figure 1. Flow diagram of program architecture.

B. Explanation of PARAMETERS

There are three parameters which are set during compilation of the program which must be tailored to the run. A description of these parameters, with a list of the subroutines in which they occur in PARAMETER statements follows.

IP1 = number of nodes in the z-direction. Must be greater than or equal to the actual number of nodes vertically in the mesh.

IP4 = number of nodes in the x-direction. Must be greater than or equal to the actual number of nodes horizontally in the mesh.

NLAYR = number of layers (including the half-space) of the 1-D earth model bounding the right and left sides of the mesh. This parameter is only used when calculating the boundary conditions to be applied to the sides of the mesh for MT modeling. It must be greater than or equal to the maximum number of layers on either side of the mesh. The earth models do not have to be the same on both sides of the mesh.

Subroutines in which these parameters appear:

PARAMETER	SUBROUTINE NAME
IP1	MAIN, SELECT, SOLVER, GAUSS1, GAUSS2, AUXFLD
IP4	MAIN, SELECT, SOLVER, GAUSS1, GAUSS2, AUXFLD
NLAYR	MAIN, EFIELD, EFLD, HFLD

C. Input list

Card 1: FORMAT(20I4)

IDX - Option parameter to select appropriate solution.

1 = 2-D line source (TURAM)

2 = TE Magnetotellurics (E-parallel mode)

3 = TM Magnetotellurics (H-parallel mode)

NODEX - Number of nodes horizontally in the mesh (must be exact)

NODEZ - Number of nodes vertically in the mesh (must be exact)

NXX - Number of blocks of equal-sized elements horizontally. (See figure 2 for the definition of a block which consists of a given number of elements with equal sized edges horizontally or vertically)

NZZ - Number of blocks of equal-sized elements vertically.

NRES - Number of <u>conductivities</u> in the mesh (including the air layer)

M1 - Number of blocks vertically above z = 0 (air layer)

NPRINT - 1 = just print input
0 = execute program

LINE1, LINE2 } Number of nodes horizontally from left edge of mesh to where the line source(s) is/are positioned. Default value = 0. For examples, when modeling TURAM, if the effects of the return current part of the loop are not being considered, then LINE2 = 0. LINE1 gives a source current flowing in the + coordinate strike direction, while LINE2 gives a current source of equal strength flowing in the opposite direction.

Card 2: FORMAT(8F10.0)

Y(I) - <u>Conductivities</u> in the mesh - A, B, C... where
A, B, C... = conductivities in the mesh
↕ ↕ ↕
0, 1. 2... = mesh code for model input (see Card 7)

F - frequency (Hz)

Card 3: FORMAT(20I4)

NX(I) - Number of equal sized intervals DELX(I) in block I

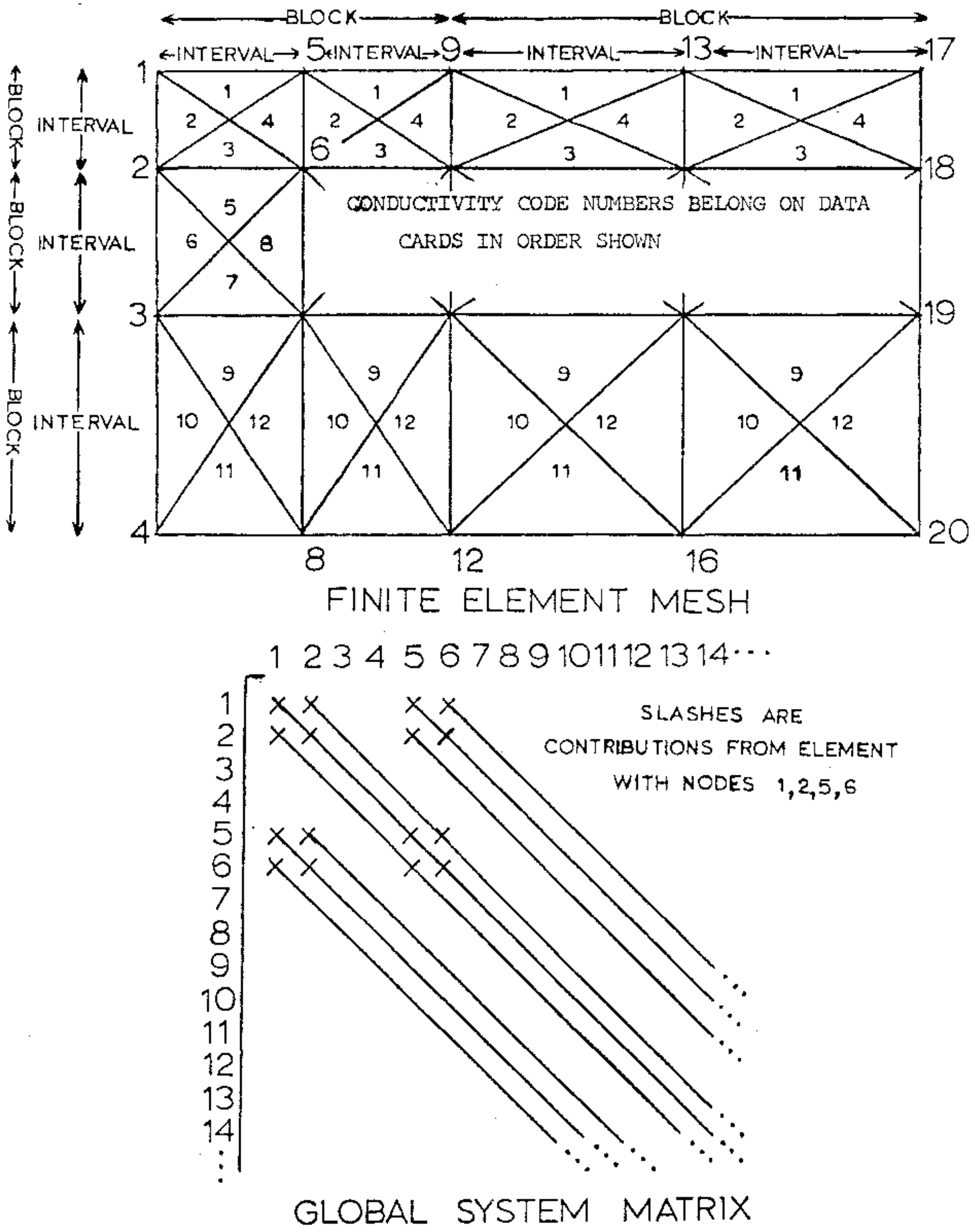


Figure 2. Finite element mesh structure, node numbering convention, conductivity code number convention. Association of node number with position in global matrix, as indicated by slashes, for element with nodes 1, 2, 5, 6.

horizontally.

Card 4: FORMAT(20I4)

DELX(I) - Size of the intervals in block I in meters

Card 5: FORMAT(20I4)

NZ(I) - Number of equal sized intervals DELZ(I) in block I vertically.

Card 6: FORMAT(8F10.0)

DELZ(I) - Size of the intervals in block I in meters.

Card 7: FORMAT(80I1)

Model Deck - Input consists of the code numbers outlined under Card 2, with the ordering convention as illustrated in figure 2. Each interval in z comprises four data cards with conductivity code numbers appropriate to each triangular element punched on the cards in the order shown in figure 2. There are, therefore, NODEX-1 code numbers on each card. Note: The code number for the conductivity of air is always zero.

Card 8: FORMAT(8F10.0)

H(I), I=1, NLYR (NLYR=NLAYR-1) - depths from z = 0 to layer interfaces of 1-D boundary condition at <u>left</u> edge of mesh in meters.

Card 9: FORMAT(8F10.0)

P(I), I-1, NLAYR - <u>resistivities</u> of the successive layers on the <u>left</u> edge of the mesh.

Cards 10 and 11 - Same as cards 8 and 9 except these cards apply to the 1-D boundary condition at the right edge of the mesh.

D. Output list

Successive columns of output for the MT programs are:

Column	
1	Distance from center of mesh to each mode
2-5	Vertical field components (Re, Im, Magnitude, Phase)
6-9	Field components perpendicular to strike
10-13	Field components parallel to strike
14	Apparent resistivity
15	Negative of the phase of the impedance

Successive columns of output for the line source program are:

Column	
1	Horizontal distance from the + line source to the nodes at z = 0
2-5	Transverse magnetic field components (Re, Im, Magnitude, Phase)
6-9	Vertical magnetic field components
10	Ratio of magnitude of transverse field to primary field
11	Ratio of magnitude of vertical field to primary field
12	Primary field

E. Notes on mesh design

Proper mesh design is important in obtaining meaningful (i.e. accurate) output from this program. Proper mesh design is an art that the programmer will gain with experience. The following rules of thumb concerning element dimensions will serve as guidelines. They are based on a unit of distance, the skin depth, defined as the distance in which the amplitude of a plane wave is attenuated by 1/e as it propogates through a homogeneous conducting medium. The formula is

Skin depth $\equiv \delta$ 500 $\sqrt{\rho/f}$ meters

where ρ = resistivity of the medium

f = frequency (Hz)

The rules of thumb are:

1) Element dimensions should not change from one element to the next by more than a factor of 3 to 5.

2) In the vicinity of a change in conductivity of the medium the element dimensions should be approximately $\delta/6$ in the medium where the element resides.

3) 2 to 3δ away from any variation in conductivity the element dimensions may be increased to the order of δ of the medium.

4) Vertical element dimensions may be increased approximately logarithmically (1, 3, 10, 30...) from the air-earth interface because of the exponential decay of the fields. The maximum vertical dimension of an element should still ideally be held to 1 to 2δ however.

5) The air layer for the TE-MT and line source problems should consist of 7 or 8 elements logarithmically increasing in vertical dimension from the air-earth interface, staring with about 10-100 m for frequencies <1Hz and 1-10 m for frequencies >1Hz.

6) A 1 or 2 node air layer is required computationally in this program (not theoretically) for the TM-MT case. A 2 m and 10 m layer has given good results.

7) Vertical mesh boundaries should ideally be extended 3 to 6 skin depths away from the nearest 2-D structure.

8) The bottom mesh boundary should ideally be 4 to 6 skin depths of the background conductivity from the air-earth interface.

9) When solving the line source problem, the mesh should be made "fine" in the region of the sources. A little experience will determine what "fine" is for a given problem. The mesh boundaries should be extended out to where the fields due to the source are approximately zero.

These rules of thumb will lead to inordinately large (and hence expensive) meshes much of the time. The programmer's task is then to cut corners where his experience tells him he may do so without too adversely affecting the accuracy of the results. Accuracy is checked by refining the mesh and checking convergence of the solutions. For information on convergence rates for linear approximation of the field see e.g. Strang and Fix (1973).

F. Notes on execution on the University of Utah Univac 1108 system

The first step in using the program is to compile the appropriate subroutines with the correct parameters as explained in III. B. The program then needs to be mapped into an absolute element for execution. The UUCC Mathpack system library (UUCC*MSLIB.) must be made available during this operation, since this is the system file where subroutines CGJR and DERIV1 reside. After compilation, a typical map sequence will be as follows:

```
@PREP‸ QUALIFIER*FILENAME.
@MAP, IS‸‸‸,QUALIFIER*FILENAME.ABSOLUTE
‸IN‸ QUALIFIER*FILENAME.MAIN
‸LIB‸ QUALIFIER*FILENAME.,UUCC*MSLIB.
```

In this sequence, QUALIFIER*FILENAME. is the user's file in which the elements of the program reside. The LIB statement is crucial since this is the statement which makes the system routines in UUCC*MSLIB. available to the program. ABSOLUTE is the name of the absolute element which is being created and stored in the file QUALIFIER*FILENAME.

The program is now ready to execute, given the proper data as described in III.C. A temporary word addressable data file must be assigned at execution for storage of the coefficient matrix while the solution is progressing. Data are stored on and retrieved from this file during execution through the use of NTRAN (See Appendix II).

A typical execution sequence would be:

```
@ASG,T‸1., D///FILESIZE
           Data Deck
@XQT,OF‸QUALIFIER*FILENAME.ABSOLUTE

@FIN
```

The first control card assigns the temporary (T option) data file. The number 1 is the unit number with which the program has been set up to identify this file. The D option makes the file word addressable. If there were no D option here, the file would be assigned as sector addressable. FILESIZE is the number of words of storage assigned to the temporary file. The formula for determining file size is:

$$\mathrm{FILESIZE} = 2*(\mathrm{NBAND}^2 + \mathrm{NNODE}*\mathrm{NBAND})$$

where $\mathrm{NBAND} = \mathrm{IP1} + 2$

$\mathrm{NNODE} = \mathrm{IP1} * \mathrm{IP4}$

We see, for example, that a 30 X 50 node problem would require the following storage:

$$2*(32^2 + 30*50*32) = 98048 \text{ words}$$

The F option on the execution statement deserves mention. This option is used to suppress the counting of underflows which occur during execution. Since the program usually generates a large number of underflows, this option can produce a considerable savings in execution time. Overflows and divide checks will still be flagged. Neither of these should occur during normal execution. Re-check the input carefully for proper format and consistency should these occur, as this is the usual source of error.

IV. Theory

This section will be concerned with a brief description of the application of the finite element method to the solution of equation 1. More detailed analysis may be found in Rijo (1977) and, e.g. Huebner (1975). Incorporation of boundary conditions and source parameters is also discussed as as the calculation of auxiliary field components which are obtained by appropriate manipulation of the field values obtained from the finite element solution.

A. Brief description of the finite element method.

The application of the finite element method to the solution of equation 1 hinges on the derivation of element matrix equations from the governing differential equation. We use the following technique. Re-write equation 1 in operational form:

2) $Lf = S$

where $L \equiv \partial/\partial x(1/k\ \partial/\partial x) + \partial/\partial z(1/k\ \partial/\partial z) + p$

Now approximate f by piecewise linear functions defined over triangular subregions e of the domain over which a solution is being sought--see figure 3.

We have

m = total number of triangular subdomains

3) $\tilde{f} = \sum_{e=1}^{m} \tilde{f}^{e}$

where

4) $\tilde{f}^{e} = \alpha_1 + \alpha_2 X + \alpha_3 Z$

Using 4, we obtain an equation for each of the field values at nodes i, j, k of the triangular region.

5) $\tilde{f}_n = \alpha_1 + \alpha_2 X_n + \alpha_3 Z_n$

When these three equations are solved for the α's and the results substituted into equation 4 we obtain

6) $\tilde{f}^{e} = N_i^e \tilde{f}_i + N_j^e \tilde{f}_j + N_k^e \tilde{f}_k$

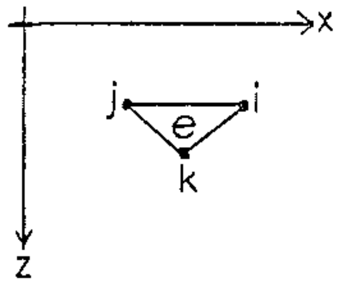
ORIGINAL EQUATION:

$$LF = S \qquad L \equiv \frac{\partial}{\partial x}\left(\frac{1}{K}\frac{\partial}{\partial x}\right) + \frac{\partial}{\partial z}\left(\frac{1}{K}\frac{\partial}{\partial z}\right) + P$$

APPROXIMATE F BY SOME $\tilde{F}$:

THEN $L\tilde{F} - S = \varepsilon$

SUPPOSE F VARIES LINEARLY OVER TRIANGULAR REGIONS **e**.



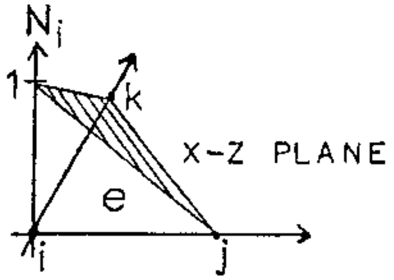
THEN $\tilde{F}^e = \alpha_1 + \alpha_2 X + \alpha_3 Z$

OR, IN TERMS OF NODAL VALUES $\tilde{F}_n = \alpha_1 + \alpha_2 X_n + \alpha_3 Z_n$

$n = i, j, k$

FINALLY:

$$\tilde{F}^e = N_i^e \tilde{F}_i + N_j^e \tilde{F}_j + N_k^e \tilde{F}_k$$



$$N_i^e = \frac{1}{2\Delta}(a_i + b_i X + c_i Z)$$

$$a_i = x_j z_k - x_k z_j$$
$$b_i = z_j - z_k$$
$$c_i = x_k - x_j$$

N_j^e , N_k^e are obtained through cyclic permutation of the subscripts i,j,k.

Figure 3. Derivation of linear approximation of an unknown field over a triangular sub-region e.

where N_n^e, n = i, j, k is defined in figure 3. N_j^e and N_k^e are obtained from the formula for N_i^e by cyclic permutation of the subscripts i, j, k. The N_n^e are a local, linearly independent, complete set of basis functions in which the unknown linear variation of the field is expanded over the triangular sub-domain e. Having defined the form of the approximation over these sub-domains, we can now substitute 3 into 2 and obtain an expression for the error of approximation, ε.

7) $L\tilde{f} - s \equiv \varepsilon$

We now wish to minimize in some sense this approximation error. One way to do this is to force the inner product of the error with the basis functions to be zero over the region where the local basis is defined, i.e.

8) $\langle N_n^e, \varepsilon \rangle = \iint_e N_n^e \varepsilon \, dxdz \equiv 0 \qquad n = i, j, k$

Mathematically, this states that the error of approximation be orthogonal to the weight functions N_n^e over the sub-domain e. In our scheme, the basis functions and weight functions are the same so that the norm of the approximation error ε is minimized by this technique (Harrington, 1967). By carrying out the integrations appropriately (see Rijo, 1977, or Huebuer, 1975) we obtain the matrix equations in figure 4. In evaluating 8 an integration by parts is performed which results in a line integral term around element boundaries. This term is associated with the Neumann boundary condition. Since we apply Dirichlet boundary conditions to all mesh edges for the three problems which are being considered, we disregard this term.

If the finite element mesh is set up in a regular fashion so that four triangular elements combine to form a quadrilateral element, we can reduce the size of the global system of equations by 20% by eliminating the unknown field value associated with node five of the quadrilateral element in figure 4.

WE WISH TO MINIMIZE IN SOME SENSE THE ERROR ε.

LET'S TAKE $$\langle N_n^e \varepsilon \rangle = \iint_e N_n^e \varepsilon \, dx\, dz = 0$$

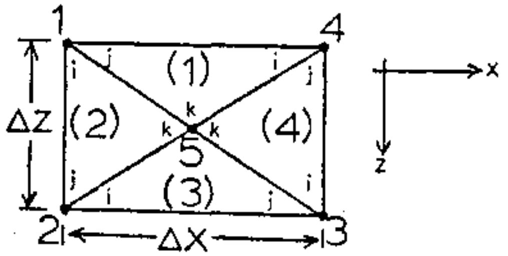
$$n = i, j, k$$

CARRYING OUT THE INTEGRATIONS:

$$\left\{ \frac{-1}{4K\Delta} \begin{bmatrix} B_i^2 + C_i^2 & B_i B_j + C_i C_j & B_i B_k + C_i C_k \\ & B_j^2 + C_j^2 & B_j B_k + C_j C_k \\ & & B_k^2 + C_k^2 \end{bmatrix} + \frac{P\Delta}{12} \begin{bmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{bmatrix} \right\} \overset{\sim}{\begin{bmatrix} F_i \\ F_j \\ F_k \end{bmatrix}} = \begin{bmatrix} S_i \\ S_j \\ S_k \end{bmatrix}$$

Δ = Area of triangular element

IT'S MORE EFFICIENT TO DEAL WITH QUADRILATERAL ELEMENTS



THE COEFFICIENT MATRIX FOR THIS ELEMENT HAS THE FORM

$$\left[\begin{array}{cccc:c} A & B & 0 & C & D \\ & E & F & 0 & G \\ & & H & I & J \\ & & & K & L \\ \hdashline & & & & M \end{array}\right] \equiv \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}$$

Figure 4. Matrix equations associated with a triangular element; formation of quadrilateral element and associated matrix equation from combination of four triangular elements.

This is done at the element level through a process known as static condensation (Huebner, 1975). When the triangular element matrix equations are combined additively in the appropriate manner a 5 X 5 system of equations is obtained. The coefficient matrix of this system has the form indicated symbolically in figure 4, and is written out explicitly in figure 5. The process of static condensation consists of partitioning the 5 X 5 matrix associated with the quadralateral element into a 2 X 2 system as shown in figures 4 and 5, and then eliminating the field variable associated with the internal node. This is achieved through appropriate manipulation of the 2 X 2 system as indicated in figure 5. The resulting 4 X 4 system involves only field values at the external nodes of the quadrilateral element. The coefficient matrix of this system is written symbolically in figure 5. This is the matrix which is actually programmed and then loaded additively into the global system coefficient matrix in the appropriate locations, as illustrated in figure 2. The appropriate locations in the global matrix are determined by the node numbering scheme. Our node numbering scheme is also shown in figure 2. Notice that the flexibility to assign different physical property factors k, p in each triangular region of the quadrilateral element has been retained, so that the discretization is still over the triangular regions, not over the quadrilateral regions.

B. Incorporation of sources and boundary conditions

The incorporation of the infinite line source of current strength I for the line source problem is an easy matter with the finite element method. The term of the source vector associated with the node in the finite element mesh where the source is located is assigned a number equal to +I if current is flowing in the + coordinate direction, and a number equal to -I if current is flowing in the - coordinate direction. This result is easily

$$\begin{bmatrix}
\underbrace{-\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}+\frac{\Delta X}{\Delta Z}\right)\frac{(K_1+K_2)}{K_1K_2}+\frac{\Delta X\Delta Z}{24}(P_1+P_2)}_{\Big\downarrow} & -\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}-\frac{\Delta X}{\Delta Z}\right)\frac{1}{K_2}+\frac{\Delta X\Delta Z}{48}P_2 & 0 & \frac{1}{4}\left(\frac{\Delta Z}{\Delta X}-\frac{\Delta X}{\Delta Z}\right)\frac{1}{K_1}+\frac{\Delta X\Delta Z}{48}P_1 & \frac{1}{2}\left(\frac{\Delta X}{K_1\Delta Z}+\frac{\Delta Z}{K_2\Delta X}\right)+\frac{\Delta X\Delta Z}{48}(P_1+P_2) \\
 & -\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}+\frac{\Delta X}{\Delta Z}\right)\frac{(K_2+K_3)}{K_2K_3}+\frac{\Delta X\Delta Z}{24}(P_2+P_3) & \frac{1}{4}\left(\frac{\Delta Z}{\Delta X}-\frac{\Delta X}{\Delta Z}\right)\frac{1}{K_3}+\frac{\Delta X\Delta Z}{48}P_3 & 0 & \frac{1}{2}\left(\frac{\Delta X}{K_3\Delta Z}+\frac{\Delta Z}{K_2\Delta X}\right)+\frac{\Delta X\Delta Z}{48}(P_2+P_3) \\
 & & -\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}+\frac{\Delta X}{\Delta Z}\right)\frac{(K_3+K_4)}{K_3K_4}+\frac{\Delta X\Delta Z}{24}(P_3+P_4) & -\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}-\frac{\Delta X}{\Delta Z}\right)\frac{1}{K_4}+\frac{\Delta X\Delta Z}{48}P_4 & \frac{1}{2}\left(\frac{\Delta X}{K_3\Delta Z}+\frac{\Delta Z}{K_4\Delta X}\right)+\frac{\Delta X\Delta Z}{48}(P_3+P_4) \\
 & \text{SYMMETRIC} & & -\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}+\frac{\Delta X}{\Delta Z}\right)\frac{(K_1+K_4)}{K_1K_4}+\frac{\Delta X\Delta Z}{24}(P_1+P_4) & \frac{1}{2}\left(\frac{\Delta X}{K_1\Delta Z}+\frac{\Delta Z}{K_4\Delta X}\right)+\frac{\Delta X\Delta Z}{48}(P_1+P_4) \\
\frac{1}{4}\left(\frac{\Delta Z}{\Delta X}+\frac{\Delta X}{\Delta Z}\right)\frac{(K_1+K_2)}{K_1K_2}+\frac{\Delta X\Delta Z}{24}(P_1+P_2) & & & & -\frac{\Delta X}{\Delta Z}\left(\frac{K_1+K_3}{K_1K_3}\right)-\frac{\Delta Z}{\Delta X}\left(\frac{K_2+K_4}{K_2K_4}\right)+\frac{\Delta X\Delta Z}{24}(P_1+P_2+P_3+P_4)
\end{bmatrix}$$

STATIC CONDENSATION:

$$\left[\begin{array}{c:c} K_{11} & K_{12} \\ \hdashline K_{21} & K_{22} \end{array}\right]\left[\begin{array}{c} X_1 \\ \hdashline X_2 \end{array}\right]=\left[\begin{array}{c} R_1 \\ \hdashline R_2 \end{array}\right]$$

ELIMINATE X_2:

$$\left[K_{11}-K_{12}K_{22}^{-1}K_{21}\right]\left[X_1\right]=\left[R_1-K_{12}K_{22}^{-1}R_2\right]$$

OR:

$$[\tilde{K}][\tilde{X}]=[\tilde{R}]$$

WHERE

$$[\tilde{K}]=\begin{bmatrix}
A-\frac{D^2}{M} & B-\frac{DG}{M} & -\frac{JD}{M} & C-\frac{LD}{M} \\
 & L-\frac{G^2}{M} & F-\frac{JG}{M} & -\frac{LG}{M} \\
 & & H-\frac{J^2}{M} & I-\frac{LJ}{M} \\
 & & & K-\frac{L^2}{M}
\end{bmatrix}$$

Figure 5. Explicit form of the 5 x 5 coefficient matrix associated with the quadrilateral element of figure 4. Process of static condensation to reduce this matrix to a 4 x 4.

derived, see Rijo (1977). I is arbitrarily assigned a value of 1 in the program. It is possible to assign a + and a - source, to simulate both long wires of a TURAM loop for example. The other terms of the source vector are zero.

When solving the TE or TM magnetotelluric problem, the entire source vector is set to zero, simulating a source at infinity. The source is introduced in the problem by applying a constant field value at the top of the mesh as a boundary condition.

Dirichlet boundary conditions are applied at all external mesh boundaries when solving the problems of Table 1. The method used in the program to incorporate these conditions once the global system has been formed is illustrated in figure 6. The following boundary conditions are applied:

Line Source problem: Homogeneous (zero) boundary conditions are specified at all external boundaries, with the assumption that the source(s) is/are located sufficiently far from the mesh edges so that the fields are approximately zero there.

TE-MT problem: A homogeneous boundary condition is applied at the bottom edge of the mesh. At each side of the mesh, fields due to a normally incident plane wave over a layered earth structure (one side may differ from the other) are calculated. The amplitude of the incident E-field is arbitrarily chosen as unity at the earth's surface, oriented in the + x (strike) direction. The resultant E-fields from this calculation are applied as boundary conditions on the sides of the mesh. The field values at the upper left and upper right corners of the mesh are then extended to the center of the mesh to give the constant field

Suppose we want to fix $f_1, f_3 = \beta_1, \beta_3$

$$\begin{bmatrix} K_{11}\times 10^{15} & k_{12} & k_{13} & k_{14} \\ k_{21} & k_{22} & k_{23} & k_{24} \\ k_{31} & k_{32} & k_{33}\times 10^{15} & k_{34} \\ k_{41} & k_{42} & k_{43} & k_{44} \end{bmatrix} \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} = \begin{bmatrix} \beta_1 k_{11}\times 10^{15} \\ S_2 \\ \beta_3 k_{33}\times 10^{15} \\ S_4 \end{bmatrix}$$

$$\text{e.g. } k_{11} \times 10^{15} \underline{f_1} + k_{12} f_1 + k_{12} f_2 + k_{13} f_3 = \underline{\beta_1} \times k_{11} \times 10^{15}$$

$$\text{or} \quad f_1 \approx \beta_1$$

$$\text{since} \quad k_{11} \times 10^{15} > k_{1j} \quad j = 2,3,4$$

Figure 6. Method of incorporating Dirichlet boundary conditions in the global system of equations.

at the top of the mesh which simulates the source for this problem.

TM-MT problem: The boundary conditions for this mode are applied in the same manner as for the TE mode, except that H-fields from the layered earth calculations are used. The source for the layered earth problem is again a normally incident plane wave with unit amplitude incident E-field, this time oriented in the + x (dip) direction. Notice the change in coordinate convention here. This is documented in the comment cards in the program. The reason for the change in convention is due to the manner in which the side boundary fields are calculated (see Appendix 1).

C. Calculation of auxiliary fields

The only field component we obtain with the finite element solution directly is the field (E or H depending on the problem) in the strike direction. Since other field components are required to calculate the parameters usually desired for interpretation, we must devise a numerical scheme for obtaining these from the field component in the strike direction. The auxiliary fields in this program are obtained through direct application of Maxwell's equations, as illustrated in figure 7. Note the different coordinate conventions for the three problems and the effects they have on the auxiliary field calculations. The derivatives indicated are evaluated numerically by fitting a piecewise polynomial to the mesh field values and then differentiating these analytically. This operation is performed by Univac 1108 system subroutine DERIV1 (see Appendix II).

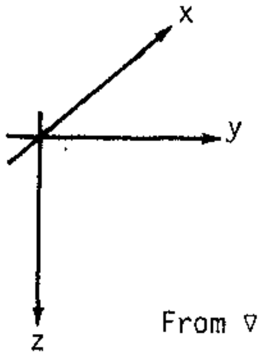
The auxiliary field calculation for the TM-MT problem is approximately constant at the earth's surface, so that the Dirichlet boundary condition could be applied at the air-earth interface in the finite element solution. However, system subroutine DERIV1 will not calculate a derivative

TE-MT and LINE SOURCE ($e^{+j\omega t}$ time dependence)

Coordinate System

Non-zero field components

E_x, H_y, H_z



$\partial/\partial x \equiv 0$

From $\nabla \times \vec{E} = -j\omega\mu\vec{H}$ get

$H_x = 0$

$H_y = -1/j\omega\mu \; \partial E_x/\partial z$

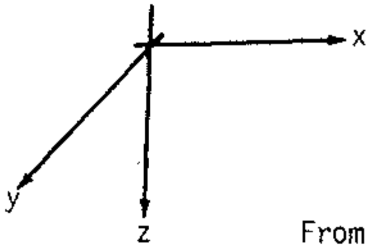
$H_z = +1/j\omega\mu \; \partial E_x/\partial y$

TM-MT ($e^{+j\omega t}$ time dependence)

Coordinate System

Non-zero field components

H_y, E_x, E_z



$\partial/\partial y \equiv 0$

From $\nabla \times H = (\sigma + j\omega\varepsilon)E$ get

$E_y = 0$

$E_x = -1/(\sigma + j\omega\varepsilon) \; \partial H_y/\partial z$

$E_z = +1/(\sigma + j\omega\varepsilon) \; \partial H_y/\partial x$

Figure 7. Calculation of auxiliary field components from the strike direction field obtained with the finite element solution.

very accurately near the end of a set of interpolated data points. Because of this, a one or two node air layer is incorporated in this problem, and the derivatives are calculated one node below the air-earth interface. For this reason, the first increment in z below the air-earth interface is made very small, say one to five meters.

References:

Harrington, R. F., 1967. Matrix methods for field problems: Proc. of the IEEE, vol. 55, no. 2, pp. 136-149.

Huebner, K. H., 1975. The Finite Element Method for Engineers: John Wiley & Sons, Inc., New York. 500 p.

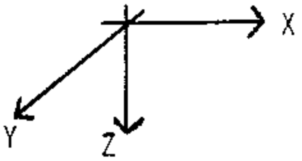
Rijo, L., 1977. Modeling of electric and electromagnetic data: Ph.D. thesis, University of Utah.

Strang, G. and Fix, F. J., 1973. An Analysis of the Finite Element Method: Prentice-Hall, Inc., Englewood Cliffs, N. J., 306 p.

Swift, C. M., Jr., 1967, A magnetotelluric investigation of an electrical conductivity anomaly in the southwestern United States: Ph.D. thesis, M.I.T.

Appendix I - Calculation of the Layered Earth Fields for the Boundary Condition for the Magnetotelluric Problem

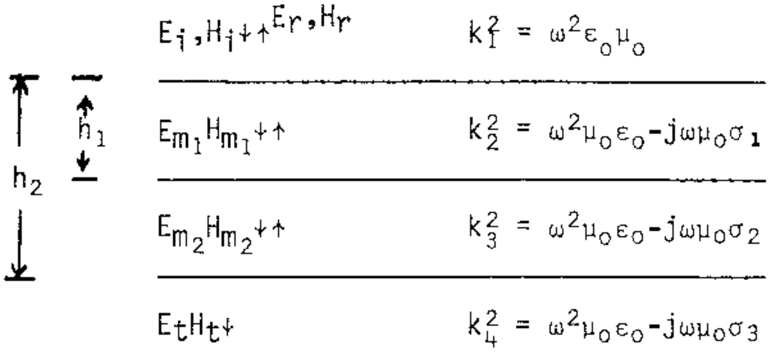
Conventions:



$e^{+j\omega t}$

time dependence

coordinate system



$E_i, H_i \downarrow \uparrow E_r, H_r$ $\quad k_1^2 = \omega^2 \varepsilon_o \mu_o$

$E_{m_1} H_{m_1} \downarrow \uparrow$ $\quad k_2^2 = \omega^2 \mu_o \varepsilon_o - j\omega\mu_o\sigma_1$

$E_{m_2} H_{m_2} \downarrow \uparrow$ $\quad k_3^2 = \omega^2 \mu_o \varepsilon_o - j\omega\mu_o\sigma_2$

$E_t H_t \downarrow$ $\quad k_4^2 = \omega^2 \mu_o \varepsilon_o - j\omega\mu_o\sigma_3$

Writing down the solutions in each layer, we have

1) $E_i = E_o e^{-jk_1 z}$ $\qquad H_i = \frac{k_1}{\omega\mu_o} E_i$

$E_r = E_1 e^{+jk_1 z}$ $\qquad H_r = \frac{-k_1}{\omega\mu_o} E_r$ $\qquad Z \leq 0$

2) $E_{m_1} = (E_2^+ e^{-jk_2 z} + E_2^- e^{+jk_2 z})$

$H_{m_1} = \frac{k_2}{\omega\mu_o} (E_2^+ e^{-jk_2 z} - E_2^- e^{+jk_2 z})$ $\qquad 0 < z \leq h_1$

3) $E_{m_2} = (E_3^+ e^{-jk_3 z} + E_3^- e^{+jk_3 z})$

$H_{m_2} = \frac{k_3}{\omega\mu_o} (E_3^+ e^{-jk_3 z} - E_3^- e^{-jk_3 z})$ $\qquad h_1 < z \leq h_2$

4) $E_t = E_4^+ e^{-jk_4 z}$

$H_t = \frac{k_4}{\omega\mu_o} E_t$ $\qquad z > h_2$

Assume $E_o = 1$.

Then $E|_{z=o} = 1 + E_1$

Let

$$Z_j \equiv \frac{\omega\mu_j}{k_j}$$

$$Z_{ij} \equiv \frac{Z_i}{Z_j} = \frac{\mu_i k_j}{\mu_j k_i} = \frac{k_j}{k_i} \quad \text{if } \mu_j = \mu_i$$

Apply continuity conditions on tangential E, H and then solve for the amplitude coefficients E_i^+ and E_i^-, $i = 1, 4$.

We obtain:

$$\left.\begin{aligned} -E_1 + E_2^+ + E_2^- &= E_0 \\ E_1 + Z_{12}[E_2^+ - E_2^-] &= E_0 \end{aligned}\right\} \quad \text{at } z = 0$$

$$\left.\begin{aligned} E_2^+A^{-1} + E_2^-A - E_3^+B^{-1} - E_3^-B &= 0 \\ E_2^+A^{-1} - E_2^-A - Z_{23}[E_3^+B^{-1} - E_3^-B] &= 0 \end{aligned}\right\} \quad \text{at } z = h_1$$

$$\left.\begin{aligned} E_3^+C^{-1} + E_3^-C - E_4^+D &= 0 \\ E_3^+C^{-1} - E_3^-C - Z_{34}E_4^+D &= 0 \end{aligned}\right\} \quad \text{at } z = h_2$$

where

$$A = e^{jk_2h_1};\ B = e^{jk_3h_1};\ C = e^{jk_3h_2};\ D = e^{jk_4h_2}$$

Re-writing in matrix notation:

$$\begin{bmatrix} -1 & 1 & 1 & 0 & 0 & 0 \\ 1 & Z_{12} & -Z_{12} & 0 & 0 & 0 \\ 0 & A^{-1} & A & -B^{-1} & -B & 0 \\ 0 & A^{-1} & -A & -Z_{23}B^{-1} & Z_{23}B & 0 \\ 0 & 0 & 0 & C^{-1} & C & -D^{-1} \\ 0 & 0 & 0 & C^{-1} & -C & -Z_{34}D^{-1} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2^+ \\ E_2^- \\ E_3^+ \\ E_3^- \\ E_4^+ \end{bmatrix} = \begin{bmatrix} E_0 \\ E_0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

This system of equations is set up and solved in subroutine EFIELD. Any number of layers may be handled by changing parameter NLAYR. Complex functions EFLD(Z) and HFLD(Z) implement equations 1 to 4 using the amplitude coefficients from EFIELD.

Appendix II - UUCC Univac 1108 System Subroutines

A. NTRAN

Ref. Univac 1108 Series Fortran V Library-Programmer's Reference,
UP - 7896, Univac Division, Sperry Rand Corp., 1971.

Highlights:

1) Drum storage is FASTRAND drum storage at the UUCC.

2) With FASTRAND storage, the D option must be used when assigning a file (see section III.F) to make the file word addressable, as required by the finite element program. If no D option is used, the file is automatically assigned as sector addressable; 1 sector equals 28 words. The D option allows FASTRAND files to be manipulated in the same manner as drum files.

3) Several operations may be grouped in a single NTRAN call.

4) It is important to remember that NTRAN provides for parallel processing. This means that NTRAN will perform user specified operations on a unit (file or tape) while at the same time allowing continued execution of the user's program. Operation 22 provides control over the parallel processing by stopping execution of the program until all NTRAN operations specified before operation 22 are complete. This prevents a program from using a file which is not yet ready, for example.

5) The CALL statement for NTRAN has the form

```
CALL NTRAN(UNIT,sequence of operations)
```

where UNIT is an integer constant or variable specifying the logical unit. The UNIT number for the program is currently set equal to 1, as described in section III.F. The sequence of operations is any list of I/O operations to be performed in order on the specified unit. An operation consists of a group of arguments. The first argument of an operation identifies the type of operation and is followed by parameters for the operation; these are fixed in number and order of occurrence by the type of operation. When referencing a FASTRAND file which has been assigned as word addressable, the current address for that file is the starting address only if the file has never been referenced in the current run. If the file was referenced before, the current address is the current address before the last CALL to the file plus the number of words transmitted or positioned in that CALL.

6) In order to check the status of transmission, each block of main storage in a FORTRAN program which is used for I/O has a block status word (an integer variable) associated with it; the name of the status word being specified in the argument list of an operation. When NTRAN is

called, the status words in the list of operations are set to -1, which indicates incomplete transmission, and the operations are then stacted in order for execution. When an interrupt occurs in an operation, the status word for that operation is set to a value which indicates the nature of completion, with the following possibilities:

STATUS WORD	NATURE OF COMPLETION
+N	normal completion; N equals the number of words transmitted.
-2	abnormal completion; attempt to read or write past an end of file marker.
-3	hardware errors, parity and character count errors (tape), or illegal unit specified. Legal units are all properly identified files and tapes.
-4	transmission aborted (previous operation had -2 or -3 status).

Notice that status -2 or -3 disables a unit for further NTRAN operations.

7) The following NTRAN I/O operations are used in the finite element program:

a) Write

The arguement group is: 1,N,B,L

N = integer constant or variable specifying the number of words to be transmitted.

B = variable name from which data is to be written.

L = status word.

b) Read

The argument group is: 2,N,B,L

N = integer constant or variable which specifies the length of the main storage block which will recieve the data.

B = variable into which data is to be read.

L = status word.

c) Position Drum

The argument group is: 6,N

N = integer constant or variable, positive or negative, which is added to the current drum address to form a new current drum address.

d) Rewind

The argument group is: 10

e) Wait and Unstack

The argument group is: 22

This operation causes a wait in NTRAN until all previous operations for the specified unit are complete before stacking any further operations or returning to the user's program. It also removes any operation which has caused an abnormal or error status and is still stacked against the specified unit, thereby enabling a file or tape which has been previously disabled, as described in 6).

The user must not change any argument of an argument group before the function is completed; i. e. before the status word for an operation has been changed from -1 to another value. All NTRAN operations are executed in sequence; completion of an operation, whether successful or unsuccessful, implies completion of all preceeding operations.

B. DERIV1

Ref. Large Scale Systems Math-Pack-Programmer's Reference, UP-7542,
Rev. 1, Univac Division, Sperry Rand Corp., 1970.

DERIV1 is a function subprogram which approximates the first derivative of a tabulated single valued function at one of the tabulated points. A parabolic approximation is used in which the tabulated function f(x) is approximated by a parabola passing through three pivotal points. The derivative of the parabola is taken as the approximate value of the derivative of f(x). The mathematical basis for the method is as follows:

Using a Taylor's series expansion of f(x+h) we obtain the following expressions for $f(x_i+ah)$ and $f(x_i-h)$:

$$f(x_i+ah) = f_i + ahf'_i + \frac{a^2h^2}{2} f''_i + \ldots\ldots$$

$$f(x_i-h) = f_i - hf_i + \frac{h^2}{2} f''_i - \ldots\ldots$$

where $f_i = f(x_i)$.

An approximate expression for f'_i is obtained by subtraction of the bottom equation from the top one followed by elimination of f''_i between the two to get

$$f'_i = \frac{1}{a(a+1)h} f(x_i+ah) - (1+a^2)f_i - a^2 f(x_i-h) + e$$

where e represents the error. The error goes to zero as h^2 for any a.

The proceedure for use of DERIV1 is as follows:

Calling statement: VAR = DERIV1(X,Y,N,XX,$K)

where

DERIV1.	is the name of the function and contains the approximation to the derivative at point XX upon return to the calling program. It is a floating point variable, as is XX. XX must equal an element of the X array, but must not equal X(1) or X(N).
X	is an array of N independent variable values which may be unequally spaced, but must be stored monotonically increasing. X is a floating point array; N is an integer.
Y	is an array of N dependent variable values. The elements of Y must be stored in correspondence to the elements of the X array. Y is also a floating point array.

K is a statement in the calling program to which control returns when one of the following conditions holds:

1) XX is not equal to an element of the X array.

2) XX = X(1)

3) XX = X(N)

4) overflow occurs in the computation of the first derivative approximation.

C. CGJR

Ref. Large Scale Systems Math-Pack Programmer's Reference, UP-7542,
Rev. 1, Univac Division, Sprrey Rand Corp., 1970.

CGJR is a subroutine which solves simultaneous equations, computes a determinant, inverts a matrix, or does any combination of these three operations, by using a Gauss-Jordan elimination technique with column pivoting.

The proceedure for using CGJR is as follows:

Calling statement: `CALL CGJR(A,NC,NR,N,MC,$K,JC,V)`

where

A	is the matrix whose inverse or determinant is to be determined. If simultaneous equations are solved, the last MC-N columns of the matrix are the constant vectors of the equations to be solved. On output, if the inverse is computed, it is stored in the first N columns of A. If simultaneous equations are solved, the last MC-N columns contain the solution vectors. A is a complex array.
NC	is an integer representing the maximum number of columns of the array A.
NR	is an integer representing the maximum number of rows of the array A.
N	is an integer representing the number of rows of the array A to be operated on.
MC	is the number of columns of the array A, representing the coefficient matrix if simultaneous equations are being solved; otherwise it is a dummy variable.
K	is a statement number in the calling program to which control is returned if an overflow or singularity is detected.

1) If an overflow is detected, JC(1) is set to the negative of the last correctly completed row of the reduction and control is then returned to statement number K in the calling program.

2) If a singularity is detected, JC(1) is set to the number of the last correctly completed row, and V is set to (0.,0.) if the determinant was to be computed. Control is then returned to statement number K in the calling program.

JC is a one dimensional permutation array of N elements which is used for permuting the rows and columns of A if an inverse is being computed. If an inverse is not computed, this array must have at least one cell for the error return identification. On output, JC(1) is N if control is returned normally.

V is a complex variable. On imput REAL(V) is the option indicator, set as follows:

1. invert matrix
2. compute determinant
3. do 1. and 2.
4. solve system of equations
5. do 1. and 4.
6. do 2. and 4.
7. do 1., 2. and 4.

Notes on usage of row dimension arguments N and NR:

The arguments N and NR refer to the row dimensions of the A matrix. N gives the number of rows operated on by the subroutine, while NR refers to the total number of rows in the matrix as dimensioned by the calling program. NR is used only in the dimension statement of the subroutine. Through proper use of these parameters, the user may specify that only a submatrix, instead of the entire matrix, be operated on by the subroutine.

Appendix III - Program Listing

```
STODT*PWLS1(1).MAIN
C     THIS PROGRAM SOLVES THE TWO DIMENSIONAL LINE SOURCE AND TE AND TM
C     MAGNETOTELLURIC PROBLEM ACCORDING TO WHETHER THE INPUT PARAMETER
C     IDX=1,2, OR 3. THE FINITE ELEMENT METHOD IS USED WITH LINEAR
C     BASIS FUNCTIONS. MKS UNITS AND EXP(+JWT) TIME DEPENDENCE IS
C     ASSUMED. THE + COORDINATE DIRECTIONS FOR THE L.S. AND TE PROBLEMS
C     ARE X-NORTH, Y-EAST, Z-DOWN. FOR THE TM PROBLEM THEY ARE X-EAST,
C     Y-SOUTH, Z-DOWN. THE STRIKE DIRECTION IS ASSUMED N-S. THE ORIGIN
C     IS AT THE LEFT EDGE OF THE MESH AT THE AIR-EARTH INTERFACE.
C
      PARAMETER IP1=27,IP4=57,IP6=30
     $,IP2=IP1*IP4,IP3=1P1+2,IP5=2*IP3
      PARAMETER NLAYR=3
      PARAMETER NLYR=NLAYR-1,NK=NLAYR+1,MDIM=2*NLAYR
      COMPLEX CK(4),CP(4),CK12,CK13,CK14,CK23,CK24,CK34,CP12,CP23,CP34,
     $CP14,CP1234,A11,A12,A14,A15,A22,A23,A25,A33,A34,A35,A44,A45,A55,
     $E11,G11,C11,H11,E22,H22,C22,E33,G33,E44,BC(IP4),
     $BC1(IP4),S1(IP2,5),S2(IP5,IP3),S(IP3,IP3),R(IP2),R1(IP5),ZERO
      COMPLEX XE(MDIM),XK(NK),DUM(MDIM,MDIM),EFLD,HFLD
      DIMENSION H(NLYR),P(NLAYR)
      COMMON/BLK2/DUM,XE,XK
      COMMON/BLK3/H,W
      COMMON/BLK1/S,S2,R,R1,NT1,NF1,NCOL1,NS1,NEQ1
      COMMON/BLK4/WU,WE,RHO,CK,CP
      COMMON/BLK5/XX,ZZ,BC,BC1,NTART,NODEX,NODEX1,NODEZ
      COMMON/BLK6/IDX,L,M
      INTEGER NPT(IP1,4,IP4),NX(IP6),NZ(IP6)
      REAL DELTAX(IP4),DELTAZ(IP1),DELX(IP6),DELZ(IP6),RHO(IP1,4,IP4)
     1,Y(10),XX(IP4),ZZ(IP4),RE(IP4),AIE(IP4)
C
C     *****************************************************************
C
      ZERO=(0.,0.)
      ELARGE=10E+15
      READ 1 IDX,NODEX,NODEZ,NXX,NZZ,NRES,M1,NPRINT,LINE1,LINE2
      READ 4 (Y(I),I=1,NRES),F            @INPUT MESH CONDUCTIVITIES
      READ 1 (NX(I),I=1,NXX)
      READ 4 (DELX(I),I=1,NXX)
      READ 1 (NZ(I),I=1,NZZ)
      READ 4 (DELZ(I),I=1,NZZ)
      NODEX1=NODEX-1
      NODEZ1=NODEZ-1
      DO 29 I=1,NODEZ1
      DO 29 L=1,4
      READ 48 (NPT(I,L,J),J=1,NODEX1)
29    CONTINUE
      PRINT 20 IDX
      PRINT 410 NODEX,NODEZ,NXX,NZZ,NRES,M1,NPRINT,LINE1,LINE2
      PRINT 420
      PRINT 300 (Y(I),I=1,NRES),F
      PRINT 430
      PRINT 1 (NX(I),I=1,NXX)
      PRINT 440
      PRINT 300 (DELX(I),I=1,NXX)
      PRINT 450
      PRINT 1 (NZ(I),I=1,NZZ)
      PRINT 460
```

```
      PRINT 300 (DELZ(I),I=1,NZZ)
      PRINT 470
C
C     THIS SECTION PRINTS OUT THE CODED MESH-IF THE MESH IS TOO LARGE
C     TO FIT ACROSS THE PAGE, JUST THE CENTER 43 ELEMENTS ARE PRINTED.
C
      M=1
      L2=NODEX1
      IF(NODEX1.LE.42)GO TO 502
      M=1+(NODEX1-42)/2
      L2=M+42
502   DO 501 I=1,NODEZ1
      PRINT 62 (NPT(I,1,J),J=M,L2)
      PRINT 63 (NPT(I,2,J),NPT(I,4,J),J=M,L2)
  501 PRINT 62 (NPT(I,3,J),J=M,L2)
C
C     THIS SECTION PROPERLY POSITIONS THE AIR-EARTH INTERFACE.
C
      NTART=1
      IF(IDX.GT.2.AND.M1.EQ.0)GO TO 220
C
C     THIS PORTION NUMBERS THE NODES PROPERLY IF THERE IS AN AIR LAYER.
C     NOTE--AT PRESENT THE TM MODE ALSO REQUIRES AN AIR LAYER TO AVOID
C     PROBLEMS ASSOCIATED WITH THE CALCULATION OF THE E-PERPENDICULAR
C     FIELD THROUGH NUMERICAL DIFFERENTIATION OF THE MESH VALUES
C     IN THE Z-DIRECTION.
C
      DO 103 I=1,M1
  103 NTART=NTART+NZ(I)
      L=NTART
      ZZ(L)=0.
      DO 710 I=M1,1,-1
      INI=NZ(I)
      DO 710 J=1,INI
      ZZ(L-1)=ZZ(L)-DELZ(I)
  710 L=L-1
      L=NTART
      M11=M1+1
      DO 711 I=M11,NZZ
      INI=NZ(I)
      DO 711 J=1,INI
      ZZ(L+1)=ZZ(L)+DELZ(I)
  711 L=L+1
      GO TO 230
C
C     THIS PORTION WILL NUMBER THE NODES PROPERLY FOR NO AIR LAYER.
C
220   L=NTART
      ZZ(L)=0.
      DO 240 I=1,NZZ
      INI=NZ(I)
      DO 240 J=1,INI
      ZZ(L+1)=ZZ(L)+DELZ(I)
      L=L+1
240   CONTINUE
230   XEO=8.854333*1.0E-12
      XMUO=3.14159265*4.0E-07
```

```
      W=6.283185*F
      IF(IDX.NE.1)GO TO 231
C
C     THIS SECTION SETS THE MESH BOUNDARY CONDITIONS FOR THE L.S.
C     PROBLEM. THE SOURCE(S) IS ASSUMED INCLUDED IN THE MESH.
C
      DO 232 J=1,NODEX
      BC(J)=ZERO
      BC1(J)=ZERO
232   CONTINUE
      PRINT 610
      GO TO 233
C
C     THIS SECTION CALCULATES THE MESH BOUNDARY CONDITIONS FOR THE
C     TE AND TM PROBLEMS. A LAYERED EARTH BOUNDARY OF UP TO 9 LAYERS
C     + A HALF-SPACE (PARAMETER NLAYR=10) CAN BE ACCOMODATED. THE
C     BOUNDARY FIELDS ARE CALCULATED FOR AN INCIDENT E-FIELD AMPLITUDE
C     OF 1 AT THE EARTHS SURFACE (NOT AT THE TOP OF THE MESH)
C     POLARIZED IN THE + X DIRECTION. THIS IS THE REASON FOR THE CHANGE
C     IN COORDINATE CONVENTION IN CALCULATING THE TE AND TM MODES. THE
C     LEFT BOUNDARY IS CALCULATED FIRST AND MAY DIFFER FROM THE RIGHT.
C
231   DO 701 J=1,2
      READ 4 (H(I),I=1,NLYR)      @INPUT INTERFACE DEPTHS FROM Z=0.
      READ 4 (P(I),I=1,NLAYR)      @INPUT BOUNDARY RESISTIVITIES.
      IF(J.EQ.1)PRINT 480
      IF(J.EQ.2)PRINT 490
      PRINT 300 (H(I),I=1,NLYR)
      PRINT 300 (P(I),I=1,NLAYR)
      XK(1)=CMPLX(W*SQRT(XEO*XMUO),.0)
      DO 700 I=2,NK
      XK(I)=CSQRT(CMPLX(0.,-W*XMUO/P(I-1)))
  700 CONTINUE
C
      CALL EFIELD
C
      DO 702 I=1,NODEZ
      Z=ZZ(I)
      IF(IDX.EQ.3)GO TO 250
      IF(J-1)703,704,703
250   IF(J-1)803,804,803
  704 BC(I)=EFLD(Z)
      GO TO 702
  703 BC1(I)=EFLD(Z)
      GO TO 702
804   BC(I)=HFLD(Z)
      GO TO 702
803   BC1(I)=HFLD(Z)
  702 CONTINUE
  701 CONTINUE
      IF(NPRINT.GE.1) GO TO 1009
      PRINT 495
C
C     ******************************************************************
C
C     THIS SECTION DETERMINES ELEMENT DIMENSIONS AND PARAMETERS NEEDED
C     IN SOLVING THE GLOBAL SYSTEM OF EQUATIONS FROM THE INPUT.
```

```
C
  233 NBAND=NODEZ+2
      NNODE=NODEX*NODEZ
      NDB=NNODE-NBAND
      NBAN1=NBAND-1
      K=1
      DO 28  I=1,NXX
      NXI=NX(I)
      DO 28 L=1,NXI
      DELTAX(K)=DELX(I)
   28 K=K+1
      K=1
      DO 38  I=1,NZZ
      NZI=NZ(I)
      DO 38 L=1,NZI
      DELTAZ(K)=DELZ(I)
   38 K=K+1
C
C     ASSOCIATE CONDUCTIVITIES WITH THE MESH INPUT CODE.
C
      DO 27 J=1,NODEZ1
      DO 27 L=1,NODEX1
      DO 27 M=1,4
      K=NPT(J,M,L)
   27 RHO(J,M,L)=Y(K+1)
C
C     ZERO OUT THE SOLUTION VECTOR AND THE GLOBAL MATRIX.
C
      DO 16 I=1,NNODE
      R(I)=ZERO
      DO 16 K=1,5
   16 S1(I,K)=ZERO
C
C     THIS SECTION CALCULATES A 4 X 4 ELEMENT MATRIX FOR A RECTANGULAR
C     ELEMENT MADE UP OF 4 TRIANGULAR ELEMENTS. THE 5 X 5 MATRIX
C     OBTAINED FROM PROPER COMBINATION OF THE FOUR 3 X 3 TRIANGULAR
C     ELEMENT MATRICIES IS REDUCED TO A 4 X 4 MATRIX THROUGH A PROCESS
C     CALLED STATIC CONDENSATION. THIS ELIMINATES THE DEGREE OF FREEDOM
C     ASSOCIATED WITH THE INTERNAL NODE OF THE RECTANGLE, THUS REDUCING
C     THE SIZE OF THE GLOBAL SYSTEM MATRIX.
C
      L1=0.
      WU=W*XMUO
      WE=W*XEO
      DO 13 L=1,NODEX1
      L1=L1+1
      DO 13 M=1,NODEZ1
      DELZX=DELTAZ(M)/(2.*DELTAX(L))
      DELXZ=DELTAX(L)/(2.*DELTAZ(M))
      A=-(DELZX+DELXZ)/2.
      B=(DELZX-DELXZ)/2.
      C=DELTAX(L)*DELTAZ(M)/48.
C
      CALL SELECT
C
      CK12=(CK(1)+CK(2))/(CK(1)*CK(2))
      CK13=(CK(1)+CK(3))/(CK(1)*CK(3))
```

```
      CK14=(CK(1)+CK(4))/(CK(1)*CK(4))
      CK23=(CK(2)+CK(3))/(CK(2)*CK(3))
      CK24=(CK(2)+CK(4))/(CK(2)*CK(4))
      CK34=(CK(3)+CK(4))/(CK(3)*CK(4))
      CP12=CP(1)+CP(2)
      CP23=CP(2)+CP(3)
      CP34=CP(3)+CP(4)
      CP14=CP(1)+CP(4)
      CP1234=CP12+CP34
C
C     THESE ARE THE ELEMENTS OF THE 5 X 5 MATRIX.
C
      A11=A*CK12+2.*C*CP12
      A12=-B/CK(2)+C*CP(2)
      A14=B/CK(1)+C*CP(1)
      A15=DELXZ/CK(1)+DELZX/CK(2)+C*CP12
      A22=A*CK23+2.*C*CP23
      A23=B/CK(3)+C*CP(3)
      A25=DELXZ/CK(3)+DELZX/CK(2)+C*CP23
      A33=A*CK34+2.*C*CP34
      A34=-B/CK(4)+C*CP(4)
      A35=DELXZ/CK(3)+DELZX/CK(4)+C*CP34
      A44=A*CK14+2.*C*CP14
      A45=DELXZ/CK(1)+DELZX/CK(4)+C*CP14
      A55=2.*(C*CP1234-DELXZ*CK13-DELZX*CK24)
C
C     THESE ARE THE ELEMENTS OF THE 4 X 4 CONDENSED MATRIX.
C
      E22=A11-A15*A15/A55
      G11=A12-A15*A25/A55
      H22=-A15*A35/A55
      C22=A14-A15*A45/A55
      E11=A22-A25*A25/A55
      C11=A23-A25*A35/A55
      H11=-A25*A45/A55
      E33=A33-A35*A35/A55
      G33=A34-A35*A45/A55
      E44=A44-A45*A45/A55
C
C     THIS SECTION LOADS THE ELEMENT MATRICIES INTO THE GLOBAL MATRIX.
C
      S1(L1,1)=S1(L1,1)+E11
      S1(L1,2)=S1(L1,2)+G11
      S1(L1,4)=S1(L1,4)+C11
      S1(L1,5)=S1(L1,5)+H11
      L2=L1+1
      S1(L2,1)=S1(L2,1)+E22
      S1(L2,3)=S1(L2,3)+H22
      S1(L2,4)=S1(L2,4)+C22
      L3=L1+NODEZ
      S1(L3,1)=S1(L3,1)+E33
      S1(L3,2)=S1(L3,2)+G33
      L4=L3+1
      S1(L4,1)=S1(L4,1)+E44
   13 L1=L1+1
      IF(IDX.NE.1)GO TO 14
C
```

```
C     HERE THE SOURCE TERM(S) IS APPLIED AT THE APPROPRIATE NODE(S) FOR
C     THE L.S. PROBLEM. A CURRENT AMPLITUDE OF 1 IS ASSUMED.
C
      LINE11=NODEZ*(LINE1-1)+NTART
      LINE22=NODEZ*(LINE2-1)+NTART
      R(LINE11)=CMPLX(1.,0.)
      IF(LINE2.NE.0)R(LINE22)=-R(LINE11)
14    NJI=NNODE-NODEZ1
      NJ1=NJI-1
      L4=NODEX/2
      L2=L4*NODEZ
      L1=L2+1
C
C     THIS SECTION APPLIES THE BOUNDARY CONDITIONS TO THE MESH EDGES.
C     *************************************************
C     TOP LEFT HALF OF MESH GETS VALUE AT TOP LEFT CORNER.
C
      DO 12 I=1,L1,NODEZ
      S1(I,1)=S1(I,1)*ELARGE
   12 R(I)=BC(1)*S1(I,1)
      L3=L1+NODEZ
C
C     TOP RIGHT HALF OF MESH GETS VALUE AT TOP RIGHT CORNER.
C
      DO 1212 I=L3,NJI,NODEZ
      S1(I,1)=S1(I,1)*ELARGE
 1212 R(I)=BC1(1)*S1(I,1)
C
C     BOTTOM LEFT HALF OF MESH GETS VALUE AT BOTTOM LEFT CORNER.
C
      DO 11 I=NODEZ,L2,NODEZ
      S1(I,1)=S1(I,1)*ELARGE
   11 R(I)=BC(NODEZ)*S1(I,1)
      L2=L2+NODEZ
C
C     BOTTOM RIGHT HALF OF MESH GETS VALUE AT BOTTOM RIGHT CORNER.
C
      DO 1111 I=L2,NNODE,NODEZ
      S1(I,1)=S1(I,1)*ELARGE
 1111 R(I)=BC1(NODEZ)*S1(I,1)
C
C     LEFT AND RIGHT SIDES GET LEFT AND RIGHT BOUNDARY VALUES.
C
      DO 9 I=2,NODEZ1
      S1(I,1)=S1(I,1)*ELARGE
      R(I)=S1(I,1)*BC(I)
      J=NJ1+I
      S1(J,1)=S1(J,1)*ELARGE
    9 R(J)=S1(J,1)*BC1(I)
C
C     THIS SECTION LOADS THE APPROPRIATE SIZE BLOCKS OF THE GLOBAL
C     MATRIX ONTO FASTRAND DRUM THROUGH THE USE OF THE UNIVAC 1108 I-O
C     DEVICE NTRAN. ONLY A SMALL PIECE OF THE GLOBAL SYSTEM WHICH IS
C     BEING WORKED ON AT ANY ONE TIME DURING THE SOLUTION OF THE
C     SYSTEM OF EQUATIONS IS STORED IN CORE.
C
      L=1
```

```
      L3=NBAND
      L2=1+NNODE/L3
      L4=2*IP3*IP3
      DO 900 J=1,L2
      DO 901 I=1,L3
      S(I,1)=S1(L,1)
      S(I,2)=S1(L,2)
      S(I,NODEZ)=S1(L,3)
      S(I,NBAN1)=S1(L,4)
      S(I,NBAND)=S1(L,5)
  901 L=L+1
  900 CALL NTRAN(1,1,L4,S,IERRO,22)
C
      CALL SOLVER(NODEZ,NODEX,NBAND)
C
C     THIS SECTION REORDERS THE ARRAY LABELING FOR THE X AND Z
C     COORDINATES OF THE NODES SO THAT THE UUCC MATHPACK NUMERICAL
C     DERIVATIVE ROUTINES CAN BE USED IN SUBROUTINE AUXFLD.
C
      L=2
      XX(1)=.0
      DO 500 I=1,NXX
      INI=NX(I)
      DO 500 J=1,INI
      XX(L)=XX(L-1)+DELX(I)
  500 L=L+1
      L=2
      ZZ(1)=0.
      DO 505 I=1,NZZ
      INI=NZ(I)
      DO 505 J=1,INI
      ZZ(L)=ZZ(L-1)+DELZ(I)
  505 L=L+1
C
      CALL AUXFLD
C
C     THIS SECTION CHANGES THE LOCATION OF X=0 FROM THE LEFT EDGE OF
C     THE MESH TO ITS CENTER FOR PRINTOUT. THE UNIT OF DISTANCE IS KM
C     IF THE DISTANCE FROM THE EDGE OF THE MESH TO THE CENTER IS
C     GREATER THAN 9 KM. IF THE L.S. PROBLEM IS BEING SOLVED, X=0 IS
C     LOCATED AT THE NODE WHERE THE SOURCE CURRENT IS FLOWING IN
C     THE + DIRECTION.
C
      J=NTART+NODEZ
      NTART=(NODEX+1)/2
      FA=1.
      XNART=XX(NTART)
      IF(XNART.GT.9000.)FA=1000.
      IF(IDX.EQ.1)XNART=XX(LINE1)
      DO 101 I=2,NODEX1
  101 XX(I)=(XX(I)-XNART)/FA
      IF(IDX.EQ.1)GO TO 80
C
C     CALCULATE MAGNITUDES, PHASES OF FIELD COMPONENTS AND APPARENT
C     RESISTIVITY AND PHASE OF THE IMPEDANCE FOR PRINTOUT WHEN SOLVING
C     FOR THE TE OR TM PROBLEM.
C
```

```
      DO 79 I=2,NODEX1
      E11=BC(I)
      H11=BC1(I)
      AV=CABS(E11)
      AH=CABS(H11)
      A=AV/AH
      AF=ATAN2(AIMAG(H11),REAL(H11))
      IF(IDX.EQ.3)GO TO 77
      ARHO=RHO(2,3,I)/AH
C     NOTE THIS IS THE NEGATIVE OF THE PHASE OF THE IMPEDANCE.
      PHASE=57.29578*(RHO(2,4,I)-AF)
      GO TO 76
   77 ARHO=AH/RHO(2,3,I)
C     NOTE THIS IS THE NEGATIVE OF THE PHASE OF THE IMPEDANCE.
      PHASE=57.29578*(AF-RHO(2,4,I))
   76 ARHO=ARHO*ARHO/WO
      RE11=REAL(E11)
      IF(ABS(RE11).LT.10E-30)RE11=10E-30
      AF=57.29578* AF
      FA=57.29578*ATAN2(AIMAG(E11),RE11)
      RE(I)=REAL(R(J))
      AIE(I)=AIMAG(R(J))
      J=J+NODEZ
      RHODG=RHO(2,4,I)*57.29578
      B=REAL(H11)
      G=AIMAG(H11)
      DELTZ4=REAL(E11)
      DELT44=AIMAG(E11)
   79 PRINT 45 XX(I),DELTZ4,DELT44,AV,FA,B,G,AH,AF,RE(I),AIE(I),
     $RHO(2,3,I),RHODG,ARHO,PHASE
      GO TO 1009
C
C     CALCULATE MAGNITUDES AND PHASES OF H-FIELD COMPONENTS, NORMALIZED
C     MAGNITUDES AND PRIMARY H-FIELD FOR PRINTOUT WHEN SOLVING THE
C     L.S. PROBLEM.
C
   80 FCTR=1./FA
      DO 89 I=2,NODEX1
      IF(ABS(XX(I)).LT.10E-04) XX(I)=FCTR/6.283185*10E-20
      HPRI=FCTR/(-6.283185*XX(I))
      HPRIM=ABS(HPRI)
      E11=BC(I)
      B11=BC1(I)
      AV=CABS(E11)
      AH=CABS(H11)
      DELTZ4=REAL(E11)
      DELT44=AIMAG(E11)
      B=REAL(H11)
      G=AIMAG(H11)
      AF=57.29578*ATAN2(DELT44,DELTZ4)
      FA=57.29578*ATAN2(G,B)
      AVNOR=AV/HPRIM
      AHNOR=AH/HPRIM
   89 PRINT 46 XX(I),B,G,AH,FA,DELTZ4,DELT44,AV,AF,AHNOR,AVNOR,HPRI
C
C     ************************************************************
C
```

```
C
C        ***********************************************************
C
1        FORMAT(20I4)
2        FORMAT(2I4,3F10.0)
4        FORMAT(6F10.0)
20       FORMAT(1H ,'IDX=1 IMPLIES INF. LINE SOURCE',/,' IDX=2 IMPLIES TE M
        $AGNETOTELLURICS',/,' IDX=3 IMPLIES TM MAGNETOTELLURICS',/,' PARAME
        $TER IDX=',I4)
45       FORMAT(1X,F8.3,12E8.3,2F8.3)
46       FORMAT(1X,F9.4,13(1X,E8.3))
48       FORMAT(80I1)
62       FORMAT(43(2XI1))
63       FORMAT(1X,43(I1,1X,I1))
300      FORMAT(10E13.4)
410      FORMAT(1H ,'NODES HORIZONTALLY=',I4,'   NODES VERTICALLY=',I4,/,'
        $BLOCKS HORIZONTALLY=',I4,'  BLOCKS VERTICALLY=',I4,/,' NRES IN MES
        $H=',I4,'  BLOCKS OF AIR=',I4,'  NPRINT=',I4,/,' POS. OF 1RST L.S.=
        $',I4,'  POS. OF 2ND L.S.=',I4)
420      FORMAT(1H ,'MESH CONDUCTIVITIES AND FREQUENCY')
430      FORMAT(1H ,'NUMBERS OF EQUAL SIZED INCREMENTS HORIZONTALLY')
440      FORMAT(1H ,'SIZE OF THE INCREMENTS IN EACH HORIZONTAL BLOCK(M)')
450      FORMAT(1H ,'NUMBERS OF EQUAL SIZED INCREMENTS VERTICALLY')
460      FORMAT(1H ,'SIZE OF THE INCREMENTS IN EACH VERTICAL BLOCK(M)')
470      FORMAT(1H ,'FINITE ELEMENT MESH CONDUCTIVITY CODE')
480      FORMAT(1H ,'LEFT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES')
490      FORMAT(1H ,'RIGHT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES')
495      FORMAT(1H1,1X,'  DELX   RE(FZ)  IM(FZ)   IFZI    PHZ   RE(FTR) IM(
        $FTR)  IFTRI     PHZ   RE(FPL) IM(FPL)  IFPLI     PHZ   AP.RES.  -PHZ
        $(Z)')
610      FORMAT(1H1,1X,'    DELX    RE(HTR)  IM(HTR)   IHTRI      PHZ      RE(HZ
        $)  IM(HZ)      IHZI        PHZ   IHTR/HPRI IHZ/HPRI   HPR    ')
1009     CONTINUE
         STOP
         END

<**>
```

```
STODT*PWLS1(1).SELECT
C      THIS SUBROUTINE CALCULATES THE APPROPRIATE COEFFICIENTS OF THE
C      HELMHOLIZ EQUATION FOR INSERTION INTO THE ELEMENT MATRICIES
C      ACCORDING TO WHICH PROBLEM IS BEING SOLVED.
C
       SUBROUTINE SELECT
       PARAMETER IP1=27,IP4=57,IP6=30
       COMPLEX CK(4),CP(4)
       REAL RHO(IP1,4,IP4)
       COMMON/BLK4/WU,WE,RHO,CK,CP
       COMMON/BLK6/IDX,L,M
       IF(IDX.EQ.1.OR.IDX.EQ.2)GO TO 10
       IF(IDX.EQ.3)GO TO 20
10     DO 100 I=1,4
       CK(I)=CMPLX(0.,WU)
       CP(I)=-CMPLX(RHO(M,I,L),WE)
100    CONTINUE
       GO TO 400
20     DO 200 I=1,4
       CK(I)=CMPLX(RHO(M,I,L),WE)
       CP(I)=-CMPLX(0.,WU)
200    CONTINUE
400    RETURN
       END

<**>
```

```
STODT*PWLS1(1).SOLVER
C     THIS SUBROUTINE SOLVES THE GLOBAL SYSTEM OF EQUATIONS USING
C     GAUSSIAN ELIMINATION AND BACK SUBSTITUTION. THE GLOBAL MATRIX IS
C     DELT WITH IN NBAND X NBAND PIECES. THE SOLUTION IS RETURNED TO
C     MAIN IN ARRAY R(J).
C
      SUBROUTINE SOLVER(N,M,NB)
      PARAMETER IP1=27,IP4=57
     $,IP2=IP1*IP4,IP3=IP1+2,IP5=2*IP3
      COMPLEX S1,S,R,R1
      COMMON/BLK1/S(IP3,IP3),S1(IP5,IP3),R(IP2),R1(IP5),NT1,NF1,NCOL1,NS
     $1,NEQ1
      CALL NTRAN(1,10,22)
      NBNB2=2*IP3*IP3
      NBK=NBNB2
      CALL NTRAN(1,2,NBK,S,IERRO,22)
      DO 8000 I=1,NB
      R1(I)=R(I)
      DO 8000 J=1,NB
 8000 S1(I,J)=S(I,J)
      NM1=N-1
      NF1=1
      NCOL1=NB
      NEQ1=NB
      NT1=NB
      NWR2=2*NBK
      NTOTAL = N*M
      NNC3=NTOTAL/NB
      NC2=2*NB
      L=NB
      NREST = NTOTAL-NNC3*NB
      IF(NREST .EQ. 0) NNC3=NNC3-1
C
C     ******************************************************************
C
      DO 8002 K=2,NNC3
      CALL NTRAN(1,2,NBK,S,IERRO,22)
      DO 8003 I=1,NB
      II=I+NB
      L=L+1
      R1(II)=R(L)
      DO 8003 J=1,NB
 8003 S1(II,J)=S(I,J)
      CALL GAUSS1
      CALL NTRAN(1,6,-NWR2,22)
      LNC2=L-NC2
      DO 8004 I=1,NB
      II=I+NB
      LL=LNC2+I
      R(LL)=R1(I)
      R1(I)=R1(II)
      DO 8004 J=1,NB
      S(I,J)=S1(I,J)
 8004 S1(I,J)=S1(II,J)
      CALL NTRAN(1,1,NBK,S,IERRO,22)
 8002 CALL NTRAN(1,6,NBK,22)
      IF(NREST .EQ. 0) NREST=NB
```

```
      NBK=2*NREST*IP3
      CALL NTRAN(1,2,NBK,S,IERRO,22)
      DO 8005 I=1,NREST
      II=I+NB
      L=L+1
      R1(II)=R(L)
      DO 8005 J=1,NB
 8005 S1(II,J)=S(I,J)
      NF1=0
      NT1=NB+NREST
      CALL GAUSS1
      NBKT=2*NBNB2+NBK
      NBK=NBNB2
      NS1=NTOTAL/NB-1
      IF(NREST .EQ. NB) NS1=NS1-1
      NREST=NREST+NB
C
C     ******************************************************************
C
      CALL GAUSS2
      NT1=NB
      NS1=NS1-1
      NF1=1
      CALL NTRAN(1,6,-NBKT,22)
 8008 IL=NS1*NB
      CALL NTRAN(1,2,NBK,S,IERRO,22)
      DO 8009 I=1,NB
      IL=IL+1
      R1(I)=R(IL)
      DO 8009 J=1,NB
 8009 S1(I,J)=S(I,J)
      CALL GAUSS2
      NS1=NS1-1
      IF( NS1 .EQ. -1) RETURN
      CALL NTRAN(1,6,-NWR2,22)
      GO TO 8008
      END
```

<**>

```
STODT*PWLS1(1).GAUSS1
C      THIS SUBROUTINE PERFORMS THE FORWARD REDUCTION PART OF
C      GAUSSIAN ELIMINATION.
C
       SUBROUTINE GAUSS1
       PARAMETER IP1=27,IP4=57
     $,IP2=IP1*IP4,IP3=IP1+2,IP5=2*IP3
       COMPLEX B,S,A,SOLU,C
       COMMON/BLK1/S(IP3,IP3),A(IP5,IP3),SOLU(IP2),B(IP5),NN,NF,NCOL,NS,
     $NEQ
       MT=NCOL
       IF (NF.EQ.0) MT=NN
       DO 300 N=1,NN
       B(N)=B(N)/A(N,1)
       MM=MT-(1-NF)*(N-1)
       IF(MM .EQ. 1) GO TO 300
       IF (MM .GT. NCOL ) MM=NCOL
       I=N
       DO 275 L=2,MM
       C=A(N,L)/A(N,1)
       I=I+1
       J=0
       DO 250 K=L,MM
       J=J+1
   250 A(I,J)=A(I,J)-C*A(N,K)
       B(I)=B(I)-A(N,L)*B(N)
   275 A(N,L)=C
   300 CONTINUE
       RETURN
       END

<**>
```

```
STODT*PWLS1(1).GAUSS2
C      THIS SUBROUTINE PERFORMS THE BACKWARD SUBSTITUTION PART OF
C      GAUSSIAN ELIMINATION.
C
       SUBROUTINE GAUSS2
       PARAMETER IP1=27,IP4=57
      $,IP2=IP1*IP4,IP3=IP1+2,IP5=2*IP3
       COMPLEX B,S,A,SOLU,D
       COMMON/BLK1/S(IP3,IP3),A(IP5,IP3),SOLU(IP2),B(IP5),NN,NF,NCOL,NS,
      $NEQ
       N=NN+1
       DO 450 M=1,NN
       N=N-1
       MM=NCOL
       LL=N+NS*NEQ
       L=LL
       D=B(N)
       IF (NF .EQ. 0) MM=M
       IF ( MM .EQ. 1) GO TO 450
       IF (MM .GT. NCOL ) MM=NCOL
       DO 425 K=2,MM
       L=L+1
   425 D=D-A(N,K)*SOLU(L)
   450 SOLU(LL)=D
       RETURN
       END

<**>
```

```
STODT*PWLS1(1).AUXFLD
C       THIS SUBROUTINE CALCULATES THE VERTICAL FIELD AND THE FIELD
C       PERPENDICULAR TO STRIKE. THESE FIELDS ARE RELATED TO THE
C       APPROPRIATE DERIVATIVES OF THE FIELD PARALLEL TO STRIKE WHICH
C       WAS SOLVED FOR WITH THE FINITE ELEMENT METHOD. THE PROPER
C       RELATIONS ARE OBTAINED FROM MAXWELLS EQUATIONS IN THE PROPER
C       COORDINATE SYSTEM. THE AUXILIARY FIELD VALUES ARE RETURNED TO
C       MAIN IN ARRAYS BC(I) (VERTICAL FIELD) AND BC1(I) (FIELD
C       PERPENDICULAR TO STRIKE).
C
        SUBROUTINE AUXFLD
        PARAMETER IP1=27,IP4=57,IP6=30
       $,IP2=IP1*IP4,IP3=IP1+2,IP5=2*IP3
        COMPLEX UC,BC(IP4),BC1(IP4),R(IP2)
        COMPLEX DUM1(IP3,IP3),DUM2(IP5,IP3),DUM3(IP5),DUM9(4),DUM10(4)
        REAL RHO(IP1,4,IP4),XX(IP4),ZZ(IP4),RE(IP4),AIE(IP4)
        COMMON/BLK1/DUM1,DUM2,R,DUM3,DUM4,DUM5,DUM6,DUM7,DUM8
        COMMON/BLK4/WU,WE,RHO,DUM9,DUM10
        COMMON/BLK5/XX,ZZ,BC,BC1,NTART,NODEX,NODEX1,NODEZ
        COMMON/BLK6/IDX,LDUM,MOUM
        IF(IDX.EQ.4)GO TO 100
        NTAR=NTART
C
C       THIS STATEMENT PROVIDES FOR E PERPENDICULAR TO BE CALCULATED
C       1 NODE BELOW THE AIR-EARTH INTERFACE IN THE TM PROBLEM TO AVOID
C       NUMERICAL INSTABILITIES IN CALCULATION OF THE APPROPRIATE
C       DERIVATIVE. PUTTING THE NODE 1M BELOW THE SURFACE APPEARS TO
C       WORK AT THE HIGHER FREQUENCIES, THIS MUST BE DEEPENED AS
C       FREQUENCY DECREASES.
C
        IF(IDX.EQ.3)NTAR=NTART+1
        J=NTART
        DO 10 I=1,NODEX
        RE(I)=REAL(R(J))
        AIE(I)=AIMAG(R(J))
        RHO(2,3,I)=CABS(R(J))
        RHO(2,4,I)=ATAN2(AIE(I),RE(I))
        J=J+NODEZ
10        CONTINUE
        DO 20 J=2,NODEX1
C
C       DERIV1 IS A UUCC MATHPACK SYSTEM ROUTINE WHICH CALCULATES
C       DERIVATIVES FROM THE COEFFICIENTS OF A SPLINE FIT TO THE SET
C       OF DATA POINTS.
C
        AH=DERIV1(XX,RE,NODEX,XX(J),$1009)
        AV=DERIV1(XX,AIE,NODEX,XX(J),$1009)
        IF(IDX.EQ.3)GO TO 70
        UC=CMPLX(0.,WU)
        GO TO 75
70      UC=CMPLX(RHO(NTART,1,J-1),WE)
75      BC(J)=CMPLX(AH,AV)/UC
20      CONTINUE
        L1=1+NODEZ
        DO 30 J=2,NODEX1
        L=L1
        DO 40 I=1,NODEZ
```

```
        RE(I)=REAL(R(L))
        AIE(I)=AIMAG(R(L))
        L=L+1
  40    CONTINUE
        AH=DERIV1(ZZ,RE,NODEZ,ZZ(NTAR),$1009)
        AV=DERIV1(ZZ,AIE,NODEZ,ZZ(NTAR),$1009)
        IF(IDX.EQ.3)GO TO 80
        UC=-CMPLX(0.,WU)
        GO TO 85
  80    UC=-CMPLX(RHO(NTART,1,J-1),WE)
  85    BC1(J)=CMPLX(AH,AV)/UC
        L1=L1+NODEZ
  30    CONTINUE
  1009  CONTINUE
  100   RETURN
        END
```

<**>

```
STODT*PWLS1(1).EFIELD
C     THIS SUBROUTINE CALCULATES THE AMPLITUDE COEFFICIENTS FOR THE
C     DOWN AND UPGOING WAVES IN EACH LAYER. THE COEFFICIENTS ARE MADE
C     AVAILABLE TO FUNCTIONS EFLD AND HFLD THROUGH ARRAY E(I). AN
C     INCIDENT E-FIELD AMPLITUDE OF 1 IN THE + X DIRECTION AT THE
C     AIR-EARTH INTERFACE IS ASSUMED.
C
      SUBROUTINE EFIELD
      PARAMETER NLAYR=3
      PARAMETER NLYR=NLAYR-1,MDIM=2*NLAYR,NDIM=MDIM+1,NK=NLAYR+1
      COMPLEX XE(MDIM,NDIM),E(MDIM),XK(NK),EXPN(NK),Z(NLAYR),
     $DUM(MDIM,MDIM),TEM,TEM1,SOURCE,VAR,OPT
      DIMENSION H(NLYR),JC(MDIM)
      COMMON/BLK2/DUM,E,XK
      COMMON/BLK3/H,W
      EQUIVALENCE (E,XE(1,NDIM))
      DATA TEM,TEM1/(0.,0.),(1.,0.)/
C
C     THIS IS THE UNIT AMPLITUDE INCIDENT E-FIELD SOURCE TERM. IT IS
C     EASILY CHANGED SO THAT SCALING MAY BE DONE FOR COMPARISON WITH
C     OTHER SOLUTIONS.
C
      DATA SOURCE/(1.,0.)/
      OPT=CMPLX(6.,0.)
C
      SN=1.
      L=1
      L1=2
      I1=1
      IJ=3
      J2=4
C
      DO 10 I=1,NLYR
      DO 20 J=1,2
      JIDX=2*I+J-2
      VAR=CMPLX(0.,-1.)*XK(I+J)*H(I)
      EXPN(JIDX)=CEXP(VAR)
20    CONTINUE
10    CONTINUE
C
      DO 30 J=1,NLAYR
      Z(J)=XK(J+1)/XK(J)
30    CONTINUE
C
      DO 40 I=1,MDIM
      DO 40 J=1,NDIM
      XE(I,J)=TEM
40    CONTINUE
C
      XE(1,1)=-TEM1
      XE(1,2)=TEM1
      XE(1,3)=TEM1
      XE(2,1)=TEM1
      XE(2,2)=Z(1)
      XE(2,3)=-Z(1)
      XE(1,NDIM)=SOURCE
      XE(2,NDIM)=SOURCE
```

```
C
      DO 100 M=1,NLYR
      DO 70 I=I1,IJ,2
      VAR=EXPN(L)
      DO 80 J=IJ,J2
      DO 90 K=1,2
      XE(J,I+K)=VAR*SN
      VAR=1./VAR
      JJ=J
      KK=K
90    CONTINUE
80    CONTINUE
      XE(JJ,I+KK)=-XE(JJ,I+KK)
      SN=-SN
      L=L+1
70    CONTINUE
      XE(J2,J2)=XE(J2,J2)*Z(L1)
      XE(J2,J2+1)=XE(J2,J2+1)*Z(L1)
      L1=L1+1
      I1=I1+2
      IJ=IJ+2
      J2=J2+2
100   CONTINUE
      XE(MDIM-1,NDIM)=TEM
      XE(MDIM,NDIM)=TEM
C     WRITE(6,300)
300   FORMAT(1H0,'SYSTEM OF EQUATIONS FROM THE BOUNDARY CONDITIONS')
C     WRITE(6,400) ((XE(I,J),J=1,7),I=1,6)
400   FORMAT(6(1X,7(1P2E9.2),//))
C
C     CGJR IS A UUCC MATHPACK SYSTEM ROUTINE FOR APPLYING GAUSS-JORDAN
C     REDUCTION TO COMPLEX MATRICIES. OPT=6 SOLVES THE SYSTEM OF
C     EQUATIONS AND EVALUATES THE DETERMINAT OF THE COEFFICIENT MATRIX.
C
      CALL CGJR(XE,NDIM,MDIM,MDIM,NDIM,$1000,JC,OPT)
C
C     WRITE(6,200)OPT
200   FORMAT(1H0,'DETERMINAT OF SYSTEM MATRIX=',1P2E10.2)
      GO TO 999
1000  WRITE(6,500)JC(1),OPT
500   FORMAT(1X,'OVERFLOW OR SINGULARITY FROM SYSTEM SUBROUTINE CGJR',
     $/,1X,'LAST CORRECTLY REDUCED ROW=',I3,5X,'LN(DET)--PARTIAL=',
     $1P2E10.2)
999   RETURN
      END
```

<**>

```
STODT*PWLS1(1).EFLD
C        EFLD IS A COMPLEX FUNCTION WHICH GIVES THE VALUE OF E AT DEPTH Z
C        USING THE AMPLITUDE COEFFICIENTS GENERATED IN SUBROUTINE EFIELD.
C        THIS FUNCTION REQUIRES DEPTH TO LAYER INTERFACES FROM THE
C        SURFACE Z=0 (NOT LAYER THICKNESSES) FOR ITS PROPER OPERATION.
C
         COMPLEX FUNCTION EFLD(Z)
         PARAMETER NLAYR=3
         PARAMETER NLYR=NLAYR-1,MDIM=2*NLAYR,NK=NLAYR+1
         COMPLEX E(MDIM),XK(NK),DUM(MDIM,MDIM),EXPN
         DIMENSION H(NLYR)
         COMMON/BLK2/DUM,E,XK
         COMMON/BLK3/H,W
C
         IF(Z.LT.0.)GO TO 10
         DO 20 J=1,NLYR
         IF(Z-H(J))15,15,20
15       JJ=J
         GO TO 30
20       CONTINUE
         EXPN=CMPLX(0.,-1.)*XK(NK)*Z
         EXPN=CEXP(EXPN)
         EFLD=E(MDIM)*EXPN
         GO TO 40
30       EXPN=CMPLX(0.,-1.)*XK(JJ+1)*Z
         EXPN=CEXP(EXPN)
         EFLD=E(2*JJ)*EXPN+E(2*JJ+1)/EXPN
         GO TO 40
10       EXPN=CMPLX(0.,-1.)*XK(1)*Z
         EXPN=CEXP(EXPN)
         EFLD=EXPN+E(1)/EXPN
40       RETURN
         END

<**>
```

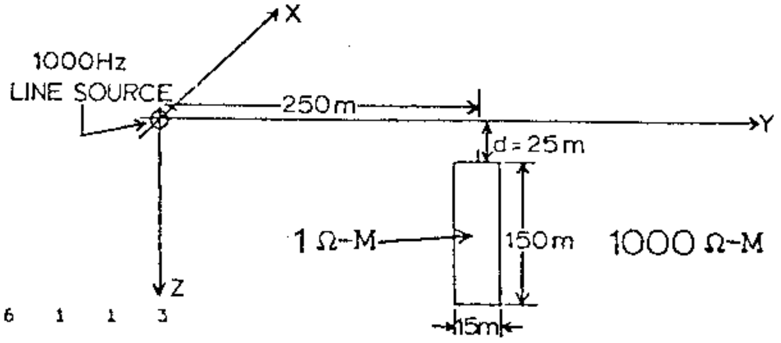
```
STODT*PWLS1(1).HFLD
C       HFLD IS A COMPLEX FUNCTION WHICH GIVES THE VALUE OF H AT DEPTH Z
C       USING THE AMPLITUDE COEFFICIENTS GENERATED IN SUBROUTINE EFIELD.
C       THIS FUNCTION REQUIRES DEPTH TO LAYER INTERFACES FROM THE
C       SURFACE Z=0 (NOT LAYER THICKNESSES) FOR ITS PROPER OPERATION.
C
        COMPLEX FUNCTION HFLD(Z)
        PARAMETER NLAYR=3
        PARAMETER NLYR=NLAYR-1,MDIM=2*NLAYR,NK=NLAYR+1
        COMPLEX E(MDIM),XK(NK),DUM(MDIM,MDIM),EXPN
        DIMENSION H(NLYR)
        COMMON/BLK2/DUM,E,XK
        COMMON/BLK3/H,W
C
        XMU0=3.14159   *0.0000004
        IF(Z.LT.0.)GO TO 10
        DO 20 J=1,NLYR
        IF(Z-H(J))15,15,20
 15     JJ=J
        GO TO 30
 20     CONTINUE
        EXPN=CMPLX(0.,-1.)*XK(NK)*Z
        EXPN=CEXP(EXPN)
        HFLD=XK(NK)*(E(MDIM)*EXPN)/(W*XMU0)
        GO TO 40
 30     EXPN=CMPLX(0.,-1.)*XK(JJ+1)*Z
        EXPN=CEXP(EXPN)
        HFLD=XK(JJ+1)*(E(2*JJ)*EXPN-E(2*JJ+1)/EXPN)/(W*XMU0)
        GO TO 40
 10     EXPN=CMPLX(0.,-1.)*XK(1)*Z
        EXPN=CEXP(EXPN)
        HFLD=XK(1)*(EXPN-E(1)/EXPN)/(W*XMU0)
 40     RETURN
        END

<**>
```

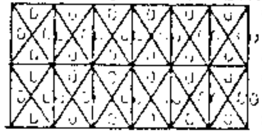
Appendix IV - Sample Runs

Note: FORTRAN library function ATAN2, which is used in this program, returns a value for the inverse tangent in the range -180,+180. Therefore, a suitable addative adjustment to the phase as printed by the program may have to be made to obtain the correct phase values for the convention the user happens to be using.

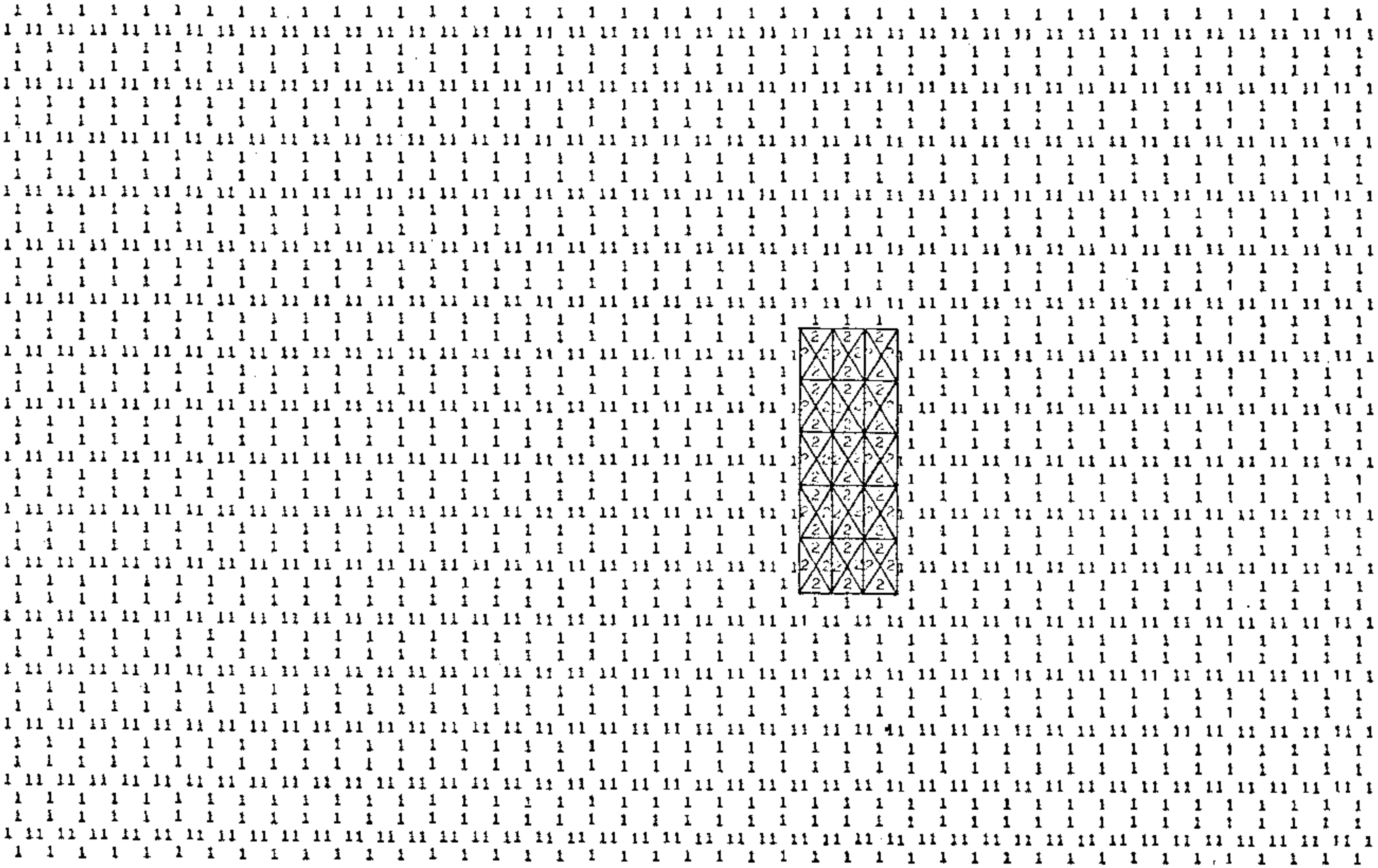
```
@ASG,T 1.,U///95000

@XQT,OF STUDT*PWLS1.ABS1
 IDX=1 IMPLIES INF. LINE SOURCE
 IDX=2 IMPLIES TE MAGNETOTELLURICS
 IDX=3 IMPLIES TM MAGNETOTELLURICS
 PARAMETER IDX=   1
 NODES HORIZONTALLY=  57   NODES VERTICALLY=  27
 BLOCKS HORIZONTALLY=  18  BLOCKS VERTICALLY=  17
 NPES IN MESH=   3  BLOCKS OF AIR=   9  NPRINT=   0
 POS. OF 1RST L.S.=  17  POS. OF 2ND L.S.=   0
 MESH CONDUCTIVITIES AND FREQUENCY
     .0000          .1000-02       .1000+01       .1000+04
 NUMBERS OF EQUAL SIZED INCREMENTS HORIZONTALLY
   3   1   1   1   3   3   7   2   3   2   1  13   3   2   6   1   1   3
 SIZE OF THE INCREMENTS IN EACH HORIZONTAL BLOCK(N)
     .3000+04       .1000+04       .3000+03       .1000+03       .2500+02       .5000+01       .2500+01       .5000+01       .2500+02       .5000+02
     .2500+02       .5000+01       .2500+02       .5000+02       .1000+03       .2000+03       .1000+04       .3000+04
 NUMBERS OF EQUAL SIZED INCREMENTS VERTICALLY
   1   1   1   1   1   1   1   1   1   5   2   4   2   1   1   1   1
 SIZE OF THE INCREMENTS IN EACH VERTICAL BLOCK(M)
     .3000+05       .1000+05       .3000+04       .1000+04       .3000+03       .1000+03       .3000+02       .1000+02       .3000+01       .3000+01
     .5000+01       .2500+02       .5000+02       .2000+03       .1000+04       .3000+04       .1500+05
 FINITE ELEMENT MESH CONDUCTIVITY CODE
```

EARTH MODEL:





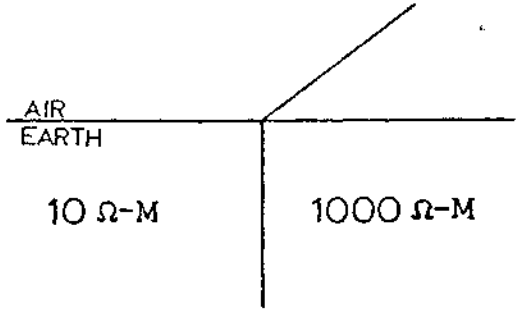
```
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0. 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
```


1
2

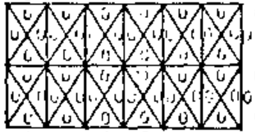
```
    DELX   RE(HTR)   IM(HTR)     IHTRI       PHZ    RE(HZ)    IM(HZ)      IHZI       PHZ IHTR/HPRI  IHZ/HPRI       HPR
 -7.5000  -.103-05   .406-06   .111-05   .159+03  -.943-07  -.778-09   .943-07  -.180+03   .522-01   .444-02   .212-04
 -4.5000  -.171-06   .169-05   .170-05   .958+02   .267-06   .179-05   .181-05   .815+02   .481-01   .512-01   .354-04
 -1.5000  -.299-04   .148-04   .333-04   .154+03  -.408-04   .341-04   .532-04   .140+03   .314+00   .502+00   .106-03
  -.5000  -.121-03  -.411-04   .128-03  -.161+03  -.288-03   .466-04   .292-03   .171+03   .401+00   .916+00   .318-03
  -.2000  -.159-03  -.104-03   .190-03  -.147+03  -.817-03   .233-04   .817-03   .178+03   .239+00   .103+01   .796-03
  -.1000  -.179-03  -.130-03   .222-03  -.144+03  -.155-02  -.225-05   .155-02  -.180+03   .139+00   .975+00   .159-02
  -.0750  -.174-03  -.138-03   .221-03  -.142+03  -.203-02  -.129-04   .203-02  -.180+03   .104+00   .959+00   .212-02
  -.0500  -.176-03  -.144-03   .227-03  -.141+03  -.323-02  -.272-04   .323-02  -.180+03   .715-01   .102+01   .318-02
  -.0250  -.206-03  -.150-03   .255-03  -.144+03  -.646-02  -.446-04   .646-02  -.180+03   .400-01   .102+01   .637-02
  -.0200  -.209-03  -.151-03   .257-03  -.144+03  -.790-02  -.487-04   .790-02  -.180+03   .324-01   .993+00   .796-02
  -.0150  -.262-03  -.152-03   .303-03  -.150+03  -.107-01  -.534-04   .107-01  -.180+03   .285-01   .100+01   .106-01
  -.0100  -.463-03  -.153-03   .487-03  -.162+03  -.159-01  -.586-04   .159-01  -.180+03   .306-01   .998+00   .159-01
  -.0075  -.554-03  -.153-03   .574-03  -.165+03  -.210-01  -.614-04   .210-01  -.180+03   .271-01   .991+00   .212-01
  -.0050  -.238-03  -.154-03   .284-03  -.147+03  -.334-01  -.645-04   .334-01  -.180+03   .891-02   .105+01   .318-01
  -.0025   .154-02  -.154-03   .154-02  -.572+01  -.803-01  -.680-04   .803-01  -.180+03   .242-01   .126+01   .637-01
   .0000   .225-02  -.153-03   .226-02  -.389+01   .226-03  -.724-04   .237-03  -.178+02   .226-21   .237-22  -.100+20
   .0025   .153-02  -.152-03   .154-02  -.568+01   .808-01  -.768-04   .808-01  -.545-01   .242-01   .127+01  -.637-01
   .0050  -.246-03  -.151-03   .289-03  -.148+03   .340-01  -.804-04   .340-01  -.136+00   .906-02   .107+01  -.318-01
   .0075  -.584-03  -.149-03   .603-03  -.166+03   .220-01  -.834-04   .220-01  -.217+00   .284-01   .104+01  -.212-01
   .0125  -.362-03  -.146-03   .390-03  -.158+03   .135-01  -.889-04   .135-01  -.377+00   .306-01   .106+01  -.127-01
   .0175  -.228-03  -.142-03   .269-03  -.148+03   .101-01  -.936-04   .101-01  -.533+00   .296-01   .111+01  -.909-02
   .0425  -.214-03  -.124-03   .248-03  -.150+03   .422-02  -.112-03   .422-02  -.153+01   .661-01   .113+01  -.374-02
   .0675  -.224-03  -.104-03   .247-03  -.155+03   .254-02  -.127-03   .255-02  -.286+01   .105+00   .108+01  -.236-02
   .0925  -.256-03  -.821-04   .269-03  -.162+03   .194-02  -.137-03   .194-02  -.406+01   .156+00   .113+01  -.172-02
   .1425  -.332-03  -.320-04   .333-03  -.174+03   .138-02  -.144-03   .139-02  -.597+01   .298+00   .124+01  -.112-02
   .1925  -.506-03   .259-04   .507-03   .177+03   .111-02  -.124-03   .111-02  -.638+01   .613+00   .135+01  -.827-03
   .2175  -.697-03   .402-04   .698-03   .177+03   .987-03  -.981-04   .992-03  -.567+01   .954+00   .136+01  -.732-03
   .2225  -.748-03   .383-04   .749-03   .177+03   .954-03  -.919-04   .958-03  -.550+01   .105+01   .134+01  -.715-03
   .2275  -.803-03   .345-04   .803-03   .178+03   .910-03  -.868-04   .914-03  -.545+01   .115+01   .131+01  -.700-03
   .2325  -.858-03   .292-04   .858-03   .176+03   .853-03  -.839-04   .857-03  -.561+01   .125+01   .125+01  -.685-03
   .2375  -.909-03   .233-04   .909-03   .179+03   .782-03  -.839-04   .787-03  -.612+01   .136+01   .117+01  -.670-03
   .2425  -.948-03   .188-04   .949-03   .179+03   .698-03  -.871-04   .703-03  -.711+01   .145+01   .107+01  -.656-03
   .2475  -.970-03   .175-04   .970-03   .179+03   .603-03  -.925-04   .610-03  -.872+01   .151+01   .948+00  -.643-03
   .2525  -.969-03   .205-04   .970-03   .179+03   .504-03  -.923-04   .514-03  -.110+02   .154+01   .815+00  -.630-03
   .2575  -.946-03   .276-04   .946-03   .178+03   .411-03  -.103-03   .423-03  -.140+02   .153+01   .685+00  -.618-03
   .2625  -.904-03   .371-04   .905-03   .178+03   .328-03  -.104-03   .345-03  -.176+02   .149+01   .568+00  -.606-03
   .2675  -.852-03   .470-04   .853-03   .177+03   .261-03  -.102-03   .281-03  -.214+02   .143+01   .471+00  -.595-03
   .2725  -.796-03   .558-04   .798-03   .176+03   .209-03  -.974-04   .231-03  -.249+02   .137+01   .395+00  -.584-03
   .2775  -.740-03   .626-04   .743-03   .175+03   .171-03  -.906-04   .193-03  -.260+02   .130+01   .337+00  -.574-03
   .2825  -.688-03   .672-04   .692-03   .174+03   .145-03  -.830-04   .167-03  -.298+02   .123+01   .296+00  -.563-03
   .3075  -.494-03   .658-04   .498-03   .172+03   .801-04  -.504-04   .946-04  -.322+02   .962+00   .183+00  -.518-03
   .3325  -.376-03   .512-04   .380-03   .172+03   .614-04  -.301-04   .684-04  -.261+02   .794+00   .143+00  -.479-03
   .3575  -.301-03   .370-04   .303-03   .173+03   .587-04  -.209-04   .623-04  -.196+02   .681+00   .140+00  -.445-03
   .4075  -.213-03   .175-04   .214-03   .175+03   .597-04  -.157-04   .617-04  -.148+02   .547+00   .158+00  -.391-03
   .4575  -.165-03   .705-05   .165-03   .178+03   .598-04  -.165-04   .621-04  -.154+02   .475+00   .178+00  -.348-03
   .5575  -.117-03  -.447-07   .117-03  -.180+03   .551-04  -.205-04   .588-04  -.204+02   .408+00   .206+00  -.285-03
   .6575  -.921-04  -.363-06   .921-04  -.180+03   .471-04  -.230-04   .524-04  -.260+02   .381+00   .217+00  -.242-03
   .7575  -.767-04   .128-05   .767-04   .179+03   .387-04  -.237-04   .454-04  -.314+02   .365+00   .216+00  -.210-03
   .8575  -.656-04   .333-05   .656-04   .177+03   .313-04  -.231-04   .389-04  -.365+02   .354+00   .210+00  -.186-03
   .9575  -.566-04   .523-05   .569-04   .175+03   .251-04  -.219-04   .333-04  -.410+02   .342+00   .200+00  -.166-03
  1.0575  -.491-04   .681-05   .495-04   .172+03   .203-04  -.202-04   .286-04  -.449+02   .329+00   .190+00  -.151-03
  1.2575  -.366-04   .887-05   .377-04   .166+03   .141-04  -.168-04   .219-04  -.501+02   .298+00   .173+00  -.127-03
  2.2575  -.104-04   .616-05   .121-04   .149+03   .307-05  -.704-05   .768-05  -.665+02   .171+00   .109+00  -.705-04
  5.2575  -.155-05   .113-05   .191-05   .144+03   .107-06  -.619-06   .628-06  -.802+02   .632-01   .207-01  -.303-04
  8.2575  -.586-06   .386-06   .702-06   .147+03   .222-07  -.100-06   .103-06  -.775+02   .364-01   .534-02  -.193-04
```

```
NORMAL EXIT.        TIME:          41086 MILLISECONDS.
```

EARTH MODEL:

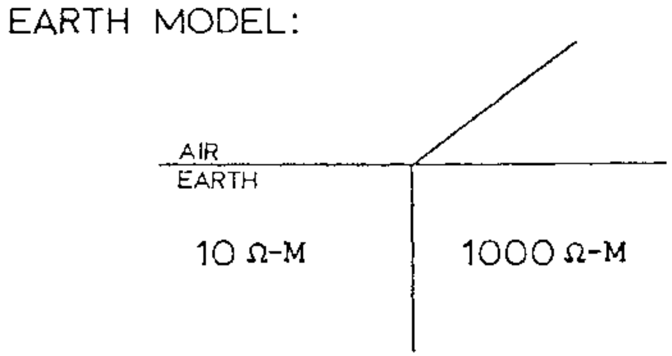


```
@ASG,T 1.,D///95000

@XQT,OF PMLS1.ABS1
 IDX=1 IMPLIES INF. LINE SOURCE
 IDX=2 IMPLIES TE MAGNETOTELLURICS
 IDX=3 IMPLIES TM MAGNETOTELLURICS
 PARAMETER IDX=   2
 NODES HORIZONTALLY=  57   NODES VERTICALLY=  27
 BLOCKS HORIZONTALLY=  13  BLOCKS VERTICALLY=  14
 NRES IN MESH=   3  BLOCKS OF AIR=   6  NPRINT=   0
 POS. OF 1ST L.S.=   0  POS. OF 2ND L.S.=   0
 MESH CONDUCTIVITIES AND FREQUENCY
     .0000          .1000+00       .1000-02       .1000+01
 NUMBERS OF EQUAL SIZED INCREMENTS HORIZONTALLY
   1   1   1   1  18   2   8   2  18   1   1   1   1
 SIZE OF THE INCREMENTS IN EACH HORIZONTAL BLOCK(M)
     .1000+06       .3000+05       .1000+05       .2000+04       .5000+03       .2500+03       .1250+03       .2500+03       .5000+03       .2000+04
     .1000+05       .3000+05       .1000+06
 NUMBERS OF EQUAL SIZED INCREMENTS VERTICALLY
   1   1   1   1   1   1   4   4   7   1   1   1   1   1
 SIZE OF THE INCREMENTS IN EACH VERTICAL BLOCK(M)
     .3000+05       .1000+05       .3000+04       .1000+04       .3000+03       .1000+03       .1000+03       .2000+03       .3000+03       .1000+04
     .3000+04       .1000+05       .3000+05       .1000+06
 FINITE ELEMENT MESH CONDUCTIVITY CODE
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
0 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
```

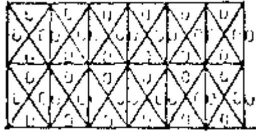


```
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 12 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
LEFT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES
    .1000+03      .2000+03
    .1000+02      .1000+02      .1000+02
RIGHT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES
    .1000+03      .2000+03
    .1000+04      .1000+04      .1000+04
```

```
    DELX   RE(FZ)  IM(FZ)    IFZI     PHZ    RE(FTR) IM(FTR)   IFTRI     PHZ    RE(FPL) IM(FPL)  IFPLI     PHZ    AP.RES.   -PHZ(Z)
 -52.000 .746-06-.107-04 .107-04-.860+02 .523-02-.895-04 .523-02-.968+00 .335-04 .333-04 .472-04 .449+02  10.309   45.870
 -22.000 .725-05-.514-04 .519-04-.820+02 .550-02-.324-03 .551-02-.337+01 .367-04 .336-04 .498-04 .424+02  10.339   45.789
 -12.000 .153-04-.968-04 .980-04-.610+02 .593-02-.655-03 .597-02-.630+01 .418-04 .343-04 .541-04 .394+02  10.390   45.694
 -10.000 .208-04-.116-03 .118-03-.798+02 .609-02-.770-03 .614-02-.721+01 .434-04 .346-04 .555-04 .385+02  10.340   45.735
  -9.500 .226-04-.123-03 .125-03-.795+02 .614-02-.803-03 .619-02-.745+01 .439-04 .347-04 .559-04 .383+02  10.334   45.751
  -9.000 .239-04-.131-03 .133-03-.796+02 .618-02-.838-03 .624-02-.771+01 .444-04 .347-04 .564-04 .381+02  10.330   45.771
  -8.500 .238-04-.140-03 .142-03-.804+02 .624-02-.875-03 .630-02-.799+01 .449-04 .348-04 .568-04 .378+02  10.323   45.793
  -8.000 .222-04-.152-03 .154-03-.817+02 .629-02-.917-03 .636-02-.829+01 .455-04 .349-04 .574-04 .375+02  10.310   45.815
  -7.500 .190-04-.167-03 .168-03-.835+02 .635-02-.963-03 .642-02-.862+01 .461-04 .350-04 .579-04 .372+02  10.287   45.830
  -7.000 .143-04-.188-03 .189-03-.856+02 .642-02-.101-02 .650-02-.897+01 .468-04 .351-04 .585-04 .369+02  10.252   45.827
  -6.500 .883-05-.217-03 .217-03-.877+02 .650-02-.107-02 .659-02-.936+01 .476-04 .351-04 .592-04 .364+02  10.200   45.785
  -6.000 .405-05-.258-03 .258-03-.891+02 .660-02-.113-02 .670-02-.975+01 .485-04 .352-04 .599-04 .359+02  10.132   45.672
  -5.500 .315-05-.315-03 .315-03-.894+02 .672-02-.120-02 .683-02-.101+02 .496-04 .352-04 .608-04 .353+02  10.052   45.447
  -5.000 .117-04-.394-03 .394-03-.883+02 .687-02-.127-02 .698-02-.105+02 .510-04 .352-04 .620-04 .346+02   9.970   45.057
  -4.500 .386-04-.500-03 .501-03-.856+02 .705-02-.133-02 .717-02-.107+02 .527-04 .353-04 .634-04 .338+02   9.909   44.447
  -4.000 .982-04-.636-03 .644-03-.812+02 .727-02-.138-02 .740-02-.107+02 .550-04 .355-04 .654-04 .329+02   9.904   43.574
  -3.500 .210-03-.806-03 .832-03-.754+02 .753-02-.139-02 .766-02-.105+02 .578-04 .360-04 .681-04 .320+02  10.008   42.429
  -3.000 .399-03-.100-02 .108-02-.683+02 .784-02-.136-02 .795-02-.985+01 .613-04 .371-04 .717-04 .312+02  10.290   41.058
  -2.500 .702-03-.121-02 .140-02-.599+02 .817-02-.126-02 .827-02-.676+01 .657-04 .392-04 .765-04 .308+02  10.843   39.582
  -2.000 .115-02-.139-02 .181-02-.504+02 .850-02-.107-02 .857-02-.715+01 .709-04 .427-04 .827-04 .311+02  11.805   38.208
  -1.500 .180-02-.149-02 .234-02-.397+02 .878-02-.772-03 .881-02-.502+01 .767-04 .483-04 .906-04 .322+02  13.399   37.225
  -1.000 .264-02-.145-02 .301-02-.285+02 .889-02-.397-03 .890-02-.256+01 .827-04 .569-04 .100-03 .345+02  16.111   37.085
   -.750 .316-02-.130-02 .341-02-.224+02 .892-02-.196-03 .883-02-.128+01 .854-04 .626-04 .106-03 .362+02  18.230   37.495
   -.500 .374-02-.106-02 .389-02-.158+02 .862-02-.257-04 .862-02-.171+00 .876-04 .693-04 .112-03 .383+02  21.334   38.472
   -.375 .406-02-.894-03 .415-02-.124+02 .844-02 .336-04 .844-02 .228+00 .888-04 .732-04 .115-03 .395+02  23.514   39.273
   -.250 .440-02-.693-03 .445-02-.895+01 .820-02 .540-04 .820-02 .378+00 .896-04 .773-04 .116-03 .408+02  26.387   40.437
   -.125 .476-02-.445-03 .478-02-.534+01 .786-02-.618-05 .786-02-.450-01 .901-04 .819-04 .122-03 .422+02  30.373   42.292
    .000 .499-02-.254-03 .499-02-.292+01 .740-02-.278-03 .740-02-.215+01 .904-04 .867-04 .125-03 .438+02  36.304   45.957
    .125 .496-02-.275-03 .496-02-.318+01 .684-02-.476-03 .684-02-.399+01 .906-04 .917-04 .129-03 .453+02  45.029   49.329
    .250 .480-02-.396-03 .482-02-.471+01 .651-02-.649-03 .654-02-.569+01 .910-04 .965-04 .133-03 .467+02  52.061   52.388
    .375 .465-02-.481-03 .467-02-.592+01 .623-02-.719-03 .627-02-.659+01 .914-04 .101-03 .136-03 .479+02  59.898   54.489
    .500 .450-02-.555-03 .454-02-.703+01 .599-02-.754-03 .604-02-.717+01 .919-04 .106-03 .140-03 .490+02  68.133   56.158
    .750 .425-02-.688-03 .431-02-.920+01 .563-02-.784-03 .568-02-.793+01 .932-04 .114-03 .147-03 .508+02  85.275   59.752
   1.000 .403-02-.794-03 .411-02-.111+02 .536-02-.791-03 .542-02-.838+01 .947-04 .122-03 .155-03 .523+02 103.213   60.688
   1.500 .365-02-.939-03 .377-02-.144+02 .501-02-.766-03 .506-02-.870+01 .981-04 .138-03 .169-03 .545+02 141.028   63.200
   2.000 .331-02-.103-02 .347-02-.172+02 .477-02-.715-03 .482-02-.852+01 .102-03 .151-03 .182-03 .560+02 181.245   64.517
   2.500 .302-02-.108-02 .321-02-.197+02 .460-02-.653-03 .465-02-.807+01 .106-03 .164-03 .195-03 .570+02 223.180   65.090
   3.000 .277-02-.111-02 .298-02-.218+02 .448-02-.587-03 .452-02-.746+01 .111-03 .175-03 .207-03 .577+02 266.020   65.191
   3.500 .255-02-.113-02 .279-02-.238+02 .439-02-.522-03 .442-02-.678+01 .115-03 .186-03 .218-03 .582+02 309.008   64.991
   4.000 .236-02-.114-02 .262-02-.257+02 .432-02-.459-03 .435-02-.606+01 .119-03 .195-03 .229-03 .585+02 351.517   64.602
   4.500 .219-02-.114-02 .247-02-.275+02 .427-02-.400-03 .429-02-.536+01 .124-03 .204-03 .239-03 .587+02 393.052   64.097
   5.000 .204-02-.114-02 .234-02-.292+02 .425-02-.346-03 .425-02-.467+01 .128-03 .213-03 .248-03 .588+02 433.237   63.522
   5.500 .190-02-.114-02 .222-02-.308+02 .421-02-.296-03 .422-02-.402+01 .133-03 .220-03 .257-03 .589+02 471.823   62.910
   6.000 .178-02-.113-02 .211-02-.324+02 .419-02-.250-03 .420-02-.341+01 .137-03 .228-03 .266-03 .589+02 508.627   62.282
   6.500 .167-02-.112-02 .201-02-.339+02 .418-02-.208-03 .418-02-.284+01 .142-03 .234-03 .274-03 .588+02 543.559   61.652
   7.000 .157-02-.112-02 .193-02-.354+02 .417-02-.169-03 .418-02-.232+01 .146-03 .241-03 .282-03 .587+02 576.571   61.029
   7.500 .148-02-.110-02 .185-02-.368+02 .417-02-.133-03 .418-02-.183+01 .151-03 .247-03 .289-03 .586+02 607.672   60.419
   8.000 .139-02-.109-02 .177-02-.381+02 .418-02-.101-03 .418-02-.138+01 .155-03 .252-03 .296-03 .584+02 636.886   59.825
   8.500 .131-02-.108-02 .170-02-.394+02 .418-02-.709-04 .419-02-.970+00 .159-03 .258-03 .303-03 .583+02 664.281   59.250
   9.000 .124-02-.107-02 .164-02-.407+02 .419-02-.434-04 .419-02-.592+00 .164-03 .263-03 .310-03 .581+02 689.916   58.694
   9.500 .117-02-.105-02 .158-02-.419+02 .421-02-.180-04 .421-02-.245+00 .168-03 .268-03 .316-03 .579+02 713.879   58.159
  10.000 .111-02-.104-02 .152-02-.430+02 .422-02 .551-05 .422-02 .748-01 .172-03 .272-03 .322-03 .577+02 736.244   57.643
  12.000 .921-03-.973-03 .134-02-.466+02 .429-02 .836-04 .430-02 .112+01 .188-03 .288-03 .344-03 .569+02 811.160   55.765
  22.000 .403-03-.680-03 .790-03-.594+02 .472-02 .204-03 .472-02 .248+01 .251-03 .330-03 .415-03 .527+02 976.458   50.206
  52.000 .146-04-.238-03 .239-03-.865+02 .529-02 .499-04 .529-02 .541+00 .324-03 .334-03 .466-03 .459+02 981.200   45.368



NORMAL EXIT.      TIME:        40394 MILLISECONDS.
```



```
@ASG,T 1.,D///95000


@XQT,OF PWLS1.ABS1
 IDX=1 IMPLIES INF. LINE SOURCE
 IDX=2 IMPLIES TE MAGNETOTELLURICS
 IDX=3 IMPLIES TM MAGNETOTELLURICS
 PARAMETER IDX=   3
 NODES HORIZONTALLY=  57   NODES VERTICALLY=  27
 BLOCKS HORIZONTALLY=  13  BLOCKS VERTICALLY=  15
 NRES IN MESH=   3  BLOCKS OF AIR=   2  NPRINT=   0
 POS. OF 1RST L.S.=   0  POS. OF 2ND L.S.=   0
 MESH CONDUCTIVITIES AND FREQUENCY
     .0000           .1000+00        .1000-02        .1000+01
 NUMBERS OF EQUAL SIZED INCREMENTS HORIZONTALLY
   1    1    1    1   16    2    8    2   16    1    1    1    1
 SIZE OF THE INCREMENTS IN EACH HORIZONTAL BLOCK(M)
     .1000+06        .3000+05        .1000+05        .2000+04        .5000+03        .2500+03        .1250+03        .2500+03        .5000+03        .2000+04
     .1000+05        .3000+05        .1000+06
 NUMBERS OF EQUAL SIZED INCREMENTS VERTICALLY
   1    1    1    1    1    1    1    3    4    7    1    1    1    1    1
 SIZE OF THE INCREMENTS IN EACH VERTICAL BLOCK(M)
     .1000+02        .3000+01        .1000+01        .3000+01        .6000+01        .2500+02        .6500+02        .1000+03        .2000+03        .3000+03
     .1000+04        .3000+04        .1000+05        .3000+05        .1000+06
 FINITE ELEMENT MESH CONDUCTIVITY CODE
```



```
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0 00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00 0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  0 00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00  00 0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
  1 11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  11  12 22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22  22 2
   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2
```

```
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11 1|2 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 22 2
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 |2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
LEFT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES
    .1000+03      .2000+03
    .1000+02      .1000+02      .1000+02
RIGHT EDGE INTERFACE DEPTHS(M) AND RESISTIVITIES
    .1000+03      .2000+03
    .1000+04      .1000+04      .1000+04
```

```
   DELX  RE(FZ)  IM(FZ)   IFZI     PHZ  RE(FTR) IM(FTR)  IFTRI    PHZ  RE(FPL) IM(FPL)  IFPLI    PHZ  AP.RES. -PHZ(Z)
-52.000-.537-14 .274-14 .603-14 .153+03 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.956-03   9.980  44.990
-22.000-.262-12-.104-14 .262-12-.180+03 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.985  44.985
-12.000-.786-12 .427-14 .786-12 .180+03 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.979  45.003
-10.000 .166-10-.381-14 .166-10-.131-01 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.967  45.016
 -9.500 .407-11-.254-14 .407-11-.357-01 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.963  45.012
 -9.000 .175-11 .364-15 .175-11 .119-01 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.958  45.004
 -8.500 .233-11-.888-16 .233-11-.219-02 .333-04 .333-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.954  44.985
 -8.000-.582-11 .133-15 .582-11 .180+03 .333-04 .332-04 .471-04 .450+02 .531-02-.885-07 .531-02-.955-03   9.951  44.956
 -7.500 .582-12-.266-16 .582-12-.262-02 .333-04 .332-04 .471-04 .449+02 .531-02-.885-07 .531-02-.955-03   9.952  44.914
 -7.000-.988-26-.178-16 .178-16-.900+02 .334-04 .332-04 .471-04 .449+02 .531-02-.885-07 .531-02-.955-03   9.961  44.858
 -6.500 .494-26 .888-17 .888-17 .900+02 .334-04 .332-04 .471-04 .448+02 .531-02-.885-07 .531-02-.955-03   9.981  44.793
 -6.000 .000    .000    .000    .000    .335-04 .332-04 .472-04 .447+02 .531-02-.885-07 .531-02-.955-03  10.020  44.732
 -5.500 .000    .000    .000    .000    .337-04 .333-04 .474-04 .447+02 .531-02-.885-07 .531-02-.955-03  10.082  44.698
 -5.000 .000    .000    .000    .000    .338-04 .335-04 .476-04 .447+02 .531-02-.885-07 .531-02-.955-03  10.173  44.733
 -4.500 .000    .000    .000    .000    .339-04 .338-04 .479-04 .449+02 .531-02-.885-07 .531-02-.955-03  10.292  44.896
 -4.000 .000    .000    .000    .000    .339-04 .342-04 .482-04 .453+02 .531-02-.885-07 .531-02-.955-03  10.432  45.272
 -3.500 .000    .000    .000    .000    .337-04 .349-04 .485-04 .460+02 .531-02-.885-07 .531-02-.955-03  10.566  45.967
 -3.000 .494-26 .888-17 .888-17 .900+02 .331-04 .356-04 .487-04 .471+02 .531-02-.885-07 .531-02-.955-03  10.639  47.107
 -2.500 .494-26 .888-17 .888-17 .900+02 .319-04 .365-04 .485-04 .488+02 .531-02-.885-07 .531-02-.955-03  10.556  48.830
 -2.000-.582-12 .169-15 .582-12 .180+03 .297-04 .371-04 .475-04 .513+02 .531-02-.885-07 .531-02-.955-03  10.156  51.275
 -1.500 .233-11-.613-15 .233-11-.151-01 .262-04 .369-04 .452-04 .546+02 .531-02-.885-07 .531-02-.955-03   9.200  54.574
 -1.000-.194-10 .165-13 .194-10 .180+03 .210-04 .346-04 .405-04 .588+02 .531-02-.885-07 .531-02-.955-03   7.358  58.810
  -.750-.698-11-.647-13 .699-11-.179+03 .175-04 .320-04 .365-04 .613+02 .531-02-.885-07 .531-02-.955-03   5.977  61.273
  -.500-.683-10 .172-11 .683-10 .179+03 .130-04 .276-04 .308-04 .639+02 .531-02-.885-07 .531-02-.955-03   4.252  63.856
  -.375-.279-10-.728-11 .289-10-.165+03 .114-04 .244-04 .269-04 .651+02 .531-02-.885-07 .531-02-.955-03   3.260  65.057
  -.250 .629-10 .442-10 .769-10 .351+02 .904-05 .202-04 .221-04 .659+02 .531-02-.887-07 .531-02-.957-03   2.201  65.898
  -.125-.279-09-.271-09 .389-09-.136+03 .660-05 .145-04 .160-04 .656+02 .531-02-.874-07 .531-02-.943-03   1.147  65.588
   .000-.316-07-.316-07 .447-07-.135+03 .414-05 .405-05 .579-05 .444+02 .531-02-.955-07 .531-02-.103-02    .151  44.404
   .125-.316-05-.316-05 .447-05-.135+03 .390-03 .381-03 .551-03 .437+02 .531-02-.878-06 .531-02-.948-021364.126  43.750
   .250-.258-07-.271-07 .375-07-.134+03 .399-03 .379-03 .550-03 .435+02 .531-02-.886-06 .531-02-.957-021361.043  43.482
   .375 .582-08 .446-08 .733-08 .375+02 .398-03 .374-03 .546-03 .432+02 .531-02-.885-06 .531-02-.955-021339.190  43.253
   .500 .386-09-.106-08 .113-08-.698+02 .390-03 .370-03 .542-03 .431+02 .531-02-.885-06 .531-02-.955-021320.072  43.112
   .750 .552-09 .397-10 .553-09 .391+01 .392-03 .364-03 .535-03 .429+02 .531-02-.885-06 .531-02-.955-021288.744  42.912
  1.000 .128-08-.101-10 .128-08-.450+00 .389-03 .360-03 .530-03 .428+02 .531-02-.885-06 .531-02-.955-021263.271  42.798
  1.500-.466-09 .446-12 .466-09 .180+03 .384-03 .354-03 .522-03 .427+02 .531-02-.885-06 .531-02-.955-021225.268  42.687
  2.000 .524-09-.135-12 .524-09-.148-01 .380-03 .350-03 .516-03 .427+02 .531-02-.885-06 .531-02-.955-021197.488  42.663
  2.500 .349-09-.712-14 .349-09-.117-02 .376-03 .347-03 .512-03 .427+02 .531-02-.885-06 .531-02-.955-021176.620  42.672
  3.000-.233-09 .355-13 .233-09 .180+03 .373-03 .344-03 .508-03 .427+02 .531-02-.885-06 .531-02-.955-021159.443  42.720
  3.500 .233-09-.284-13 .233-09-.700-02 .371-03 .343-03 .505-03 .428+02 .531-02-.885-06 .531-02-.955-021145.540  42.779
  4.000-.233-09 .426-13 .233-09 .180+03 .368-03 .341-03 .502-03 .428+02 .531-02-.885-06 .531-02-.955-021134.264  42.839
  4.500 .000    .000    .000    .000    .366-03 .340-03 .500-03 .429+02 .531-02-.885-06 .531-02-.955-021124.761  42.902
  5.000 .000    .000    .000    .000    .365-03 .340-03 .498-03 .430+02 .531-02-.885-06 .531-02-.955-021116.432  42.973
  5.500 .000    .000    .000    .000    .363-03 .339-03 .497-03 .430+02 .531-02-.885-06 .531-02-.955-021109.623  43.035
  6.000 .791-21 .142-13 .142-13 .900+02 .362-03 .338-03 .495-03 .431+02 .531-02-.885-06 .531-02-.955-021103.516  43.102
  6.500 .000    .000    .000    .000    .361-03 .338-03 .494-03 .432+02 .531-02-.885-06 .531-02-.955-021098.132  43.167
  7.000 .000    .000    .000    .000    .359-03 .338-03 .493-03 .432+02 .531-02-.885-06 .531-02-.955-021093.530  43.227
  7.500 .000    .000    .000    .000    .358-03 .337-03 .492-03 .433+02 .531-02-.885-06 .531-02-.955-021089.498  43.284
  8.000 .000    .000    .000    .000    .358-03 .337-03 .491-03 .433+02 .531-02-.885-06 .531-02-.955-021085.854  43.341
  8.500 .000    .000    .000    .000    .357-03 .337-03 .491-03 .434+02 .531-02-.885-06 .531-02-.955-021082.534  43.396
  9.000 .233-09-.284-13 .233-09-.700-02 .356-03 .337-03 .490-03 .434+02 .531-02-.885-06 .531-02-.955-021079.698  43.445
  9.500-.128-08 .135-12 .128-08 .180+03 .355-03 .337-03 .489-03 .435+02 .531-02-.885-06 .531-02-.955-021076.967  43.497
 10.000-.235-08 .289-12 .235-08 .180+03 .355-03 .337-03 .489-03 .435+02 .531-02-.885-06 .531-02-.955-021074.881  43.536
 12.000 .302-09 .881-13 .302-09 .167-01 .352-03 .337-03 .487-03 .437+02 .531-02-.885-06 .531-02-.955-021066.990  43.706
 22.000 .471-10-.674-13 .471-10-.821-01 .347-03 .337-03 .484-03 .441+02 .531-02-.885-06 .531-02-.955-021051.778  44.138
 52.000-.272-11 .860-13 .272-11 .178+03 .342-03 .338-03 .481-03 .446+02 .531-02-.885-06 .531-02-.955-021040.224  44.615
```

```
NORMAL EXIT.        TIME:        41784 MILLISECONDS.
```