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WAMP: A USERS MANUAL FOR THE WIRE ANTENNA MODELING PROGRAM

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13. ABSTRACT

Program WAMP is a Wire Antenna Modeling Program written in FORTRAN IV and applicable to arbitrary antenna and support structures. WAMP models an antenna as a series of interconnected straight wire segments, and solves the electromagnetic boundary value problems by numerically evaluating an electric field integral equation.

Antennas may be analyzed in free space, over a perfect ground, a radial ground screen or in the presence of any homogeneous media. Antenna input impedance, current distributions, near-electric fields and far-field radiation patterns are also calculated.

The users manual covers both the theory and numerical techniques employed in WAMP. The program's input variables are defined, and illustrative examples are used to demonstrate the program's capabilities.

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I. INTRODUCTON

WAMP (Wire Antenna Modeling Program) is a general purpose frequency domain antenna modeling computer program. Antennas of arbitrary form and orientation may be modeled and analyzed in both free-space and in the presence of a conducting half space.

The WAMP users manual is written to serve two purposes. The first, and prime purpose, is to provide the user with a basic working knowledge of the program's input requirements and capabilities. Examples will be employed to illustrate the use of the program. The second purpose of this manual is to present a brief description of the theoretical formulation behind the numerical techniques used in the WAMP code.

Section II, which immediately follows, presents a brief development of the thin-wire electric field integral equation (EFIE). This is followed in Section III by a description of the numerical techniques used to solve the EFIE for a segmented structure, and the methods employed to model an antenna in the presence of an imperfectly conducting half-space. (A listing of the program's subroutines and their function is provided in Appendix A).

Sections IV, V, AND VI are devoted to applications. Section IV describes in detail the program input parameters needed to model an antenna structure, Section V contains a series of illustrative examples designed to demonstrate the WAMP program, and Section VI concludes with a section on modeling guidelines and special calculations.

II. THEORETICAL DEVELOPMENT OF THE ELECTRIC FIELD INTEGRAL EQUATION

Discussion of the Boundary Value Problem. The solution to Maxwell's equation which satisfies specified behavior of the fields at given locations or boundaries, requires treatment of a boundary value problem. Classically, such problems have been successfully treated only for special boundary surfaces to which the method of separation of variables could be applied. This eliminated complex surface shapes from consideration and restricted the three-dimensional solutions to the sphere and various simple sphere modifications. This situation resulted principally from inability to calculate the eigenfunctions for the various special geometries, although considerable progress has been made in this area in recent years due to availability of numerical techniques and more sophisticated computers. An additional problem arises in these special coordinate systems since the boundary condition equations may be coupled, so that a solution of an infinite matrix is required, in principle at least, rather than the term-by-term solution which is encountered for the spherical case. At any rate, the shapes to which the classical analysis are restricted force the use of a different approach to problems which involve complex geometrical shapes.

Integral Equations Formulation. Because of the problems cited above, general three-dimensional boundary value problems require a basically numerical approach. This approach usually begins from an integral-equation viewpoint rather than the differential equation approach implicit in the classical method. There is, however, no unique integral equation formulation for a given problem, so some leeway in treatment is afforded at the outset. For reasons to be clarified later, our attention is restricted here to the electric field integral equation (EFIE). As a starting point, the electric field $\bar{E}$ due to a volume current distribution $\bar{J}$ is written by means of Green's dyadic as

$$\bar{E}(\bar{r}_0) = \iiint_V i\omega\mu_0 \, \bar{J}(\bar{r}) \cdot \bar{\bar{G}}(\bar{r},\bar{r}_0) \, dV \tag{1}$$

where $\bar{r}_0$ and $\bar{r}$ are the observation and source points, respectively, and the Green's dyadic is expressed in the usual notation as

$$\bar{\bar{G}}(\bar{r},\bar{r}_0) = -(1/4\pi)\,[\bar{\bar{I}} + (1/k^2)\ \nabla\nabla]\, g$$

where

$$g = \exp(-ik|\bar{r}-\bar{r}_0|)/|(\bar{r}-\bar{r}_0)|$$

and $\bar{\bar{I}}$ is the unit second-rank tensor. The suppressed time variation is $\exp(i\omega t)$ with ω the radian frequency. The plane wave propagation constant is k, and is related to ε_0 and μ_0, the permittivity and permeability of free space respectively, and ω by

$$k = \omega\sqrt{\mu_0\varepsilon_0}$$

When the current distribution is limited to the surface of a perfectly conducting body, Equation (1) becomes

$$\bar{E}(\bar{r}_0) = \iint_S i\omega\mu_0 \, \bar{K}(\bar{r}) \cdot \bar{\bar{G}}(\bar{r},\bar{r}_0) \, dA \tag{2}$$

with $\bar{K}$ the surface current density. If this surface current is induced by an incident electric field $\bar{E}^I$, then an integral equation for the unknown surface current K can be obtained from Equation (2) and the boundary condition that

$$\hat{n}(\bar{r}_0) \times [\bar{E}^S(\bar{r}_0) + \bar{E}^I(\bar{r}_0)] = 0 \tag{3}$$

with $\hat{n}(\bar{r}_0)$ a surface normal at $\bar{r}_0$ and $\bar{E}^S$ the scattered field of the individual current distribution. Equating $\bar{E}^S$ of Equation (3) with $\bar{E}$ of Equation (2) leads to

$$- \hat{n}(\bar{r}_0) \times \bar{E}^I(\bar{r}_0) = \hat{n}(\bar{r}_0) \times \iint_S i\omega\mu_0 \, \bar{K}(\bar{r}) \cdot \bar{\bar{G}}(\bar{r},\bar{r}_0) \, dA \qquad (4)$$

Thin Wire Approximation. Upon restricting our attention to circular cross-section bodies of small diameter compared with the wavelength, the azimuthal current may be neglected, and Equation (4) becomes

$$\hat{n}(\bar{r}_0) \times E^I(\bar{r}_0) = \hat{n}(\bar{r}_0) \times \frac{1}{4\pi} \iint_S \{ i\omega_0\mu_0 \, K_s(\bar{r}) \, [\hat{s} + \frac{\hat{s}\cdot\nabla\nabla}{k^2}] \, g(\bar{r},\bar{r}_0) \} \, dA \qquad (5)$$

where $\hat{s}$ is the unit tangent vector at $\bar{r}$ pointing in the direction of the current. A scalar integral equation for the current is obtained by taking the dot product of Equation (5) with the unit tangent vector $\hat{s}_0$ at the observation point $\bar{r}_0$ as

$$\hat{s}_0 \cdot \bar{E}^I(\bar{r}_0) = \frac{1}{4\pi} \iint_S i\omega\mu_0 \, K_s(\bar{r}_0) [\hat{s} \cdot \hat{s}_0 + (\hat{s} \cdot \nabla)^2 \frac{1}{k^2}] \, g(\bar{r},\bar{r}_0) \, dA \qquad (6)$$

If the assumption is now made that the surface current, K_s is independent of the azimuthal variable, Equation (6) can be written

$$\hat{s}_0 \cdot \bar{E}^I(r_0) = \frac{1}{4\pi} \iint_s a i\omega_0\mu_0 \, K_s(S) \int_0^{2\pi} [\hat{s} \cdot \hat{s}_0 + \frac{1}{k^2} \frac{\partial^2}{\partial s \partial s_0}] \, g(\bar{r},\bar{r}_0) \, d\phi ds \qquad (7)$$

where a is the wire radius and the s integration is over the entire length of wire.

A final approximation is that the current may be realistically represented as a filament of strength $I_s(s) = 2\pi a \, K_s(s)$ flowing on the wire axis while the field is evaluated on the wire surface, allowing Equation (7) to be written as

$$\hat{s}_0 \cdot \bar{E}^I(\bar{r}_0) = (i\omega\mu_0/4\pi) \int_L I(s) [\hat{s} \cdot \hat{s}_0 + \frac{1}{k^2} \frac{\partial^2}{\partial s \partial s_0}] \, g(\bar{r},\bar{r}_0) \, ds \qquad (8)$$

where $|\bar{r} - \bar{r}_0|$ is now measured from the wire axis, or source point, to the observation point on the wire surface, which can thus never be closer than the wire radius a. By considering the current as a tubular sheet on the wire axis while evaluating the electric field on the wire surface, one can resolve the ambiguity in the azimuth involved. The form of Equation (8) is not changed using this convention, but the interpretation of the tangential field evaluation is simplified when non-parallel, non-planar wires are considered.

III. METHOD OF NUMERICAL SOLUTION

A numerical solution to an integral equation may be undertaken by the method of moments. This is a well-founded mathematical technique briefly stated as a method for finding the unknown by forcing the integral equation which is solved by the method of moments described below.

Reduction to Linear System (Collocation) - Equation (8) may be written symbolically as:

$$L(f) = g \tag{9}$$

following Harrington's (1968) notation. The solution of Equation (8) (or of Equation 9) is obtained by the method of moments. An intuitive approach to solving Equation (9) for the unknown function f is to set f equal to a constant f_i within N subintervals of the domain of L, and to require Equation (9) to be satisfied at N points over the range of L, thus acquiring N equations in the f_i unknowns. This is a specialized application of the method of moments which is more generally written as follows. Let

$$f = \sum \alpha_n f_n$$

with the basis functions f_n defined in the domain of L so that Equation (9) may be written

$$\sum \alpha_n L(f_n) = g \tag{10}$$

Then, with the set of weighting functions w_m, defined in the range of L, the inner product is formed as

$$\sum \alpha_n \langle w_m, L(f_n)\rangle = \langle w_m, g\rangle \tag{11}$$

where m = 1, 2, 3, ... N, Equation (11) can be written in matrix form as

$$[G_{mn}][\alpha_n] = [s_m] \tag{12}$$

where

$$G_{mn} = \langle w_m, L(f_n)\rangle$$

and

$$s_m = \langle w_m, g \rangle$$

and the matrix G_{mn} is referred to in this case as the structure matrix. If the inverse of G_{mn} exists, then the α_n can be found and thus the function f which is the desired solution, for any specified source function s_m.

The proper choice of weighting functions and basis functions, as well as the subsectioning of the domain of L is not an obvious one. Although there is some leeway in the matter, careful consideration of the physics of the problem and the nature of the expected solution will show that some representations for the f_n will be more efficient than others in terms of computer time and accuracy. Constant, linear, quadratic, trigonometric and Fourier series have all been used for this role. The weighting functions have generally been more restricted in choice than f_n. The special case, $w_n = f_n$, is referred to as Galerkin's method (see, for example, Harrington, 1968). More often, the weights are δ-functions, a method referred to as collocation, so that the inner product (Eq. 11) merely becomes the sequence of values $L(f_n)_m$ and g_m. These are, respectively, the tangential electric fields due to current segment n at observation point m and the tangential incident electric field at observation point m. It is interesting to note that Galerkin's method is equivalent to the Rayleigh-Ritz variational method. Harrington (1968) thoroughly discusses the method moments.

Current Expansion - The WAMP thin-wire program employes the collocation method with constant, sine and cosine terms for the f_n segment or current basis function, i.e.,

$$I(s) = \sum_{i=1}^{N} U_i(s)[A_i + B_i \sin k(s-s_i) + C_i \cos k(s-s_i)] =$$

$$\sum_{i=1}^{N} U_i(s)\ I_i(s) \tag{13}$$

where $U_i(s)$ is 1 when s is on segment i and zero otherwise. Equation (13) is disadvantageous because three constants are required to specify the current on each segment, so that apparently 3N linear equations need be solved. This prompts the question, why use the sine and cosine terms for the current at all? There are a number of reasons for using this sinusoidal current expansion, but they are essentially summarized by the observation that a more physically realistic current solution is obtained with this expansion.

It is not necessary to employ the integral equation itself to find the extra unknowns introduced by the sinusoidal expansion. Two of the three constants for each segment may be obtained by requiring the current on adjacent segments to satisfy some specified mutual conditions. The extrapolated current from a given segment must match the center current values on two adjacent segments to satisfy the required condition for two-wire junctions in the thin-wire program. Junctions of three or more wires are handled in similar fashion (Maxum, et al, 1969).

The sinusoidal current expansion appears to make the system of equations resulting from collocation somewhat more involved, but the required computer time is not significantly increased when compared with the same number of current unknowns without using the sinusoidal expansion. Other current expansion functions - linear, quadratic, Fourier series - could be used in place of the constant-sine-cosine expression, but this particular expansion has a number of additional advantages over the other possibilities mentioned. For instance, a solution for the current to a specified accuracy for a half-wave dipole scatterer and antenna requires the fewest current segments using the sinusoidal expansion (Neureuther, et al, 1968). This advantage can be expected to carry over to more complex geometries. Second, the solution will more accurately exhibit the required dependence on wire radius (Andreason, 1968) because the constant current term produces infinite tangential electric field on the current axis, as opposed to the sine and cosine terms which do not.

Third, the parallel and perpendicular electric field components (due to the sine and cosine current terms) and the radial field components (due to constant current terms) may be analytically evaluated. This eliminates the necessity for extensive numerical integration to evaluate all the elements in the coefficient matrix G_{mn}. Only the tangential electric field excited by the constant current terms requires numerical integration and this is handled by applying a Romberg variable-interval width technique (Miller, 1970) to the difference integrand.

Calculation of the Structure Matrix - It is worthwhile to discuss here the form of the matrix elements which result from applying the method of collocation to the integral Equation (8). Each entry G_{ij} in the structure matrix represents the tangential electric field at observation point i on the structure produced by unit current flowing on segment j. The boundary condition on the tangential electric field is enforced at each observation point. The collocation method of solving the integral equation is thus basically one of calculating electric field components at specific points due to the induced current on the structure.

It was stated that the thin-wire approximation involves the explicit assumption that the effects of azimuthal currents can be neglected in comparison with those of axially directed currents and that, in addition, the cylindrical tube of axial current has no azimuthal dependence. The former assumption allows us to consider only one current component rather than two, while the latter provides partial justification for reducing the surface integral to a line integral. It may be deduced from an examination of Equations (7) and (8), however, that even where K_s is independent of ϕ the kernel of the integration equation depends in general upon both ϕ and s. However, the integrand is independent of ϕ in the special case where the observation point is located on the axis of a linear tube of current, and the ϕ integration of Equation (7) may be replaced without approximation by the factor 2π.

We choose to locate the observation points where the tangential electric field is to be calculated on the axis rather than on the surface of each wire segment. The ϕ integration in Equation (7) is thus exact for the self-field as well as the mutual fields for all current segments having a common axis. In addition, the possible ambiguity involved in evaluating the incident field over a 2π variation in ϕ on the wire surface is resolved. As a final point, the observation point is always at least as far as the wire radius from the source point.

When the mutual fields of non-axially aligned current segments are required, the ϕ integration is not so simply performed. And if no approximation were used, the ϕ integration would require numerical evaluation. The most obvious approach is to then consider the tubular current source to approximate a linear filament on the wire axis, a procedure which again replaced the ϕ integration by a 2π factor. Unfortunately, this approximation eliminates the influence of the wire radius from all mutual field terms on the phase change and geometrical attenuation of the field caused by the separation of the source and observation points.

An alternative to the above method is replacement of the current tube by a current filament which is not located on the wire axis but is displaced in distance from it by the wire radius. The direction of displacement is perpendicular to the plane of the wire axis and the line joining the observation point and wire axis midpoint (the observation point for the self-term field). The geometry of this method is shown in Figure 1.

To summarize briefly, the surface integral is reduced to a line integral by neglecting azimuthal* currents and azimuthal variation of the axial current. Self-field terms are calculated with the observation point on the axis of a cylindrical current tube, while mutual field terms are calculated at the same observation point with the current represented as a filament displaced from the wire axis by the wire radius.

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* Taken here to mean the direction measured along the intersection of the current tube surface with a plane perpendicular to the axis of the current tube.

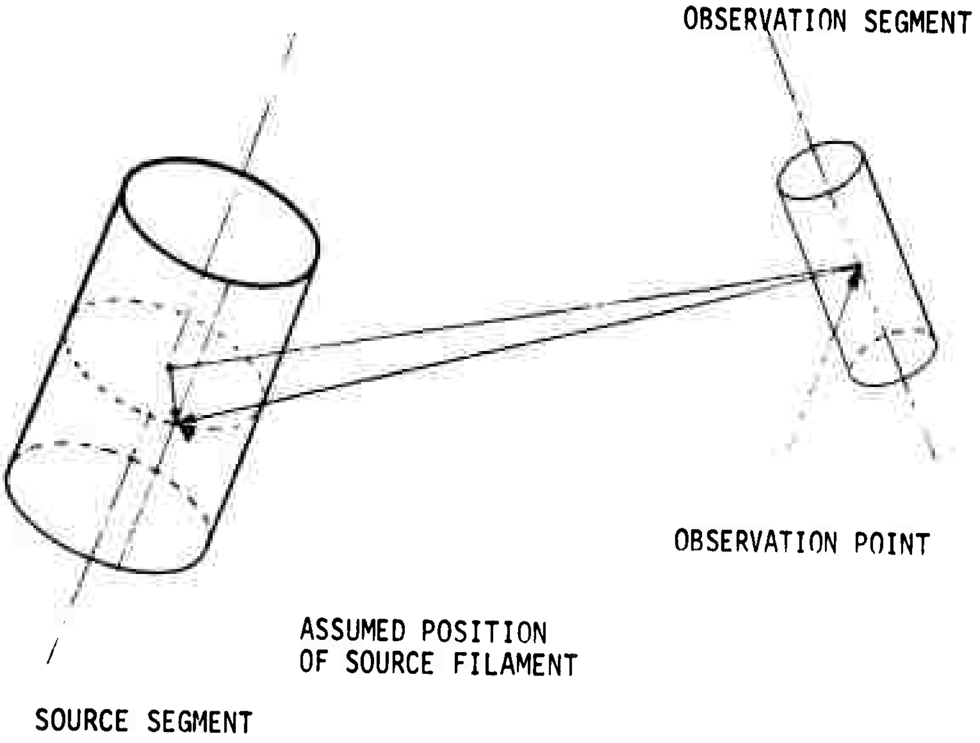


Figure 1a. Thin-wire Current Approximation

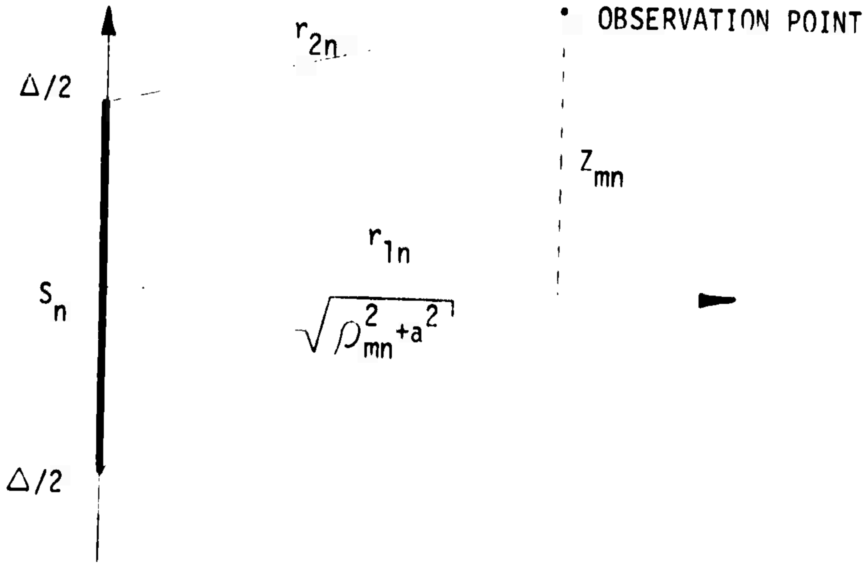


Figure 1b. Geometric Parameters for Field Evaluation.

We can now write the integral Equation (8) in the form

$$E_m = (i\omega\mu_0/4\pi) \sum_{M=1}^{N} \int_{\Delta S_n} [\hat{s}_m \cdot \hat{s}_n + \frac{1}{k^2} \frac{\partial^2}{\partial s \partial s_0}] \, g(r_m, r) \, I_m(s) \, ds \qquad (14)$$

m=1, 2, ..., N observation points

where Δs_n denotes the length of source segment n,

$$g(r_m, r) = \frac{\exp[-ik \sqrt{\rho^2 + (s_m - s)^2}}{\sqrt{\rho^2 + (s_m - s)^2}}$$

and it should be noted that the integration over L has been reduced to a summation of N separate straight-wire segment integrals. It is convenient to rewrite Equation (14) in terms of cylindrical coordinates referred to the wire segment being integrated. Then we get

$$E_m = (i\omega\mu_0/4\pi) \sum_{m=1}^{N} \int_{\Delta z_n} [\hat{z}_n \cdot s_m - \frac{1}{k^2} \frac{\partial^2}{\partial z_n \partial s_m}] \, g(r_{mn}, z_n) \, I_n(z_n) \, dz_n \qquad (15)$$

where

$$g(r_{mn}, z_n) = \exp(-ikr_{mn})/r_{mn}$$

and

$$r_{mn} = \sqrt{(z_{mn} - z_m)^2 + \rho^2_{mn} + a_n^2}$$

a_n is the radius of wire segment n, and ρ_{mn} and z_{mn} are the radial and z-coordinates of the observation point at the center of segment m referred to the midpoint of source segment n.

<u>Ground Effects</u> - The integral equations (14) and (15) apply only to wire structures located in free space, or more generally in a homogeneous medium having electrical constants μ and ε. Location of the structure near the interface between two electrically dissimilar media, however, leads to reflected fields which can modify the free space current distributions, and thus an additional term must be added to the integral equation for it to apply to the antenna problems of interest here.

Historically, the basic work on the solution of this problem was formulated in 1909 by A. Sommerfeld (1964). By deriving field expressions for vertical and horizontal electric and magnetic Hertzian dipoles in free space as influenced by the ground plane, Sommerfeld obtained the Green's functions which permit equations (14) or (15) to be rigorously extended to the interface problem.

Unfortunately, the solution of the Sommerfeld integrals requires a double numerical integration which can be very costly in terms of computer time. Miller, et al., (1972a, 1972b) describes an approximation that is used in the WAMP program. The approximation is to represent ground reflected fields via plane wave reflection coefficients. This procedure is basically quite simple, involving decomposition of the image fields into TM and TE modes relative to the vertical plane containing the image and observation points, after which the reflected fields are obtained by multiplying the image fields by the appropriate reflection coefficients. The advantage of this technique lies in the fact that it represents but a simple extension to the free space integral-equation treatment.

Impedance Loading - The discussion has been thus far limited to the case of a perfectly conducting element. The approach may also be generalized to allow for lumped loading of the structure by introducing a voltage drop term in the integral equation. If the impedance loading per unit length on segment m is z_m, then Equation (15) becomes:

$$E_m - I_m z_m = \text{same R.H.S. as Equation (15)}$$

Solution of the System of Equations - The solution of the integral equation is reduced by the method of collocation to the problem of solving a linear system of equations for the N sampled current values. The problem is far from being resolved at this point, however, since the linear system which is generated may contain a very large number of complex unknowns. A numerical solution of such a system would be impractical without the availability of a large-core, high-speed digital computer. An additional factor of importance in the linear system solution is the use of an efficient and accurate numerical technique; an especially significant aspect of the problem since the solution time increases as the cube of the number of unknowns (see, for example, Forsythe & Moler, 1967). The method used to solve the linear system of equations is discussed next.

The final step in solving the integral equation for the induced current is a matrix multiplication of the solution or inverse matrix times the source vector.

The induced current solution can be written in the form

$$[I] = -[G]^{-1}[E] \tag{16}$$

The values then obtained for the sampled current values at the centers of the N segments on the structure are used to obtain the current interpolation functions for each segment.

The solution technique employed in the WAMP program to solve the system of equations is the Gauss-Doolittle method (Ralston, 1965). The basic step in the Gauss-Doolittle method is factorization of the structure matrix [G] into the product of an upper triangular matrix [U], and a lower triangular matrix [L], i.e.

$$[G] = [L][U] \tag{17}$$

and thus,

$$[L][U][I] = -[E] \tag{18}$$

Let

$$[U][I] = [F] \tag{19}$$

so that

$$[L][F] = -[E] \tag{20}$$

Next, equation (20) is solved for the elements of [F] by forward substitution using the known elements of [E]. Equation (19) is then solved for the elements of [I] by backward substitution using the known elements of [F].

Matrix Symmetry - Many antenna structures exhibit geometric symmetries which may be exploited to a great advantage in terms of computer storage requirements and execution times. Structure symmetry can be used to increase the calculation efficiency by reducing the time required to fill the structure matrix G, and by decreasing the computations required to factor and solve the linear system of equations. The matrix fill time, for example, is reduced by a factor on the order of $1/n$, and the inversion time by $1/n^2$, for a structure with n-fold rotational symmetry.

The reduction in matrix fill time is easily understood. Consider a structure having 4-fold rotational symmetry, such as Figure 2 below,

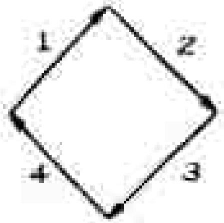


Figure 2. Structure with 4-fold Rotational Symmetry.

which will have a structure matrix [G] of the form:

$$[G] = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix} \qquad (21)$$

where

$$\begin{array}{ccccccc} g_{11} & = & g_{22} & = & g_{33} & = & g_{44} \\ g_{12} & = & g_{23} & = & g_{34} & = & g_{41} \\ g_{13} & = & g_{24} & = & g_{31} & = & g_{42} \\ g_{14} & = & g_{21} & = & g_{32} & = & g_{43} \end{array} \qquad (22)$$

Thus, rather than their being $N^2 = 16$ matrix elements to calculate, there are only N^2/n or 4 to obtain, and the reduction in the structure matrix fill time and storage is on the order of $1/n$.

This version of the WAMP code is set up to handle rotationally symmetric structures with elements located on the axis of rotational symmetry. An example of such a structure is shown in Figure 3.

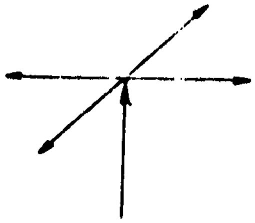


Figure 3. A structure with 4-fold rotational symmetry and center wire. (Turnstile Antenna)

The structure matrix is of the form given by (23):

$$[G] = \left[\begin{array}{cccc|c} A_1 & A_2 & A_3 & A_4 & B_1 \\ A_4 & A_1 & A_2 & A_3 & B_2 \\ A_3 & A_4 & A_1 & A_2 & B_3 \\ A_2 & A_3 & A_4 & A_1 & B_4 \\ \hline C_1 & C_2 & C_3 & C_4 & D_1 \end{array}\right] \tag{23}$$

$$B_1 = B_2 = B_3 = B_4 \tag{24}$$

and

$$C_1 = C_2 = C_3 = C_4$$

which is stored in the computer as:

$$\begin{bmatrix} A_1 & A_2 & A_3 & A_4 & B_1 \\ C_1 & C_1 & C_1 & C_1 & D_1 \end{bmatrix} \tag{25}$$

The solution to a system of equations of this symmetric form may be accomplished by the following operations. First write the matrix equation, noting the partitioning:

$$\left[\begin{array}{c|c} A_{nxn} & B_{nxm} \\ \hline C_{mxn} & D_{mxm} \end{array}\right] \left[\begin{array}{c} X_n \\ \hline Y_m \end{array}\right] \qquad \left[\begin{array}{c} U_n \\ \hline V_m \end{array}\right] \tag{26}$$

where we have the relationships:

$$A_{mxn}\ X_n\ +\ B_{nxm}\ Y_m\ =\ U_n$$

and

$$C_{mxn}\ X_n\ +\ D_{mxm}\ Y_m\ =\ V_m \tag{27}$$

or

$$X_n\ =\ A^{-1}_{mxn}\ U_n\ -\ A^{-1}_{nxn}\ B_{nxm}\ Y_m \tag{28}$$

and

$$(D_{mxm}\ -\ C_{mxn}\ A^{-1}_{nxn}\ B_{nxm})\ Y_m\ =\ V_m\ -\ C_{mxn}\ A^{-1}_{Un} \tag{29}$$

To solve the equations (28) and (29) for the X_n and Y_m matrices, we perform the following sequence of operations:

1. Factor A_{nxn} in place.
2. Compute $E_{nxm} = A^{-1}_{nxn}\ B_{nxm}$ by solving $A_{nxn}\ E_{nxm} = B_{nxm}$ in place and storing the result in B.
3. Compute $F_{mxm} = D_{mxm} - C_{mxn}\ E_{nxm}$ and store the result in D.
4. Now factor D_{mxm} in place.
5. Then compute $W_n = A^{-1}_{nxn}\ U_n$ in place.
6. Compute $Z_m = V_m - C_{mxn}\ W_n$ and store in V_m.
7. Solve $F_{mxm}\ Y_m = Z_m$ for Y_m and store in V_m.
8. Finally, compute $X_n = W_n - E_{nxm}\ Y_m$ and store the result in U_n.

Solution Sequence - We may now list the sequence of operations performed in WAMP to obtain the solution for an antenna structure. The basic steps are listed below:

1. Initialize WAMP and read in the antenna input frequency and the media over which the antenna is located, i.e., free space, over a perfect ground or a finite homogeneous media.

2. Convert a physical description of the antenna structure given in terms of the cartesian end-point coordinates of wire elements into a series of interconnected short straight-line wire segments. The segments will be used to describe the structure's line integral path.

3. With the structure defined, the structure matrix is then computed by the methods outlined earlier in this section. The electric field integral equation is first evaluated for the antenna in free space, where the co-location technique is used to fill in all the entries of the structure matrix.

   If it is selected to model the antenna over a homogeneous halfspace, the structure matrix entries are then recalculated and modified by the ground reflected terms. The reflected fields are found by first computing the perfect ground image fields, and then these fields are modified by the appropriate ground reflection coefficient which is a function of the ground media and the specular angle between thesource and the observation points.

4. If segments on the structure are impedance loaded, e.g. an inductive load used for resonating an antenna, the loading may be simply included in the structure's impedance matrix at this point.

5. The structure matrix may then be factored as outlined in the previous section. Structure symmetries are exploited to minimize the amount of core storage required and the amount of computations needed.

6. Once the structure matrix is factored, the antenna source vector is setup by applying a tangential E-field to those segments excited.

7. The factored structure matrix and the source field vector are then solved to yield the unknown currents at the center of each of the N segments.

8. Once the segment currents are known, the antenna input impedance and admittance may be calculated.

9. The coefficients A, B and C of the current basis function, Equation (13) are next determined and their values printed out.

10. The two last steps in the program are the computations of the near and far electric fields. These computations are only made if selected as program options.

This completes the description of the WAMP code. The next section describes in some detail the input parameters required to use the program.

IV. PROGRAM INPUTS

WAMP is written to conform with ANSI X 3.0 FORTRAN, and allows for in core execution on a 147K CDC 3300 computer system. All program inputs are via punched card data decks, and all program outputs appear on an on-line printer output. A main executive program, and 20 subroutines comprise this version of the WAMP code.* Most of the program's inputs are requested by the MAIN program, however, several subroutines (DATAGN, CMSETUP and NEFLD) may also request additional data inputs. Figure 4 provides a basic flow diagram of the sequence of data inputs, which is followed by more complete details on the program's input variables.

DATA DECK STRUCTURE

The structure of the input data deck for WAMP is illustrated in the flow chart of Figure 4. Note that not all inputs are requested by the program, and they are dependent on the run options selected by the second input data card. Additional details on each data input parameter follows.

Run Comments - (Format [10A8]) The first card of a data deck is used to provide 80 characters of run identification. Any text which fits on one card may be used, and the message will appear on the first page of the program output.

Run Options (Format [16I5]) The option card allows the user to select several program options at execution time. The parameters are listed below:

NPRINT --- Controls level of printed output. Input Range 0-2, with more detailed outputs are given for higher numbers. Typically NPRINT = 1.

ILOAD --- If the structure has impedance loaded elements, make ILOAD = 1. The load values will be read in later.

IPGND --- If you want to model the structure over a perfect ground plane, set IPGND = 1.

IGSCRN --- If IGSCRN = 1, a radial wire ground screen is modeled. Screen parameters are read-in in subroutine CMSETUP later.

---

* A listing of WAMP is included in Appendix A. A brief description of each subroutine is also included.

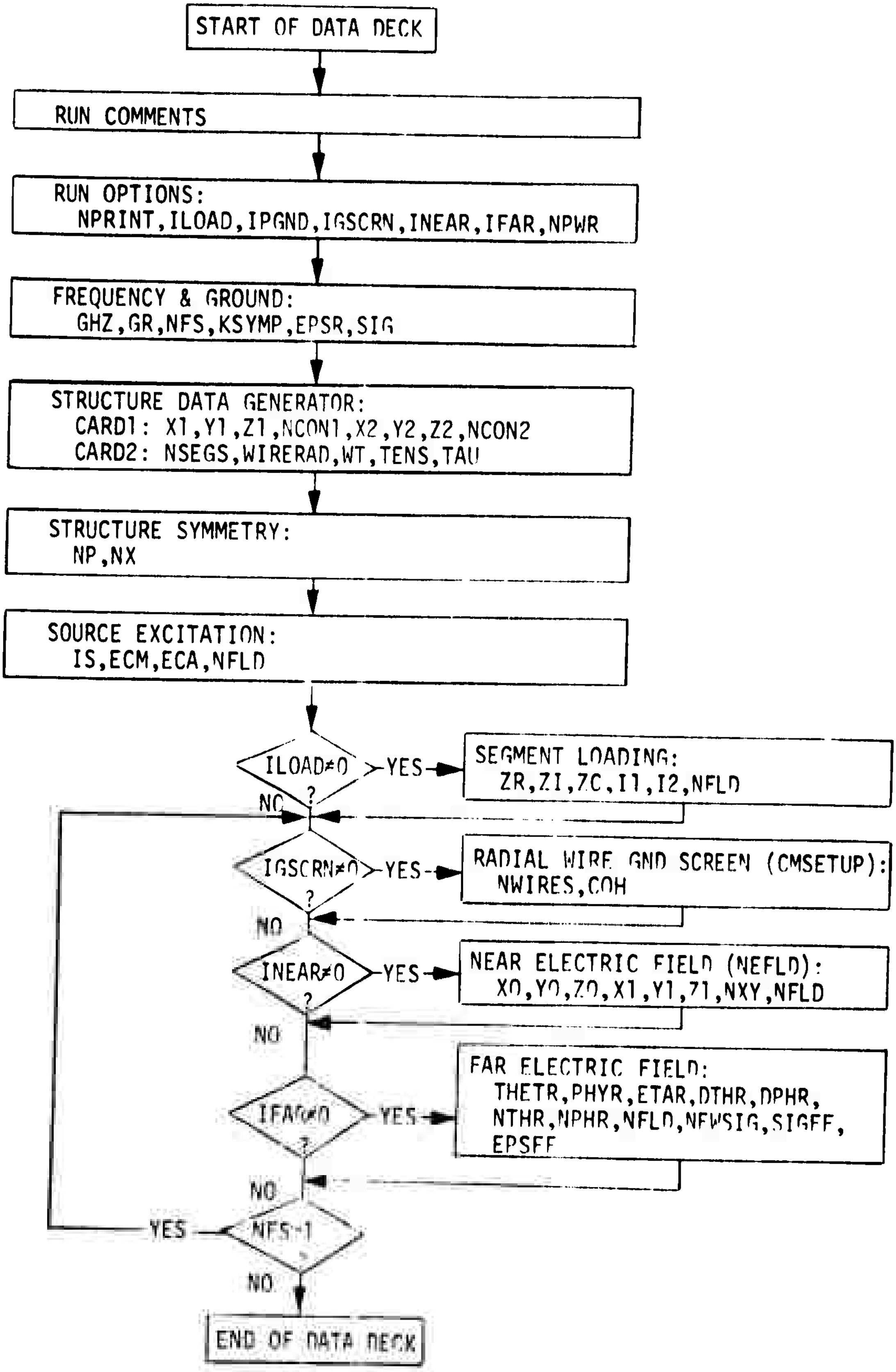


Figure 4. Flowchart of WAMP Input Data Deck Cards

INEAR --- If INEAR = 1 the near field subroutine is called. The location of the field observation points to be evaluated are requested by the NEFLD subroutine.

IFAR --- Far field calculations are performed if IFAR = 1. The far field observation angles are read in later.

NPWR --- If NPWR = 1, the total input power to the antenna is normalized to 1 watt. All field values will also be normalized to this power.

Frequency and Ground (Format [2F10.5, 2I5, 2F10.5]) The frequency and ground card allows the user to specify the frequency at which the analysis is to be performed, a Δ frequency, and the number of Δ frequency steps to be evaluated. The user also has the option of performing the analysis in free-space or over a conducting half space. If the latter is selected, the ground media parameters must be supplied.

GHZ --- Input frequency in Giga-Hertz.

GR --- Δ frequency in GHz. If NFS is greater than 1, the frequency is changed by GHz = GHz + GR each frequency step.

NFS --- NFS is the number of frequency steps, and it must be greater than or equal to 1.

KSYMP -- For analysis in free space, set KSYMP = 1. For an analysis over a halfspace, set KSYMP = 2. KSYMP must be either 1 or 2.

EPSR -- If KSYMP = 2, then read in the value of the relative dielectric constant of the ground media.

SIG --- If KSYMP = 2, then read in the value of the ground conductivity expressed in mhos/metre.

Structure Data Generator Inputs - After the frequency and ground cards are read, the main program calls the DATAGN subroutine. The purpose of this subroutine is to transform a physical model of an antenna structure into quantities which describe the structure to the WAMP code. Basically, all structures are modeled by straight-line wire elements. (A catenary element is a special feature allowed by this subroutine and is described in more detail in Section VI). The elements in turn are subdivided into a number of straight-line segments, and it is the segments which are used as the structure descriptors to the program.

Each wire segment is specified by its center-point coordinates, its orientation angles, its length, and its radius. In addition to the segment's physical parameters, electrical inter-connection data must also be provided. The two arrays, ICON1 and ICON2 of COMMON BLOCK/1/ are used to store the connection data relative to the negative and positive ends respectively of each segment.

All structure elements are specified to the program in terms of their cartesian end point coordinates, with dimensions given in metres. Elements are described to the DATAGN subroutine by specifying on one card the two end point coordinates, and interconnection data, and on a second card the number of segments to be used to describe the element, the element's wire radius, plus some additional details if a catenary is to be modeled, or if a variable length segment is to be used to model the element.

The connection data must conform to the following rules: Given a positive reference direction of the i-th segment defined by α_i and β_i and the arrow as illustrated in segment coordinate system of Figure 5, ICON1(i) must contain the index of the segment to which the negative end of the i-th wire is connected. A multiple connection is identified by assigning a unique negative number to the endpoint connection value of each segment connected to the junction, and an unconnected segment is assigned a value 0 at the unconnected end. One rule which must be observed is that if two segments are connected and the negative or positive ends coincide, as illustrated by Example 3 of Figure 6, this junction although not a multiple junction must also be assigned a unique negative number. Segments which are grounded must be given an ICON value equal to the segment's own index, see Example 4, Figure 6.

ICON2(i) array is similar and refers to the positive endpoint.

The input variables NCON1 and NCON2 allow the user to specify the ICON1 value (negative end) of the first segment of an element, and NCON2 allows the user to specify ICON2 value (positive end) of the last segment of the element. These rules are illustrated by a few examples as shown in Figure 6.

Thus the data generator input variables are described as follows:

DATAGN Card 1 (Format [3F10.5, I5, 3F10.5, I5]):

X1, Y1, Z1	---	Cartesian coordinates of the negative end point of the line element. Dimensions are in metres.
NCON1	---	Specifies the ICON1 value for the first segment of the element.
X2, Y2, Z2	---	Cartesian coordinates of the positive end point of the line element.
NCON2	---	Specifies the ICON2 value of the last segment of the element.

DATAGN Card 2 (Format [I5, 4F10.5]):

NSEGS* --- Number of segments in the line element.

WIRERAD --- Segment wire radius given in metres.

WT --- Wire weight given in pounds/metre. (Needed only if a catenary element is desired.)

TENS --- Wire tension in pounds, which is needed only for a catenary. If TENS ≤ 1., no catenary is used.

TAU --- Segment length expansion (contraction) factor.

Note: additional details on this factor are given later in Section VI and Appendix B.

<u>Structure Symmetry</u> (Format [16I5]) After the antenna structure has been described, structure symmetries must be specified. The WAMP code is set up to exploit either no symmetry or up to 12 sectors of rotational symmetry. In addition, elements on the axis of rotational symmetry may also be used. The symmetry card requires the following parameters:

NP --- NP equals the number of segments in a rotationally symmetric sector. (Excluding segments on axis of symmetry.)

NX --- NX equals the number of segments on the axis of rotational symmetry.

Note that the program will work for the special case where NP = N (no symmetry) and NX = 0. NP + NX must be less than or equal to 22 for this version of WAMP.

If structure symmetry is to be exploited, a formalism exists which must be followed if a proper structure matrix is to be set up. Basically, the rules for setting up the proper structure symmetry are as follows:

1. All elements in a sector of rotational symmetry must be completely specified before going to the next sector.

---

* Note: If NSEGS is a positive number, the DATAGN subroutine jumps back to request an additional pair of line element cards to specify the next element of the structure. Input continues until a NSEGS (negative number of segments) is used to specify the last element of the structure. At this point, the program control returns to the main program.

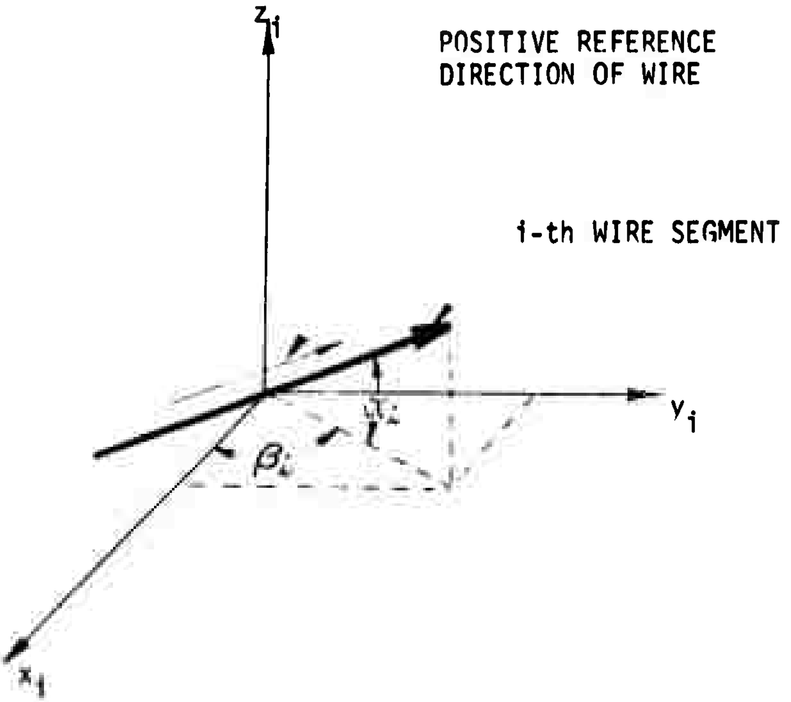
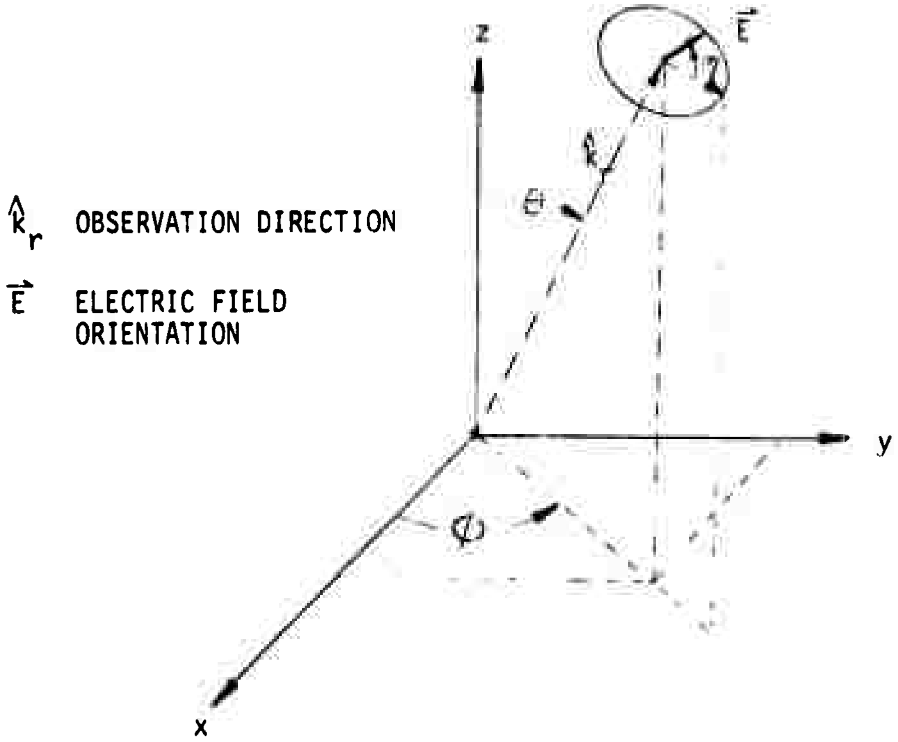


Figure 5a. Segment Coordinate System.



Fibure 5b. Field Coordinate System

WAMP COORDINATE SYSTEM

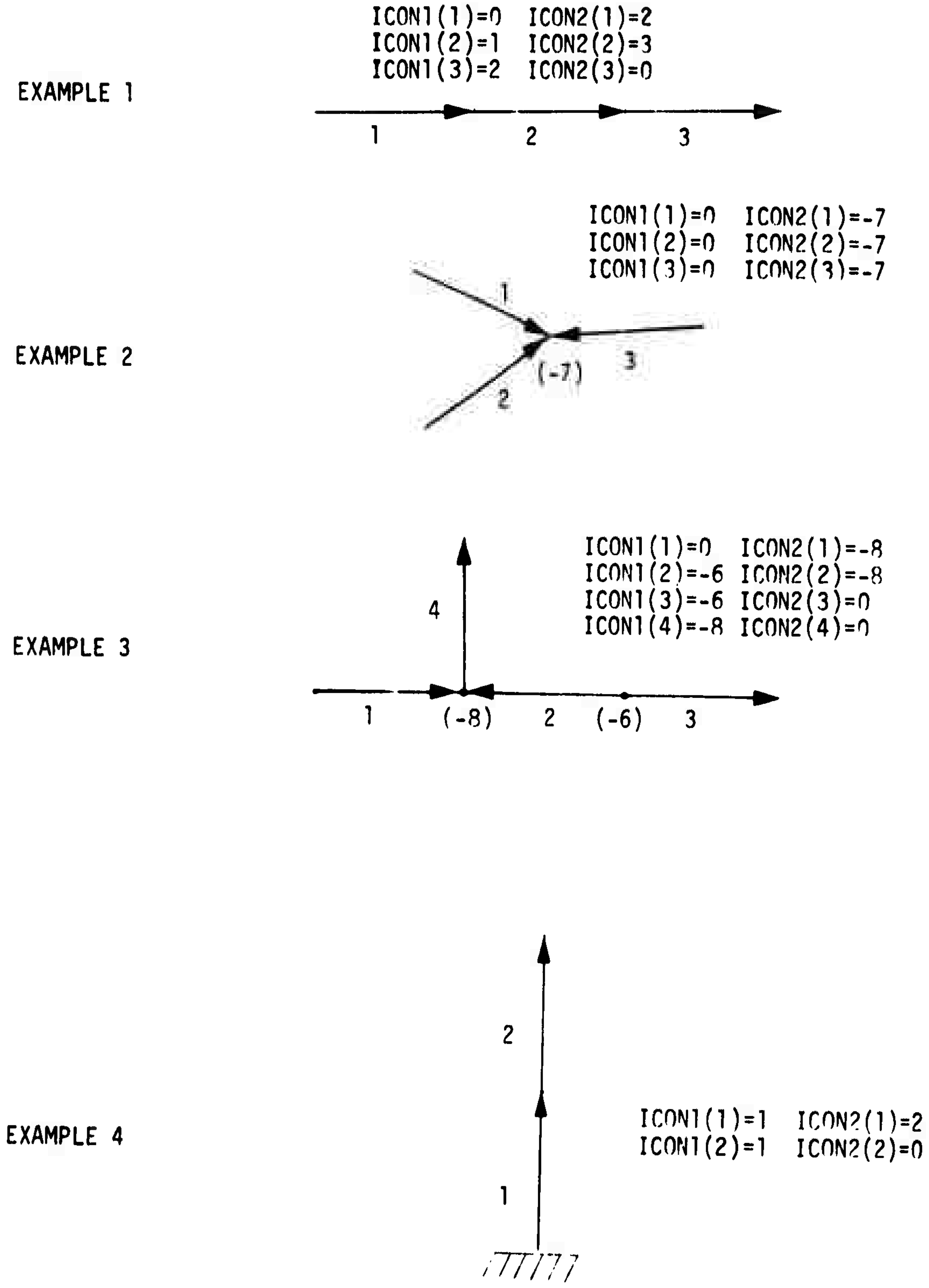


Figure 6. Examples of the ICON Connection Values for Various Types of Segment Junctions.

2. One may progress in either a clockwise or counter clockwise fashion around the axis of symmetry in describing the structure.

3. Elements located on the axis of rotational symmetry must be specified <u>last</u> to the data generator subroutine.

<u>Source Excitation</u> (Format [I5, 2F10.5, I5]) The source card allows the user to specify the segments which are driven. Any of the segments may be driven, and no symmetry of the excitation is assumed. In order to compute a correct input impedance, a 1.0 V at 0° phase angle source must be used.

IS --- Segment number to which the source is applied.

ECM --- Magnitude of driving source voltage in volts.

ECA --- Phase of source in degrees.

NFLD --- If NFLD = 1, an additional source card is read in. Input of source cards continues until NFLD = 0. This feature is used to specify multiple excitations.

This completes a normal data deck. Additional inputs may be required if certain options are selected on the run option card. These inputs are described below.

<u>Segment Loading</u> (Format [3E10.3, 3I5]): If ILOAD on the RUN OPTION card ≠ 0, the segment loading option is selected. Resistive and reactive loading of segments is allowed. Symmetric loading of rotationally symmetric segments is assumed, and only one sector of symmetric loads need be specified. The inputs are listed below:

ZR -- Resistance value in ohms distributed on each of the specified segments.

ZI -- Inductance value in henrys distributed on each of the specified segments.

ZC -- Series capacitance in Farads on each segment (Note: if ZC = 0. On input, no capacitive loading is included.)

I1,I2 -- Specify the range of segments numbers which are loaded. All segments from I1 to I2 each receive the above load values.

NFLD -- If NFLD ≠ 0, an additional load card may be specified.

Radial Wire Ground Screen (Format [I5, E10.5]) If IGSCRN on the RUN OPTION card ≠ 0, a radial wire ground screen model is placed in parallel with the normal ground media. The ground screen parameters listed below are read in by subroutine CMSETUP.

NWIRES -- Number of radial wires.

COH -- Wire radius in metres of the radial wires.

Near-Electric Field (Format [6F10.5, 2I5]) Subroutine NEFLD is used to compute the near E-field at specified points in the structure's coordinate system. NEFLD is called only if INEAR = 1 on OPTION CARD.

X0, Y0, Z0 --- Are the initial field evaluation coordinates. (metres)

X1, Y1, Z1 --- Are the final field evaluation coordinates. (metres)

NXY --- NXY + 1 field evaluation points are made along the straight line connecting point 0 with point 1.

NFLD --- If NFLD ≠ 0 an additional near field evaluation path may be specified.

Far-Electric Field (Format [5F10.5, 4I5, 2F5.1]) A far field radiation pattern will be computed if IFAR on the OPTION CARD = 1. A provision is made to allow a far field calculation over a media which is different than the media over which the antenna is located. The farfield inputs, which refer to Figure 5, are listed below:

THETR --- Initial Theta angle in degrees.

PHYR --- Initial Phi angle in degrees.

ETAR --- Polarization angle Eta in degrees. (See Figure 5)

DTHR --- Delta Theta step size in degrees.

DPHR --- Delta Phi step size in degrees.

NTAR --- Number of Theta angle steps.

NPHR --- Number of Phi angle steps.

NFLD --- If NFLD ≠ 0, another far field card may be read in. Up to five cards may be specified.

NEWSIG --- If NEWSIG = 1, new values of sigma and epsilon will be read in for the far field.

SIGFF --- Far field sigma value in mhos per metre.

EPSFF --- Relative dielectric constant for far field.

Note that if a new value of sigma and epsilon are not requested, the far field ground media is the same as the ground media of the antenna.

Multiple Data Decks - The above cards complete the data for one specific structure. Multiple data decks may be stacked one behind another to provide for multiple runs. The program control returns to read the next comment card, and if an end-of-file is encountered, the run is terminated.

V. SAMPLE PROBLEMS

Perhaps the easiest way to gain a working familiarity with the WAMP code is to use it to model some simple antenna structures which are familiar, and which we can compare the computed results with known data. This section illustrates the use of WAMP by a series of examples. The input data decks and the pertinent output will be shown.

Example 1 - Half Wavelength Horizontal Dipole - A half wavelength electric dipole is a good place to start. For this example, the antenna specifications are given as follows:

Frequency - 10 MHz

Length - $\lambda/2$ = 15 meters

Wire radius - 8.3 mm (Ω = 15)

Height above ground - 10 meters

Ground media - $\varepsilon_r = 25$, $\sigma = 10^{-2}$ mhos/m.

The first step is to describe the structure in terms of straight line elements whose end point coordinates are given in terms of the system's cartesian coordinates. For the dipole, this is simple, and is illustrated in Figure 8.

The input data deck may now be set up. (Refer to the previous section for a more detailed description of the input parameters)

Card 1: Comment Card

Halfwave Horizontal Dipole -- Example 1A

Card 2: Run Options

NPRINT = 2 Get a printout

ILOAD = 0 No loading

IPGND = 0 No perfect ground

IGSCRN = 0 No ground screen

INEAR = 0 No near field calculations

IFAR = 0 No far field calculations

NPWR = 0 Don't normalize input to 1 watt

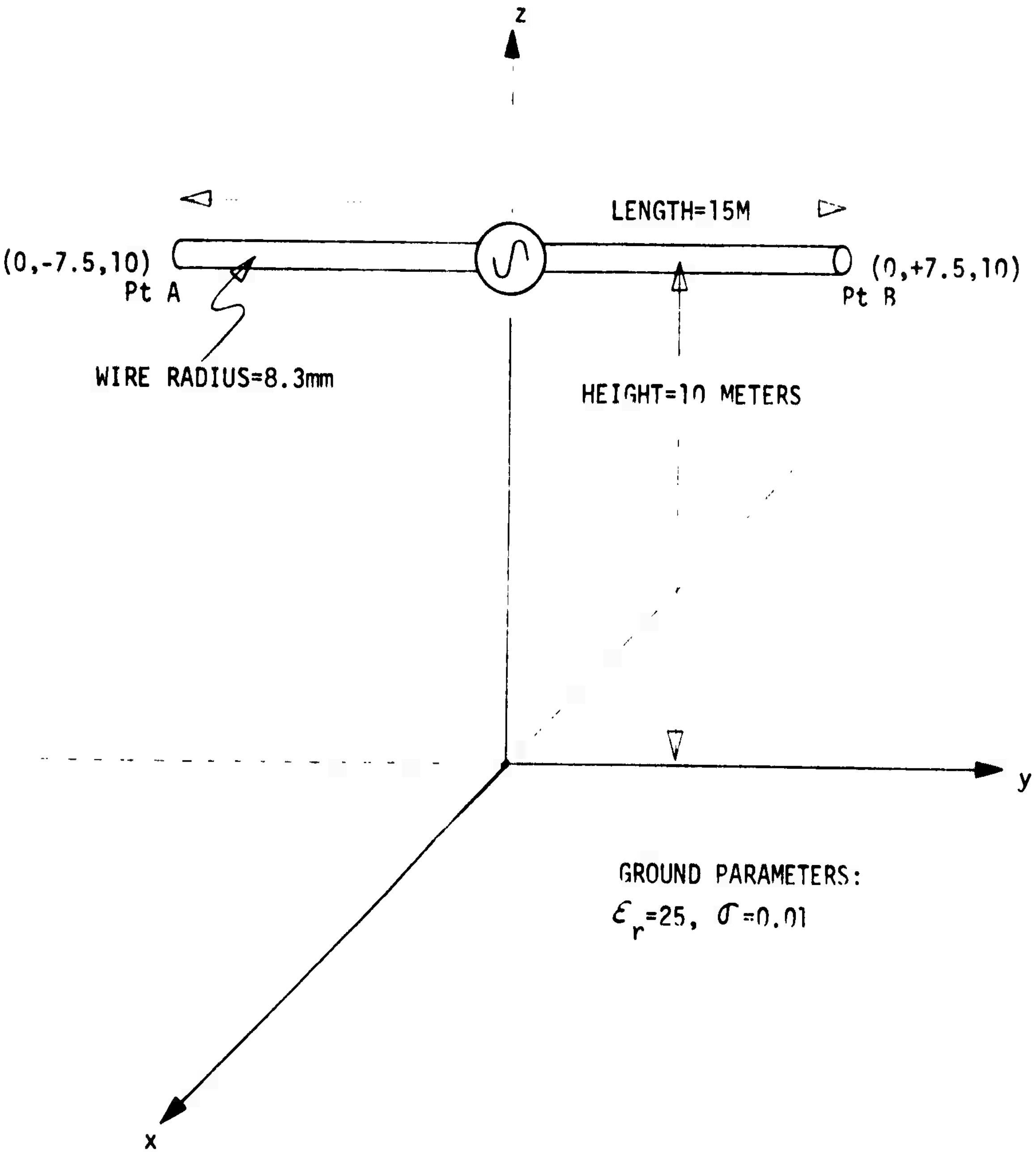


Figure 8. Half Wavelength Horizontal Dipole for Example 1.

We have chosen a very simple example, and none of the program's options have been selected.

Card 3: Frequency and Ground

GHZ	=	0.01	Input frequency = 10 MHz
GR	=	0.	No frequency steps
NFS	=	1	One frequency
*KSYMP	=	1	First model antenna in free space
EPSR	=	25.	Ground dielectric constant
SIG	=	0.01	Ground conductivity mhos/m

*Note that since the analysis is first being made in free space, ϵ_r and σ of the ground are not required at this point, but were included for later use.

Cards 4 and 5: Data Generator Inputs

CARD 4	X1	=	0	Coordinates
	Y1	=	-7.5	of end point
	Z1	=	10.	A
	NCON1	=	0	End point A is an open circuit
	X2	=	0	Coordinates
	Y2	=	7.5	of end point
	Z2	=	10.	B
	NCON2	=	0	End point B is an open circuit
CARD 5	NSEGS	=	-7	Model with 7 segments (number is negative to end data generator inputs)
	WIRERAD	=	0.0083	The radius of the dipole is 8.3 mm
	WT	=	0.	No catenary
	TEN	=	0.	
	TAU	=	0.	No variable length segment, all =

The DATAGN will use this data to form a seven segment description of the dipole as shown in theprogram's output, Figure 10.

Card 6: Structure Symmetry

NP = 7 No symmetry will be used, NP = NSEGS = 7

NX = 0 No segments on axis of symmetry

Card 7: Source Excitation

IS = 4 Excite the center segment

ECM = 1. Use a 1.0 volt,

ECA = 0. 0.degree source

NFLD = 0 Only one source card needed.

This completes the data deck requirements. The next step is to submit the program for execution and obtain the computer printout. The punched data deck is shown in Figure 9, while the numerical results are shown below in Figure 10.

```
HALF WAVE HORIZONTAL DIPOLE -- EXAMPLE 1A
   2     0    0    0    0    0
      .01       0.    1    1       25.       .01
       0.      -7.5       10     0        0.       7.5        10.    0
  -7     .0083        0.        0.        0.
   7     0
   4         1.       0.   0
```

```
1****************************

 WIRE ANTENNA MODELING PROGRAM

 ****************************



  HALF WAVE HORIZONTAL DIPOLE -- EXAMPLE 1A

    2    0    0    0    0    0   -0

 FREQUENCY              =  1.00000E-02
 FREQUENCY INCREMENT    =        .0E+00
 NO. FREQUENCY STEPS    =   1
 WAVELENGTH  (METERS)   =  2.99793E+01



 ANTENNA IS MODELED IN FREE SPACE




1 DATA GENERATOR INPUT DATA CARDS


       .0  -7.50000  10.00000     0          0   7.50000  10.00800     0
  -7    .00830         .0          .0          .0


NUMBER OF SEGMENTS   =   7
NO. SEG. IN A SECTOR =   7
NO. SEG. ON AXIS OF ROTATION =    0



1 STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

  COORDINATES OF SEG. CENTER      SEG.      WIRE     ORIENTATION ANGLES   CONNECTION DATA
     X         Y          Z       LENGTH    RADIUS      ALPHA       BETA    I-    I    I+
   -.00000   -.21443    .33356    .07148 .00027686        .0     90.000    0     1    2
   -.00000   -.14296    .33356    .07148 .00027686        .0     90.000    1     2    3
   -.00000   -.07148    .33356    .07148 .00027686        .0     90.000    2     3    4
   -.00000   -.00000    .33356    .07148 .00027686        .0     90.000    3     4    5
   -.00000    .07148    .33356    .07148 .00027686        .0     90.000    4     5    6
   -.00000    .14296    .33356    .07148 .00027686        .0     90.000    5     6    7
   -.00000    .21443    .33356    .07148 .00027686        .0     90.000    6     7    0

 TOTAL WIRE LENGTH     = 5.00345238214E-01

 ANTENNA SOURCE DISTRIBUTIONS
   SEG.          VOL   TAGE
   NO.     MAG.        PHASE
    4   1.00000          .0    0

  I=  1
 -4.934E+01  3.542E+04 -5.608E+01 -1.347E+04 -5 198E+01  9 222E+01 -4.680E+01 -1 011E+02 -4 017E+01 -4 397E+01
 -3.287E+01 -1.862E+01 -2.232E+01 -2.803E+00

  I=  2
 -4.854E+01 -1.127E+04 -5.716E+01  1.980E+04 -5 527E+01  1 086E+04 -5 198E+01 -9 222E+01  4 680E+01  1 011E+02
 -4.053E+01 -4.394E+01 -2.921E+01 -1 635E+01

  I=  3
 -4.584E+01 -9.044E+01 -5.595E+01 -1.086E+04 -5.640E+01  1.972E+04 -5.527E+01 -1.086E+04 -5.198E+01 -9.222E+01
 -4.727E+01 -1.012E+02 -3.576E+01 -4.182E+01

  I=  4
 -4.145E+01 -9.641E+01 -5.256E+01 -9.239E+01 -5.527E+01 -1.086E+04 -5.640E+01  1.972E+04 -5.527E+01 -1.086E+04
 -5.256E+01 -9.239E+01 -4.145E+01 -9.641E+01

  I=  5
 -3.576E+01 -4.182E+01 -4.727E+01 -1.012E+02 -5.198E+01 -9.222E+01 -5.527E+01 -1.086E+04 -5.640E+01  1.972E+04
 -5.595E+01 -1.086E+04 -4.584E+01 -9.044E+01

  I=  6
 -2.921E+01 -1.635E+01 -4.053E+01 -4.394E+01 -4.680E+01 -1.011E+02 -5.198E+01 -9.222E+01 -5.527E+01 -1.086E+04
 -5.716E+01  1.980E+04 -4.854E+01 -1.127E+04

  I=  7
 -2.232E+01 -2.803E+00 -3.287E+01 -1.862E+01 -4.017E+01 -4.397E+01 -4.680E+01 -1.011E+02 -5.198E+01 -9.222E+01
 -5.608E+01 -1.347E+04 -4.934E+01  3.542E+04
```

```
I SEGMENT EXCITATION (VOLTS/WAVELENGTH)
 SEG NUMBER   REAL PART   IMAGINARY PART

     4       -1.399E+01        -.0E+00
```

```
ISEG.   CURRENT-                                                   SEG.    CURRENT -
 NO.     REAL          IMAGINARY   MAGNITUDE        PHASE           NO.     REAL          IMAGINARY   MAGNITUDE        PHASE
    1   2.4803E-03 -1.5673E-03  2.93403718E-03   -32.289            5    9.0704E-03 -5.1156E-03  1.04134882E-02   -29.423
    2   6.4306E-03 -3.8720E-03  7.50633360E-03   -31.053            6    6.4306E-03 -3.8720E-03  7.50633368E-03   -31.053
    3   9.0704E-03 -5.1156E-03  1.04134882E-02   -29.423            7    2.4803E-03 -1.5673E-03  2.93403721E-03   -32.289
    4   1.0002E-02 -5.0996E-03  1 12272401E-02   -27.014
    ADMIT=  1.0002E-02 -5.0996E-03           ZPED=  7 9351E+01  4.0458E+01
     1.1227E-02        -27.014             8.9069E+01       27.014
```

```
I  I       AR          AI            BR          BI           CR          CI
     1  -3.5004E-03  3.5049E-03   1.0465E-02 -6.4669E-03  5.9807E-03 -5.0722E-03
     2  -1.7703E-04  1.4781E-03   7.5893E-03 -4.0863E-03  6 6078E-03 -5.3502E-03
     3   4.5920E-04  1.2354E-03   4.1133E-03 -1.4137E-03  8.6112E-03 -6.3510E-03
     4   6.0482E-04 -5.2611E-03   3.9307E-11 -9.1031E-11  9 3974E-03  1.6156E-04
     5   4.5920E-04  1 2354E-03  -4.1133E-03  1.4137E-03  8.6112E-03 -6.3510E-03
     6  -1.7703E-04  1.4781E-03  -7.5893E-03  4.0863E-03  6.6078E-03 -5.3502E-03
     7  -3.5004E-03  3.5049E-03  -1.0465E-02  6.4669E-03  5.9807E-03 -5.0722E-03
```

Example 1B. -- The results of example 1A were obtained for the dipole in free-space. It is a very simple matter to now model the antenna over an imperfectly conducting halfspace, as specified on Figure 8. Only the KSYMP variable on card 3 need be set to 2, as shown on the data card in Figure 12.

```
HALF WAVE HORIZONTAL DIPOLE -- EXAMPLE 1B
  2    0    0    0    0    0
       .01       0.    1    2       25.        .01
       0.      -7.5        10.  0         0.         7.5         10.    0
 -7      .0083        0.         0.         0.
  7    0
  4        1.         0.   0
```

```
 |****************************

  WIRE ANTENNA MODELING PROGRAM

  ****************************


   HALF WAVE HORIZONTAL DIPOLE -- EXAMPLE 18

     2     0     0     0     0     0    -0

 FREQUENCY                =  1 00000E-02
 FREQUENCY INCREMENT      =        .0E+00
 NO. FREQUENCY STEPS      =   1
 WAVELENGTH  (METERS)     =  2.99793E+01


 GROUND PLANE AT Z = 0.
 DIELECTRIC CONSTANT      =  2.50000E+01
 CONDUCTIVITY             =  1.00000E-02



 I DATA GENERATOR INPUT DATA CARDS


          .0  -7.50000  10.00000     0           .0   7.50000  10.00000     0
    -7     .00830         .0         .0          .0

 NUMBER OF SEGMENTS    =   7
 NO. SEG. IN A SECTOR  =   7
 NO. SEG. ON AXIS OF ROTATION =    0



 I STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

   COORDINATES OF SEG. CENTER      SEG.       WIRE     ORIENTATION ANGLES   CONNECTION DATA
       X          Y         Z      LENGTH    RADIUS       ALPHA      BETA    I-     I    I+
   -.00000    -.21443    .33356    .07148  .00027686         .0    90.000    0     1     2
   -.00000    -.14296    .33356    .07148  .00027686          0    90.000    1     2     3
   -.00000    -.07148    .33356    .07148  .00027686         .0    90.000    2     3     4
   -.00000    -.00000    .33356    .07148  .00027686         .0    90.000    3     4     5
   -.00000     .07148    .33356    .07148  .00027686         .0    90.000    4     5     6
   -.00000     .14296    .33356    .07148  .00027686         .0    90.000    5     6     7
   -.00000     .21443    .33356    .07148  .00027686         .0    90.000    6     7     0

 TOTAL WIRE LENGTH     = 5.003452382814E-01

 ANTENNA SOURCE DISTRIBUTIONS
   SEG.         VOLTAGE
   NO.     MAG.        PHASE
    4    1.00000         .0    0

  I=  1
 -8.135E+01  3.541E+04 -6.977E+01 -1.348E+04 -6.483E+01 -9 338E+01 -5.863E+01 -1.011E+02 -5.065E+01 -4.278E+01
 -4.184E+01 -1.417E+01 -2.873E+01 -5.232E-04

  I=  2
 -8.039E+01 -1.127E+04 -7.106E+01  1.979E+04 -6.877E+01 -1 086E+04 -6.483E+01 -9 338E+01 -5 863E+01 -1 011E+02
 -5.111E+01 -4.270E+01 -3.712E+01 -1.435E+01

  I=  3
 -5.715E+01 -9.153E+01 -6 982E+01 -1.086E+04 -7.012E+01  1 972E+04 -6.877E+01 -1.086E+04 -6.483E+01 -9.338E+01
 -5.923E+01 -1.012E+02 -4.504E+01 -4.087E+01

  I=  4
 -5.189E+01 -9.855E+01 -6.557E+01 -9.353E+01 -6.877E+01 -1 086E+04 -7.012E+01  1.972E+04 -6.877E+01 -1.086E+04
 -6.557E+01 -9.353E+01 -5.189E+01 -9.855E+01

  I=  5
 -4.504E+01 -4.087E+01 -5.923E+01 -1.012E+02 -6.483E+01 -9 338E+01 -6.877E+01 -1.086E+04 -7.012E+01  1.972E+04
 -6.982E+01 -1.086E+04 -5.715E+01 -9.153E+01

  I=  6
 -3.712E+01 -1.435E+01 -5.111E+01 -4.270E+01 -5.863E+01 -1 011E+02 -6.483E+01 -9.338E+01 -6.877E+01 -1.086E+04
 -7.108E+01  1.978E+04 -8.039E+01 -1.127E+04

  I=  7
 -2.873E+01 -5.232E-04 -4.184E+01 -1.417E+01 -5.065E+01 -4.278E+01 -5.863E+01 -1.011E+02 -6.483E+01 -9.338E+01
 -6.977E+01 -1.348E+04 -8.135E+01  3.541E+04
```

```
I SEGMENT EXCITATION (VOLTS/WAVELENGTH)
 SEG NUMBER   REAL PART   IMAGINARY PART

     4       -1.388E+01         -.0E+00
```

```
ISEG.   CURRENT-                                                SEG.    CURRENT -
 NO.      REAL          IMAGINARY   MAGNITUDE        PHASE        NO.     REAL         IMAGINARY   MAGNITUDE       PHASE
    1   2.1481E-03 -1.1743E-03  2.44809552E-03  -28.664            5   7.8629E-03 -3.6798E-03  8.68132877E-03  -25.078
    2   5.5727E-03 -2.8536E-03  6.26084806E-03  -27.115            6   5.5727E-03 -2.8538E-03  6.26084813E-03  -27.115
    3   7.8629E-03 -3.6796E-03  8.68132871E-03  -25.078            7   2.1481E-03 -1.1743E-03  2.44809555E-03  -28.664
    4   8.6717E-03 -3.5162E-03  9.35749738E-03  -22.072
   ADMIT=  8.6717E-03 -3.5162E-03           ZPED=  9.9034E+01  4.0157E+01
     9.3575E-03     -22.072              1.0687E+02      22.072
```

```
I  I      AR          AI          BR          BI           CR          CI
    1  -3.0077E-03  2.9457E-03   9.0655E-03 -4.8090E-03   5.1558E-03 -4.1200E-03
    2  -1.4703E-04  1.4489E-03   6.5815E-03 -2.8853E-03   5.7197E-03 -4.3025E-03
    3   3.9338E-04  1.3090E-03   3.5689E-03 -7.6312E-04   7.4696E-03 -4.9886E-03
    4   5.1588E-04 -5.1638E-03   3.3652E-11 -8.4748E-11   8.1559E-03  1.6476E-03
    5   3.9338E-04  1.3090E-03  -3.5689E-03  7.6312E-04   7.4696E-03 -4.9886E-03
    6  -1.4703E-04  1.4489E-03  -6.5815E-03  2.8853E-03   5.7197E-03 -4.3025E-03
    7  -3.0077E-03  2.9457E-03  -9.0655E-03  4.8090E-03   5.1558E-03 -4.1200E-03
```

Example 2 - Two 5/8 Wavelength Monopoles, 1/3 Wavelength Apart

As a second example, we will model two antennas, both fed, and compute the far field space radiation pattern. This example serves to illustrate the use of structure symmetry, the grounding of antenna elements and the use of the far-field option. The physical configuration is that shown in Figure 13, where we have made use of the structure's symmetry in the selection of the coordinate system's origin. The structure of the data deck is as follows:

Card 1: Run Comments

Card 2: Run Options

NPRINT = 1 Nominal printout

ILOAD = 0 No loading

IPGND = 1 Use a perfect ground

IGSCRN = 0 No ground screen

INEAR = 0 No near fields

IFAR = 1 Select far fields

NPWR = 0 Don't normalize power

Card 3: Frequency and Grounds

GHZ = 0.01 10 MHz input frequency

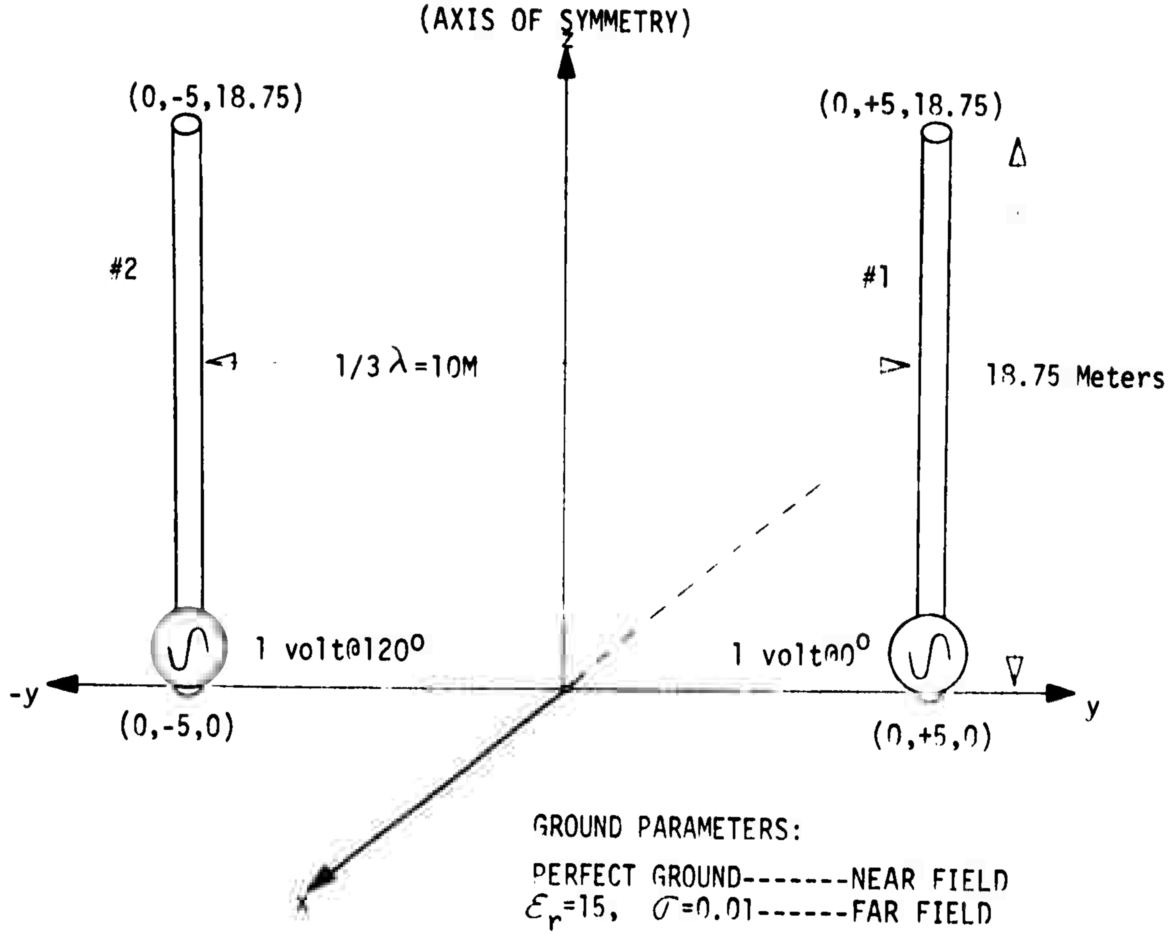
GR = 0 No frequency steps

NFS = 1 Only one frequency

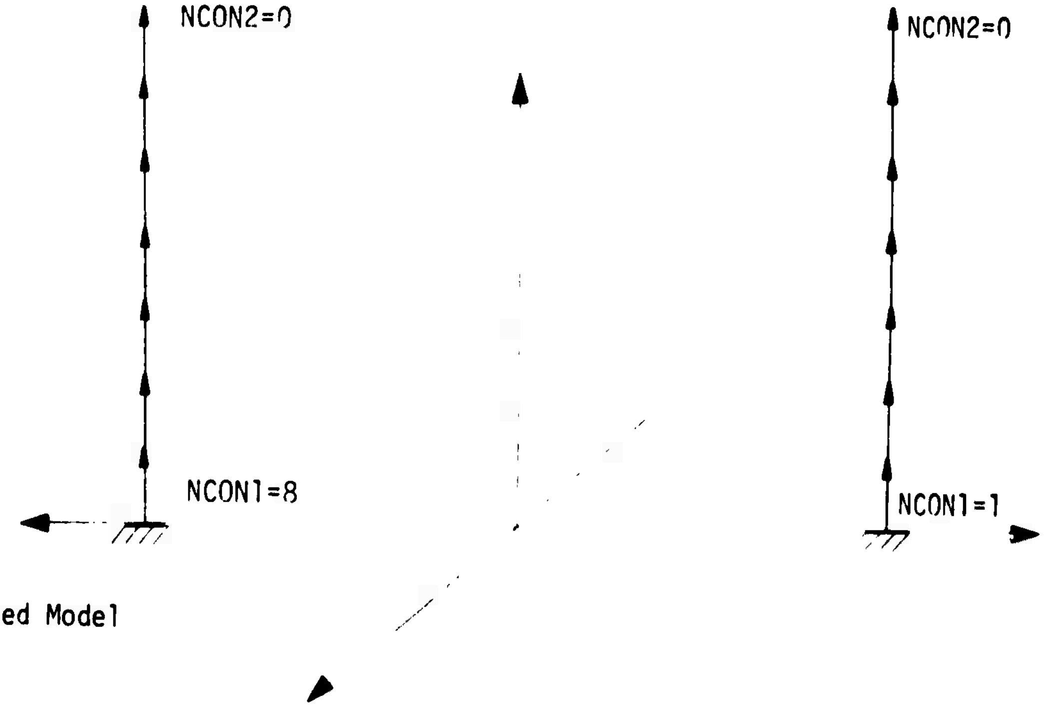
KSYMP = 2 Analyze over ground

EPSR = 1. Set EPSR = 1 as a dummy value even though

SIG = 0. ϵ_r and σ are not used.



a. Physical Model



b. Segmented Model

Figure 13 Two 5/8 Wavelength Monopoles--Both Fed.

Cards 4, 5, 6, and 7: Data Generator Inputs (see Figure 13)

Cards 4 & 5 Model Monopole #1	X1	= 0.	Coordinates of bottom
	Y1	= 5.	end of
	Z1	= 0.	Monopole 1
	NCON1	= 1	Segment 1 is grounded
	X2	= 0.	Coordinates of top
	Y2	= 5.	end of
	Z2	= 18.75	Monopole 1
	NCON2	= 0	Segment 7 is unconnected
	NSEGS	= +7	7 segments uased (A +7 means another set of data cards will be read)
	WIRERAD	= 0.01	10 cm radius wire
	WT	= 0.	No catenary
	TENS	= 0.	No catenary
	TAU	= 0.	Equal length segments
Cards 6 & 7 Model Monopole #2	X1	= 0.	Coordinates of bottom
	Y1	= -5.	of
	Z1	= 0.	Monopole #2
	NCON1	= 8	Segment #8 is grounded
	X2	= 0.	Coordinates of top
	Y2	= -5.	of
	Z2	= 18.75	Monopole #2
	NCON2	= 0	Segment #14 is unconnected
	NSEGS	= -7	7 segments for monopole #2 (minus # ends input)
	WIRERAD	= 0.01	10 cm radius wire
	WT	= 0.	No catenary
	TENS	= 0.	No catenary
	TAU	= 0.	

Card 8: Structure Symmetry

NP	=	7	7 segments per symmetric section - (2 sectors of symmetry)
NX	=	0	No segments on axis of symmetry

Cards 9 and 10: Source Excitation

IS	=	1	Excite segment #1
ECM	=	1.	1 volt source
ECA	=	0.	0 degree phase
NFLD	=	1	Read in another source card
IS	=	8	Also excite segment #8
ECM	=	1.	1 volt source
ECA	=	+120.	+120° phase
NFLD	=	0	End source input

Card 11: Far Field Input

THETR	=	0.	Initial θ angle
PHYR	=	-180.	Initial ϕ angle
ETAR	=	0.	Polarization angle = 0°
DTHR	=	5.	5 degree step in θ
DPHR	=	10.	10 degree step in ϕ
NTHR	=	19	19 steps in θ
NPHR	=	19	19 steps in ϕ
NFLD	=	0	No more farfield inputs
NEWSIG	=	1	Compute far field over finite ground
SIGFF	=	0.01	Conductivity of far field medium in mhos/metre
EPSFF	=	15	Relative dielectric content of far field.

The completed data deck for example 2 is shown in Figure 14, and the computed results are shown in Figure 15. The far field radiation pattern is shown in Figure 16.

```
2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2
   1    0    1    0    0    1    0
      01         0.    1    2         1         0.
      0.         5.         0.    1         0.         5.      18.75    0
   7       .01        0.         0.        0.
      0.        -5.         0.    8         0.        -5.      18.75    0
  -7       .01        0.         0.        0.
   7    0
   1       1.         0.    1
   8       1        120.    0
      0.        -90.        0.         5.        10.    19    19    0    1  .01  15.
```

```
1****************************

 WIRE ANTENNA MODELING PROGRAM

 ****************************



  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

    1    0    1    0    0    1    0

 FREQUENCY              =  1 00000E-02
 FREQUENCY INCREMENT    =        .0E+00
 NO. FREQUENCY STEPS    =   1
 WAVELENGTH  (METERS)   =  2.99793E+01

 A PERFECT GROUND PLANE AT Z=0.




1 DATA GENERATOR INPUT DATA CARDS


        .0   5.00000          .0    1         .0   5.00000  18.75000    0
    7    .01000         .0         .0         .0
        .0  -5.00000          .0    8         .0  -5.00000  18 75000    0
   -7    .01000         .0         .0         .0

 NUMBER OF SEGMENTS    =  14
 NO. SEG  IN A SECTOR  =   7
 NO. SEG. ON AXIS OF ROTATION =    0
```

```
I STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

  COORDINATES OF SEG  CENTER      SEG       WIRE     ORIENTATION ANGLES    CONNECTION DATA
       X         Y          Z       LENGTH     RADIUS       ALPHA        BETA     I-      I    I+
   -.00000     16678      04467      08935 .00033356     90 000            0     1      1     2
   -.00000     16678      13402      08935  00033356     90 000            0     1      2     3
   -.00000    .16678      22337      08935  00033356     90 000            0     2      3     4
   -.00000     16678      31272      08935  00033356     90 000           .0     3      4     5
   - 00000     16678      40206      08935  00033356     90 000            0     4      5     6
   -.00000     16678      49141      08935  00033356     90 000            0     5      6     7
   -.00000     16678      58076      08935  00033356     90 000            0     6      7     0
   -.00000   - 16678      04467      08935  00033356     90 000            0     8      8     9
   -.00000   - 16678      13402      08935  00033356     90 000            0     8      9    10
   -.00000   -.16678      22337      08935  00033356     90 000           .0     9     10    11
   - 00000   - 16678      31272      08935  00033356     90 000            0    10     11    12
   - 00000   - 16678      40206      08935  00033356     90 000            0    11     12    13
   -.00000   - 16678      49141      08935  00033356     90 000            0    12     13    14
   -.00000   - 16678      58076      08935  00033356     90 000            0    13     14     0

 TOTAL WIRE LENGTH     = 1 25086309554E+00

 ANTENNA SOURCE DISTRIBUTIONS
   SEG.          VOLTAGE
   NO       MAG         PHASE
    1    1 00000          .0     1
    8    1.00000 120 00000      0


I SEGMENT EXCITATION (VOLTS/WAVELENGTH)
 SEG NUMBER   REAL PART   IMAGINARY PART

     1       -1 119E+01        - 0E+00

     8        5.596E+00    -9 693E+00
```

```
ISEG.    CURRENT-
 NO        REAL          IMAGINARY    MAGNITUDE          PHASE
     1    9 4610E-04   2 4985E-03   2.67167139E-03    69 260
     2    7.4950E-04   3 2809E-04   8 18161744E-04    23 641
     3    4.2282E-04  -1 8219E-03   1 87036486E-03   -76 935
     4    7.4905E-05  -3 3470E-03   3 34779155E-03   -88 718
     5   -1.8073E-04  -3 8063E-03   3.81059325E-03   -92 719
     6   -2.6253E-04  -3 0521E-03   3.06341972E-03   -94 916
     7   -1 4182E-04  -1.2557E-03   1.26363391E-03   -96 444
     8   -1 9377E-03  -7 7683E-04   2 08758554E-03  -158 154
```

```
SEG.     CURRENT
  NO       REAL           IMAGINARY    MAGNITUDE          PHASE
   8   -1.9377E-03   7 7683E-04   2.08758554E 03  -158.154
   9   -1 0512E-04   2 4689E-04   2.68340310E-04   113.062
  10    1 6795E-03   1 2123E-03   2.07129504E-03    35.822
  11    2 9194E-03   1.8427E-03   3.45231094E-03    32.260
  12    3.2594E-03   1 9521E-03   3.79929258E-03    30.918
  13    2.5887E-03   1 5005E-03   2.99215487E-03    30.097
  14    1.0588E-03   5 9774E-04   1.21587527E-03    29.447
```

```
I   I        AR          AI           BR          BI           CR          CI
    1   3.0563E-04 -4.5722E-03  -1 8465E-04 -2 0385E-03   6.4046E-04   7 0707E-03
    2   3.2573E-04  3.9462E-04  -4 9147E-04 -4 0579E-03   4 2377E-04  -6 6532E-05
    3   3.5366E-04  2 1421E-04  -6.3359E-04 -3 4517E-03   6 9161E-05  -2.0362E-03
    4   3.7551E-04  1 2464E-04  -5.6686E-04 -1 8637E-03  -3.0060E-04  -3 4716E-03
    5   3.8559E-04  1.4695E-04  -3.1692E-04  2.7688E-04  -5.6632E-04  -3 9533E-03
    6   3.9719E-04  3 4351E-04   3 6550E-05  2 3956E-03   6 5972E-04  -3.3957E-03
    7   5.2205E-04  1.4402E-03   4 1815E-04  4 1518E-03  -6 6387E-04  -2.6959E-03
    8   4 0322E-03  2 5582E-03   1.7212E-03  9 6150E-04   5 9699E-03  -3 3350E-03
    9  -2.8127E-04  5 6747E-05   3.3973E-03  1 8682E-03   1.5615E 04   1 9015E-04
   10  -9.5079E-05  1 2132E-04   2 8406E 03  1 4988E-03   1 7746E-03   1 0909E 03
   11  -1.1977E-05  1.4505E-04   1.4839E-03  6 9487E-04   2 9314E 03   1 6977E-03
   12  -3.3312E-05  1.2455E-04  -3 1053E-04  3 2147E-04   3 2928E-03   1 8275E-03
   13  -2.1048E-04  3.0969E-05  -2.0669E-03  1 2720E 03   2 7992E-03   1 4695E-03
   14  -1.1484E-03 -4 7789E-04  -3 5103E-03  2 0058E 03   2 2072E-03   1 0756E-03
```

```
1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1 5000E+01 AND CONDUCTIVITY =   1 0000E-02 FOR FAR FIELD CALCULATIONS

 OBSERVATION ANGLES    ELECTRIC FIELD
   THETA      PHI            R-COMPONENT     THETA-COMPONENT     PHI-COMPONENT       MAGNITUDE          PHASE
       0   -90.000           2 3936E-15        3 0859E-22        6.0467E-11        6.0467E-11       -116 2122
   5 000   -90.000           2.0695E-15        2 0783E-02        3 6020E-11        2.0783E-02        -52.5110
  10.000   -90.000           2.5039E-15        3 1645E-02        3 0825E-11        3.1645E-02        -55 5531
  15 000   -90.000           1.3415E-15        3 2644E-02        2.5367E-11        3.2644E-02        -61.2927
  20.000   -90.000           1 1690E-15        2 5259E-02        1.9265E-11        2 5259E-02        -74 3210
  25.000   -90.000           1.6653E-16        1 5471E-02        1 2188E-'1        1 5471E-02       -116.3613
  30.000   -90.000           1.0146E-15        2 2725E-02        4 1005E-12        2 2725E-02        176.2860
  35.000   -90.000           7.4683E-16        4 2057E-02        6.2834E-12        4.2057E-02        151.8711
  40.000   -90 000           1.5464E-15        6 0345E-02        1.689[illegible]E-11        6.0345E-02        139.9473
  45.000   -90.000           1.0053E-15        7 2481E-02        2.8[illegible]8E-11        7.2481E-02        129 6603
  50.000   -90.000           1.4433E-15        7 6358E-02        3 9249E-11        7.6358E-02        116.9156
  55.000   -90.000           1 5424E-15        7 4257E-02        4 8868E-11        7.4257E-02         97.9356
  60.000   -90 000           8.8991E-16        7 5224E-02        5 5771E-11        7 5224E-02         70.6651
  65.000   -90.000           5 6610E-16        8 9585E-02        5 8709E-11        8.9585E 02         42 4816
  70.000   -90 000           1 2947E-15        1 1407E-01        5.6703E-11        1 1407E-01         22 4997
  75.000   -90.000           7 3277E-16        1 3455E-01        4.9276E-11        1 3455E 01          9.9769
  80.000   -90.000           4.7073E-16        1 3517E-01        3 6620E-11        1.35[illegible] 01          1 5081
  85 000   -90.000           1 2261E-16        9 8724E-02        1.9664E-11        9.8724E-02         -5.4658
  90.000   -90.000           8.3861E-27        8 4204E-12        1 1907E-21        8.4204E-12        166.4396
      .0   -80.000           2 3936E-15        1 0500E-11        5 9548E-11        6.0467E-11         63 7878
   5.000   -80.000           3 2760E-15        2 0854E-02        3 5561E-11        2.0854E-02        -52 4842
  10 000   -80.000           1.9565E-15        3 1931E-02        3 0548E- 1        3.1931E-02        -55.4619
  15.000   -80.000           7.4683E-16        3 3272E-02        2.5295E-11        3.3272E-02        -61.0111
  20.000   -80.000           9.8767E-16        2.6262E-02        1.9430E-11        2.6262E-02        -73 2583
  25.000   -80.000           7 1642E-16        1 6209E-02        1.2630E-11        1 6209E-02       -111.1011
  30.000   -80.000           6.8448E-16        2 1416E-02        4.8026E-12        2.1416E-02       -179.3314
  35.000   -80.000           8.6711E-16        3 9867E-02        5.2034E-12        3.9867E-02        153.7073
  40.000   -80.000           1.2009E-15        5.7788E-02        1 5378E-11        5 7788E-02        141.1025
  45.000   -80.000           8.0059E-16        6 9816E-02        2.6295E-11        6.9816E-02        130.6083
  50.000   -80.000           1.6012E-15        7 3741E-02        3.6980E-11        7.3741E-02        117.8362
  55.000   -80.000           8.8861E-16        7 1640E-02        4.6321E-11        7.1640E-02         98.8812
  60.000   -80.000           1.4655E-15        7 2280E-02        5.3067E-11        7 2280E-02         71.4541
  65.000   -80.000           1.1802E-15        8.6008E-02        5 6008E-11        8.6008E-02         42 8807
  70.000   -80.000           8.8991E-16        1 0986E-01        5.4194E-11        1.0986E-01         22.6324
  75.000   -80.000           4 9651E-16        1.2997E-01        4.7156E-11        1.2997E 01         10 0016
  80.000   -80.000           2.2650E-16        1 3082E-01        3.5074E-11        1 3082E-01          1.4932
  85.000   -80.000           1.7085E-16        9.5652E-02        1 8843E-11        9.5652E-02         -5.4950
  90 000   -80.000           2.1867E-25        8 1613E-12        1 1408E-21        8.1613E-12        166.4035
      .0   -70.000           2.3936E-15        2.0681E-11        5.6820E-11        6.0467E-11         63.7878
   5.000   -70.000           3.2451E-15        2 1066E-02        3.4181E-11        2.1066E-02        -52.4056
  10.000   -70.000           2.4183E-15        3 2782E-02        2.9688E-11        3.2782E-02        -55.2004
  15.000   -70.000           9.0366E-16        3 5136E-02        2.5021E-11        3 5136E-02        -60.2340
  20.000   -70.000           1.0123E-15        2 9284E-02        1.9036E-11        2.9284E-02        -70.5355
  25.000   -70.000           4.0341E-16        1 9060E-02        1.3826E-11        1.9060E-02        -98.3347
  30.000   -70.000           9 3095E-17        1 8455E-02        6.8280E-12        1.8455E-02       -163.1064
```

```
 I  2 MONOPOLES 5/8 WAVELENGTH -- 1 3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1 5000E+01 AND CONDUCTIVITY =   1 0000E-02 FOR FAR FIELD CALCULATIONS

  OBSERVATION ANGLES   ELECTRIC FIELD
    THETA      PHI              R-COMPONENT      THETA COMPONENT     PHI-COMPONENT       MAGNITUDE       PHASE
   35 000   -70.000              6.7132E-16        3 3648E-02         2.4639E-12        3 3648E 02      160 5371
   40 000   -70 000              9 6946E-16        5 0326E-02         1 1104E 11        5 0326E 02      145 2187
   45 000   -70 000              1 4476E 15        6 1983E-02         2 0870E 11        6 1983E 02      133 9014
   50 000   -70 000              1 0533E-15        6 6037E 02         3 0518E 11        6 6037E 02      120 9982
   55 000   -70.000              9 8092E-16        6 3932E-02         3 9044E 11        6 3932E 02      102 1435
   60 000   -70 000              1 1271E-15        6 3554E 02         4 5321E 11        6 3554E 02       74 2274
   65.000   -70 000              1 0934E-15        7 5312E-02         4 8255E 11        7 5312E 02       44 2902
   70 000   -70 000              1 2225E-15        9 7192E 02         4 6976E 11        9 7192E 02       23.0948
   75 000   -70 000              5 2369E-16        1 1618E-01         4 1048E 11        1 1618E 01       10 0863
   80 000   -70 000              4 6848E-16        1 1773E 01         3 0616E 11        1 1773E 01        1.4422
   85 000   -70.000              5 8981E 17        8 6391E 02         1 6474E 11        8 6391E 02        5.5939
   90 000   -70.000              4 0915E-25        7 3790E 12         9 9829E 22        7 3790E 12      166.2969
        0   -60.000              2 3936E 15        3 0233E 11         5 2366E 11        6 0467E 11       63 7878
    5.000   -60 000              3 2141E 15        2 1410E 02         3 1876E 11        2 1410E 02      -52 2806
   10 000   -60 000              2 0795E-15        3 4167E-02         2 8169E 11        3 4167E-02      -54.8014
   15 000   -60.000              1 0164E-15        3 8181E 02         2 4384E 11        3 8181E-02      -59.1284
   20 000   -60 000              7 8505E-16        3 4310E 02         2 0222E 11        3 4310E 02      -67 1319
   25 000   -60 000              7 3014E 16        2 5044E 02         1 5408E 11        2 5044E 02      -84.8314
   30 000   -60.000              6 2373E-16        1 7894E-02         9 7517E 12        1 7894E 02     -130 0149
   35 000   -60 000              2.1377E-16        2 5125E 02         3 3939E 12        2 5125E 02      178.4790
   40.000   -60.000              1 4433E-15        3 8883E-02         4 9582E-12        3 8883E 02      155.2477
   45 000   -60.000              1 3007E-15        4 9669E-02         1 2858E-11        4 9669E 02      141.4751
   50.000   -60 000              9.4206E-16        5 3869E-02         2 0881E 11        5 3869E-02      128.0777
   55.000   -80 000              8 2523E-16        5 1765E-02         2 8115E 11        5 1765E-02      109.5291
   60 000   -60.000              7 7728E-16        4 9552E-02         3 3625E-11        4 9552E 02       80.8418
   65 000   -60 000              4.9651E-16        5 7703E-02         3 6495E 11        5 7703E 02       47.7207
   70 000   -60.000              6.6613E-16        7 6134E-02         3 5989E 11        7 6134E-02       24.1837
   75 000   -60 000              5 7220E-16        9 3152E-02         3 1723E 11        9 3152E 02       10.2793
   80.000   -60 000              5 8039E-16        9 5811E-02         2 3795E-11        9 5811E 02        1.3286
   85.000   -60.000              2.0206E-16        7 0867E-02         1 2845E 11        7 0867E 02       -5.8117
   90 000   -60.000              4.2861E-25        6 0669E-12         7 7881E 22        6 0669E-12      166.0510
       .0   -50 000              2.3936E-15        3 8867E-11         4 6320E-11        6 0467E-11       63.7878
    5 000   -50.000              2.4975E-15        2 1876E-02         2 8643E-11        2 1876E 02      -52 1173
   10.000   -50.000              2 8098E-15        3 6039E-02         2 5880E-11        3 6039E-02      -54 3088
   15 000   -50.000              1 2959E-15        4 2307E -02        2 3144E-11        4 2307E-02      -57.8821
   20.000   -50.000              1.6136E-15        4 1230E-02         2 0196E-11        4.1230E 02      -63.8513
   25.000   -50.000              5 0440E-16        3 4373E-02         1.6809E-11        3 4373E 02      -74.7121
   30.000   -50 000              8 9088E-16        2 5185E-02         1 2801E-11        2 5185E-02      -97.1350
   35.000   -50.000              7.7765E-16        2 1080E-02         8 0941E-12        2 1080E 02     -139.6731
   40.000   -50.000              1.3990E-15        2 7006E-02         2 9450E-12        2 7006E-02     -178.6291
   45.000   -50 000              7.2164E-16        3 5249E-02         3 8583E 12        3 5249E 02      159 8010
   50.000   -50.000              9.2389E-16        3 9326E-02         9 7135E-12        3 9326E 02      144 3826
   55.000   -50.000              8.9681E-16        3 7351E-02         1 5286E-11        3 7351E 02      126 8940
   60.000   -50.000              1 6739E-15        3 2342E-02         1 9768E 11        3 2342E 02       98 7211
   85.000   -50.000              4 7103E-16        3 4106E-02         2 2463E-11        3 4106E 02       58 0442
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+0  AND CONDUCTIVITY =   1 0000E-02 FOR FAR FIELD CALCULATIONS.

 OBSERVATION ANGLES    ELECTRIC FIELD
   THETA     PHI              R-COMPONENT     THETA-COMPONENT    PHI-COMPONENT       MAGNITUDE         PHASE
  70.000  -50.000             6 8943E-16        4 7025E-02        2.2806E-11        4 7025E-02       27.2373
  75.000  -50.000             1.7772E-16        6 1103E-02        2 0487E-11        6 1103E-02       10 7769
  80.000  -50 000             1.7145E-16        6 5209E-02        1 5552E-11        6.5209E-02        1.0504
  85.000  -50.000             1.8697E-16        4 9150E-02        8 4513E-12        4 9150E-02       -6.3309
  90.000  -50.000             5.5558E-25        4 2321E-12        5 1389E-22        4 2321E-12      165.4820
       0  -40.000             2.3936E-15        4 6320E-11        3 8867E-11        6.0467E-11       63.7878
   5 000  -40.000             3.1626E-15        2 2448E-02        2 4494E-11        2 2448E-02      -51.9253
  10 000  -40.000             2.2549E-15        3 8334E-02        2 2702E-11        3 8334E-02      -53.7676
  15 000  -40.000             1.6012E-15        4 7374E-02        2 1031E-11        4 7374E-02      -56 6440
  20.000  -40 000             1.2947E-15        4 9815E 02        1.9306E-11        4 9815E-02      -61.0666
  25 000  -40.000             1 7040E-15        4 6575E-02        1 7359E-11        4 6575E-02      -68.0248
  30 000  -40.000             1.9142E-15        3 9469E 02        1.5038E-11        3.9469E-02      -79.4766
  35.000  -40.000             9 9698E-16        3 1583E-02        1 2240E-11        3 1583E-02      -98.8210
  40.000  -40.000             7.4683E-16        2 7154E-02        8 9511E-12        2.7154E-02     -127.6475
  45.000  -40 000             1.2403E-15        2 7984E-02        5 2846E-12        2.7984E-02     -156.7538
  50.000  -40.000             1.0602E-15        3 0171E 02        1 7577E-12        3.0171E-02      177 4751
  55.000  -40.000             1.3668E-16        2 9183E-02        2.9747E-12        2 9183E-02      167.6040
  60.000  -40.000             4 7752E-16        2 3228E-02        6 1398E-12        2 3228E-02      152 5092
  65 000  -40.000             3.6638E-16        1 3982E-02        8 4883E-12        1 3982E-02      123.6922
  70.000  -40.000             3.3537E-16        1 1787E-02        9.5618E-12        1.1787E-02       52 3137
  75.000  -40.000             1.2795E-16        2.0796E-02        9.1273E-12        2.0796E-02       13.5232
  80.000  -40 000             4.8528E-16        2 6571E-02        7.1827E-12        2.6571E-02        -.1849
  85.000  -40.000             1.3660E-16        2 1684E-02        3.9789E-12        2.1684E-02       -8.4214
  90 000  -40.000             3.9223E-25        1 9095E-12        2.4333E-22        1.9095E-12      163.2208
      .0  -30.000             2 3936E-15        5 2366E-11        3 0233E-11        6.0467E-11       63.7878
   5.000  -30.000             3.3343E-15        2 3107E-02        1 9465E-11        2.3107E-02      -51.7147
  10 000  -30.000             3.1365E-15        4 0973E-02        1 8538E-11        4 0973E-02      -53.2161
  15.000  -30.000             2.0488E-15        5.3198E-02        1 7786E-11        5.3198E-02      -55.5034
  20.000  -30.000             1.4571E-15        5 9739E-02        1 7108E-11        5.9739E-02      -58.8407
  25.000  -30.000             1.8611E-15        6.0983E 02        1 6386E-11        6.0983E-02      -63.6646
  30 000  -30.000             2.3479E-15        5.7862E-02        1.5514E-11        5 7862E-02      -70.6805
  35.000  -30.000             1.5414E 15        5.1989E 02        1 4394E-11        5 1989E-02      -80.9330
  40.000  -30.000             1.0190E-15        4.5676E-02        1 2967E-11        4 5676E-02      -95.5104
  45.000  -30.000             1.1116E-15        4 1421E-02        1 1225E-11        4 1421E-02     -114.0983
  50 000  -30.000             1.8377E-15        4 0341E-02        9.2173E-12        4 0341E-02     -133.2809
  55.000  -30.000             5 1179E-16        4 1018E-02        7 0609E-12        4.1018E-02     -148.9558
  60.000  -30.000             7.3277E-16        4 0942E-02        4.9251E-12        4.0942E-02     -159.9453
  65.000  -30.000             8.9088E-16        3 8470E-02        3 0067E-12        3.8470E-02     -167.0894
  70.000  -30.000             2.8177E-16        3.3352E-02        1 4957E-12        3.3352E-02     -171.4498
  75.000  -30.000             4.6476E-16        2.6398E-02        5 7367E-13        2.6398E-02     -173.8519
  80.000  -30.000             2.2602E-16        1.8738E-02        3 6724E-13        1 8738E-02     -175.2032
  85.000  -30.000             1.3986E-17        1 0717E-02        2 7577E-13        1.0717E-02     -177 2573
  90.000  -30.000             1.7401E-25        8.3547E-13        1 8760E-23        8.3547E-13       -3.4473
      .0  -20.000             2.3936E-15        5.6820E-11        2 0681E-11        6.0467E-11       63.7878
   5.000  -20.000             2.8231E-15        2.3832E-02        1.3623E-11        2 3832E-02      -51.4953
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS


 OBSERVATION ANGLES   ELECTRIC FIELD
   THETA      PHI          R-COMPONENT     THETA-COMPONENT     PHI-COMPONENT         MAGNITUDE          PHASE
   10.000   -20.000         2.8475E-15       4.3864E-02         1.3335E-11         4.3864E-02        -52.6820
   15.000   -20.000         1.7244E-15       5.9569E-02         1.3227E-11         5.9569E-02        -54.4999
   20.000   -20.000         2.1102E-15       7.0610E-02         1.3248E-11         7.0610E-02        -57.1037
   25.000   -20.000         1.7902E-15       7.6886E-02         1.3339E-11         7.6886E-02        -60.7443
   30.000   -20.000         1.9270E-15       7.8628E-02         1.3432E-11         7.8628E-02        -65.8097
   35.000   -20.000         1.7772E-15       7.6558E-02         1.3455E-11         7.6558E-02        -72.8762
   40.000   -20.000         2.0015E-15       7.2063E-02         1.3336E-11         7.2063E-02        -82.7018
   45.000   -20.000         1.1226E-15       6.7281E-02         1.3013E-11         6.7281E-02         95.9377
   50.000   -20.000         7.4683E-16       6.4736E-02         1.2442E-11         6.4736E-02       -112.2253
   55.000   -20.000         9.5505E-16       6.6064E-02         1.1598E-11         6.6064E-02       -129.3306
   60.000   -20.000         8.9509E-16       7.0665E-02         1.0484E-11         7.0665E-02       -144.3904
   65.000   -20.000         6.7760E-16       7.6081E-02         9.1237E-12         7.6081E-02        156.1380
   70.000   -20.000         1.0130E-15       7.9383E-02         7.5554E-12         7.9383E-02       -164.9302
   75.000   -20.000         [illegible].0873E-16       7.7797E-02         5.8244E-12         7.7797E-02       -171.6780
   80.000   -20.000         2.4286E-16       6.8290E-02         3.[illegible]06E-12         6.8290E-02       -177.3430
   85.000   -20.000         1.3895E-16       4.6040E-02         2.0237E-12         4.6040E-02        176.9568
   90.000   -20.000         4.5525E-25       3.8249E-12         1.2040E-22         3.8249E-12        -10.7511
       .0   -10.000         2.3936E-15       5.9548E-11         1.0500E-11         6.0467E-11         63.7878
    5.000   -10.000         2.9528E-15       2.4600E-02         7.0820E-12         2.4600E-02        -51.2756
   10.000   -10.000         3.4294E-15       4.6908E-02         7.1181E-12         4.6908E-02        -52.1864
   15.000   -10.000         2.0015E-15       6.6254E-02         7.2754E-12         6.6254E-02        -53.6411
   20.000   -10.000         2.3714E-15       8.1999E-02         7.5387E-12         8.1999E-02        -55.7551
   25.000   -10.000         2.5895E-15       9.3562E-02         7.8888E-12         9.3562E-02        -58.7164
   30.000   -10.000         2.5631E-15       1.0052E-01         8.2952E-12         1.0052E-01         62.8243
   35.000   -10.000         2.7465E-15       1.0282E-01         8.7179E-12         1.0282E-01        -68.5455
   40.000   -10.000         2.5662E-15       1.0107E-01         9.1051E-12         1.0107E-01         76.5738
   45.000   -10.000         2.4582E-15       9.6999E-02         9.3982E-12         9.6999E-02        -87.7852
   50.000   -10.000         1.8073E-15       9.3733E-02         9.5321E-12         9.3733E-02       -102.7434
   55.000   -10.000         2.8021E-15       9.5089E-02         9.4414E-12         9.5089E-02       -120.4518
   60.000   -10.000         1.6505E-15       1.0300E-01         9.0673E-12         1.0300E-01       -137.8700
   65.000   -10.000         1.3506E-15       1.1527E-01         8.3642E-12         1.1527E-01       -152.2656
   70.000   -10.000         2.0260E-15       1.2660E-01         7.3075E-12         1.2660E-01       -163.1043
   75.000   -10.000         8.9207E-16       1.3039E-01         5.8976E-12         1.3039E-01       -171.2092
   80.000   -10.000         5.5720E-16       1.1909E-01         4.1656E-12         1.1909E-01       -177.7025
   85.000   -10.000         1.4120E-16       8.2354E-02         2.1710E-12         8.2354E-02        176.1562
   90.000   -10.000         1.0041E-24       6.8996E-12         1.3017E-22         6.8996E-12        -11.7009
       .0        .0         2.3936E-15       6.0467E-11              0E+00         6.0467E-11         63.7878
    5.000        .0         3.1287E-15       2.5387E-02              0E+00         2.5387E-02        -51.0629
   10.000        .0         3.2880E-15       5.0005E-02              0E+00         5.0005E-02        -51.7374
   15.000        .0         3.1426E-15       7.3016E-02              0E+00         7.3016E-02        -52.9106
   20.000        .0         2.7104E-15       9.3466E-02              0E+00         9.3466E-02        -54.7044
   25.000        .0         2.5317E-15       1.1030E-01              0E+00         1.1030E-01        -57.2587
   30.000        .0         2.1557E-15       1.2247E-01              0E+00         1.2247E-01        -60.8401
   35.000        .0         3.5958E-15       1.2916E-01              0E+00         1.2916E-01        -65.9000
   40.000        .0         3.7221E-15       1.3029E-01              0E+00         1.3029E-01        -73.0832
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS.

 OBSERVATION ANGLES   ELECTRIC FIELD
   THETA     PHI             R-COMPONENT     THETA-COMPONENT    PHI-COMPONENT      MAGNITUDE        PHASE
   45.000      .0            3.5804E-15       1.2715E-01          .0E+00         1.2715E-01      -83.3473
   50.000      .0            2.5177E-15       1.2324E-01          .0E+00         1.2324E-01      -97.6244
   55.000      .0            1.6910E-15       1.2420E-01          .0E+00         1.2420E-01     -115.5959
   60.000      .0            2.7822E-15       1.3454E-01          .0E+00         1.3454E-01     -134.3442
   65.000      .0            1.4043E-15       1.5287E-01          .0E+00         1.5287E-01     -150.2797
   70.000      .0            4.9651E-16       1.7171E-01          .0E+00         1.7171E-01     -162.2340
   75.000      .0            2.2061E-15       1.8065E-01          .0E+00         1.8065E-01     -171.0011
   80.000      .0            7.7743E-16       1.6772E-01          .0E+00         1.6772E-01     -177.8531
   85.000      .0            3.6638E-16       1.1714E-01          .0E+00         1.1714E-01      175.8318
   90.000      .0            1.2941E-24       9.8491E-12          .0E+00         9.8491E-12      -12.0854
       0    10.000           2.3936E-15       5.9548E-11       1.0500E-11        6.0467E-11       63.7878
    5.000   10.000           3.1632E-15       2.6167E-02       7.4178E-12        2.6167E-02      -50.8629
   10.000   10.000           3.7364E-15       5.3055E-02       7.8142E-12        5.3055E-02      -51.3403
   15.000   10.000           2.2542E-15       7.9626E-02       8.3808E-12        7.9626E-02      -52.3175
   20.000   10.000           3.4844E-15       1.0460E-01       9.1258E-12        1.0460E-01      -53.8807
   25.000   10.000           2.7756E-15       1.2644E-01       1.0047E-11        1.2644E-01      -56.1801
   30.000   10.000           2.9790E-15       1.4350E-01       1.1124E-11        1.4350E-01      -59.4639
   35.000   10.000           5.6173E-15       1.5428E-01       1.2308E-11        1.5428E-01      -64.1373
   40.000   10.000           3.3009E-15       1.5804E-11       1.3522E-11        1.5804E-01       70.8516
   45.000   10.000           1.7772E-15       1.5566E-01       1.4652E-11        1.5566E-01      -80.5836
   50.000   10.000           1.9860E-15       1.5097E-01       1.5557E-11        1.5097E-01      -94.4488
   55.000   10.000           3.3009E-15       1.5112E-01       1.6075E-11        1.5112E-01     -112.5426
   60.000   10.000           3.9534E-15       1.6307E-01       1.6037E-11        1.6307E-01     -132.1183
   65.000   10.000           2.2204E-15       1.8644E-01       1.5294E-11        1.8644E-01     -149.0520
   70.000   10.000           3.1402E-15       2.1183E-01       1.3740E-11        2.1183E-01     -161.7139
   75.000   10.000           1.3609E-15       2.2536E-01       1.1338E-11        2.2536E-01     -170.8807
   80.000   10.000           9.7799E-16       2.1097E-01       8.1375E-12        2.1097E-01     -177.9380
   85.000   10.000           1.9107E-16       1.4810E-01       4.2828E-12        1.4810E-01      175.6514
   90.000   10.000           1.8515E-24       1.2469E-11       2.5758E-22        1.2469E-11      -12.2885
      .0    20.000           2.3936E-15       5.6820E-11       2.0681E-11        6.0467E-11       63.7878
    5.000   20.000           3.1846E-15       2.6917E-02       1.4926E-11        2.6917E-02      -50.6800
   10.000   20.000           3.6701E-15       5.5964E-02       1.6034E-11        5.5964E-02      -50.9963
   15.000   20.000           2.0837E-15       8.5874E-02       1.7511E-11        8.5874E-02      -51.8218
   20.000   20.000           3.5108E-15       1.1502E-01       1.9393E-11        1.1502E-01      -53.2317
   25.000   20.000           3.3984E-15       1.4141E-01       2.1689E-11        1.4141E-01      -55.3644
   30.000   20.000           3.4684E-15       1.6282E-01       2.4362E-11        1.6282E-01      -58.4544
   35.000   20.000           6.2686E-15       1.7714E-01       2.7312E-11        1.7714E-01      -62.8910
   40.000   20.000           5.2779E-15       1.8304E-01       3.0356E-11        1.8304E-01      -69.3114
   45.000   20.000           2.4349E-15       1.8110E-01       3.3231E-11        1.8110E-01      -78.7023
   50.000   20.000           2.6658E-15       1.7537E-01       3.5597E-11        1.7537E-01      -92.2851
   55.000   20.000           2.3804E-15       1.7431E-01       3.7055E-11        1.7431E-01     -110.4331
   60.000   20.000           3.9721E-15       1.8705E-01       3.7197E-11        1.8705E-01     -130.5657
   65.000   20.000           2.2204E-15       2.1422E-01       3.5651E-11        2.1422E-01     -148.2022
   70.000   20.000           1.8871E-15       2.4485E-01       3.2155E-11        2.4485E-01     -161.3602
   75.000   20.000           1.7841E-15       2.6208E-01       2.6613E-11        2.6208E-01     -170.8002
```

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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS.

 OBSERVATION ANGLES    ELECTRIC FIELD
   THETA      PHI              R-COMPONENT      THETA-COMPONENT     PHI-COMPONENT        MAGNITUDE         PHASE
  80.000    20.000            6.8189E-16         2.4647E-01          1.9141E-11          2.4647E-01      -177.9941
  85.000    20.000            3.3887E-16         1.7348E-01          1.0086E-11          1.7348E-01       175.5332
  90.000    20.000            1.6890E-24         1.4623E-11          6.0672E-22          1.4623E-11       -12.4275
      .0    30.000            2.3936E-15         5.2366E-11          3.0233E-11          6.0467E-11        63.7878
   5.000    30.000            3.9629E-15         2.7616E-02          2.2248E-11          2.7616E-02       -50.5174
  10.000    30.000            4.3002E-15         5.8647E-02          2.4302E-11          5.8647E-02       -50.7043
  15.000    30.000            3.5423E-15         9.1579E-02          2.6928E-11          9.1579E-02       -51.4175
  20.000    30.000            3.0627E-15         1.2443E-01          3.0202E-11          1.2443E-01       -52.7198
  25.000    30.000            3.3009E-15         1.5476E-01          3.4152E-11          1.5476E-01       -54.7390
  30.000    30.000            5.1789E-15         1.7983E-01          3.8726E-11          1.7983E-01       -57.6984
  35.000    30.000            5.4616E-15         1.9700E-01          4.3764E-11          1.9700E-01       -61.9751
  40.000    30.000            4.1895E-15         2.0446E-01          4.8967E-11          2.0446E-01       -68.1941
  45.000    30.000            7.1063E-15         2.0255E-01          5.3895E-11          2.0255E-01       -77.3454
  50.000    30.000            2.6853E-15         1.9554E-01          5.7973E-11          1.9554E-01       -90.7172
  55.000    30.000            3.6621E-15         1.9294E-01          6.0545E-11          1.9294E-01       108.8824
  60.000    30.000            2.6738E-15         2.0570E-01          6.0924E-11          2.0570E-01      -129.4103
  65.000    30.000            1.8971E-15         2.3536E-01          5.8496E-11          2.3536E-01      -147.5703
  70.000    30.000            1.8971E-15         2.6975E-01          5.2825E-11          2.6975E-01      -161.0994
  75.000    30.000            1.7764E-15         2.8965E-01          4.3757E-11          2.8965E-01      -170.7414
  80.000    30.000            9.0632E-16         2.7305E-01          3.1489E-11          2.7305E-01      -178.0348
  85.000    30.000            7.9201E-16         1.9245E-01          1.6598E-11          1.9245E-01       175.4479
  90.000    30.000            2.1765E-24         1.6226E-11          9.9857E-22          1.6226E-11       -12.5237
      .0    40.000            2.3936E-15         4.6320E-11          3.8867E-11          6.0467E-11        63.7878
   5.000    40.000            3.9931E-15         2.8243E-02          2.9094E-11          2.8243E-02       -50.3774
  10.000    40.000            3.6557E-15         6.1031E-02          3.2222E-11          6.1031E-02       -50.4623
  15.000    40.000            3.6338E-15         9.6594E-02          3.6109E-11          9.6594E-02       -51.0925
  20.000    40.000            3.7813E-15         1.3260E-01          4.0871E-11          1.3260E-01       -52.3185
  25.000    40.000            3.9284E-15         1.6619E-01          4.6560E-11          1.6619E-01       -54.2579
  30.000    40.000            4.8698E-15         1.9418E-01          5.3109E-11          1.9418E-01       -57.1254
  35.000    40.000            5.5644E-15         2.1346E-01          6.0290E-11          2.1346E-01       -61.2879
  40.000    40.000            4.5722E-15         2.2140E-01          6.7674E-11          2.2190E-01       -67.3609
  45.000    40.000            4.6364E-15         2.1964E-01          7.4646E-11          2.1964E-01       -76.3338
  50.000    40.000            4.0288E-15         2.1118E-01          8.0400E-11          2.1118E-01       -89.5399
  55.000    40.000            4.5084E-15         2.0684E-01          8.4016E-11          2.0684E-01      -107.7006
  60.000    40.000            2.5121E-15         2.1898E-01          8.4550E-11          2.1898E-01      -128.5177
  65.000    40.000            2.8436E-15         2.4994E-01          8.1161E-11          2.4994E-01      -147.0805
  70.000    40.000            2.2644E-15         2.8667E-01          7.3264E-11          2.8667E-01      -160.8980
  75.000    40.000            2.2267E-15         3.0823E-01          6.0658E-11          3.0823E-01      -170.6962
  80.000    40.000            4.5776E-16         2.9085E-01          4.3634E-11          2.9085E-01      -178.0660
  85.000    40.000            5.5788E-16         2.0512E-01          2.2993E-11          2.0512E-01       175.3826
  90.000    40.000            2.5701E-24         1.7298E-11          1.3831E-21          1.7298E-11       -12.5981
      .0    50.000            2.3936E-15         3.8867E-11          4.6320E-11          6.0467E-11        63.7878
   5.000    50.000            3.3420E-15         2.8780E-02          3.5174E-11          2.8780E-02       -50.2614
  10.000    50.000            4.7080E-15         6.3058E-02          3.9388E-11          6.3058E-02       -50.2680
  15.000    50.000            3.3839E-15         1.0081E-01          4.4512E-11          1.0081E-01       -50.8377
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS.

 OBSERVATION ANGLES   ELECTRIC FIELD
  THETA     PHI            R-COMPONENT      THETA-COMPONENT     PHI-COMPONENT        MAGNITUDE        PHASE
 20.000   50.000            3.8858E-15        1.3938E-01         5.0710E-11         1.3938E-01      -52.0091
 25.000   50.000            3.4542E-15        1.7554E-01         5.8045E-11         1.7554E-01      -53.8918
 30.000   50.000            5.1789E-15        2 0571E-01         6.6429E-11         2.0571E-01      -56.6829
 35.000   50.000            5.6741E-15        2.2644E-01         7.5564E-11         2.2644E-01      -60.7717
 40 000   50.000            5.7732E-15        2.3533E-01         8.4911E-11         2.3533E-01      -66.7358
 45.000   50.000            5.4672E-15        2.3247E-01         9.3674E-11         2.3247E-01      -75.5727
 50.000   50.000            3.5537E-15        2 2252E-01         1.0085E-10         2.2252E-01      -88.6464
 55.000   50.000            5.1263E-15        2.1641E-01         1.0528E-10         2.1641E-01     -106.7905
 60.000   50.000            4.9302E-15        2.2755E-01         1.0582E-10         2.2755E-01     -127 8208
 65.000   50.000            2.5895E-15        2 5887E-01         1.0143E-10         2.5887E-01     -146.6858
 70.000   50.000            1.7342E-15        2.9674E-01         9.1438E-11         2.9674E-01     -160.7397
 75.000   50.000            1.8784E-15        3.1910E-01         7.5614E-11         3.1910E-01     -170.6607
 80.000   50.000            8.8821E-16        3.0116E-01         5.4341E-11         3.0116E-01     -178.0905
 85.000   50.000            6.7422E-16        2.1240E-01         2.8618E-11         2.1240E-01      175.3314
 90.000   50 000            2.0417E-24        1.7912E-11         1.7213E-21         1.7912E-11      -12.6522
     .0   60.000            2.3936E-15        3.0233E-11         5.2366E-11         6.0467E-11       63.7878
  5 000   60.000            4.4171E-15        2.9213E-02         4.0222E-11         2.9213E-02      -50.1704
 10.000   60.000            3.9923E-15        6.4678E-02         4.5418E-11         6.4678E-02      -50.1193
 15.000   60.000            3.0867E-15        1.0415E-01         5.1639E-11         1.0415E-01      -50.6460
 20 000   60.000            3.2953E-15        1.4468E-01         5.9081E-11         1.4468E-01      -51.7791
 25.000   60.000            5.6741E-15        1.8274E-01         6.7819E-11         1.8274E-01      -53.6217
 30.000   60.000            6.0606E-15        2.1443E-01         7.7744E-11         2.1443E-01      -56.3751
 35.000   60.000            3.4684E-15        2.3607E-01         8.8494E-11         2.3607E-01      -60.3930
 40.000   60.000            4.0698E-15        2.4506E-01         9.9418E-11         2.4506E-01      -66.2764
 45.000   60.000            4.1792E-15        2.4149E-01         1.0958E-10         2.4149E-01      -75.0108
 50.000   60.000            6.2247E-15        2.3016E-01         1.1780E-10         2.3016E-01      -87.9810
 55.000   60.000            4.0214E-15        2.2244E-01         1.2277E-10         2.2244E-01     -106.1037
 60.000   60.000            1.7342E-15        2.3243E-01         1.2316E-10         2.3243E-01     -127.2877
 65.000   60.000            2.3915E-15        2.6351E-01         1.1784E-10         2.6351E-01     -146.3986
 70.000   60.000            2.8087E-15        3.0170E-01         1.0604E-10         3.0170E-01     -160.6177
 75.000   60.000            4.0156E-15        3.2429E-01         8.7557E-11         3.2429E-01     -170.6334
 80.000   60.000            1.5545E-15        3.0598E-01         6.2851E-11         3.0596E-01     -178.1093
 85.000   60.000            5.5511E-16        2.1573E-01         3.3076E-11         2.1573E-01      175.2920
 90.000   60.000            1.3705E-24        1.8191E-11         1.9885E-21         1.8191E-11      -12.7060
     .0   70.000            2.3936E-15        2.0681E-11         5.6820E-11         6.0467E-11       63.7878
  5.000   70.000            4.5041E-15        2.9531E-02         4.4006E-11         2.9531E-02      -50.1051
 10.000   70.000            4.6242E-15        6.5859E-02         4.9981E-11         6.5859E-02      -50.0144
 15.000   70.000            3.2972E-15        1.0656E-01         5.7058E-11         1.0656E-01      -50.5124
 20.000   70.000            3.4542E-15        1.4847E-01         6.5455E-11         1.4847E-01      -51.6200
 25.000   70.000            3.8148E-15        1.8782E-01         7.5255E-11         1.8782E-01      -53.4356
 30.000   70.000            4.2422E-15        2.2050E-01         8.6326E-11         2.2050E-01      -56.1567
 35.000   70.000            5.5844E-15        2.4262E-01         9.8251E-11         2.4262E-01      -60.1324
 40.000   70.000            4.9651E-15        2.5153E-01         1.1030E-10         2.5153E-01      -65.9587
 45.000   70.000            6.2804E-15        2.4730E-01         1.2143E-10         2.4730E-01      -74.6215
 50.000   70.000            3.7080E-15        2.3486E-01         1.3034E-10         2.3486E-01      -87.5163
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS.


 OBSERVATION ANGLES   ELECTRIC FIELD
   THETA     PHI            R-COMPONENT      THETA-COMPONENT     PHI-COMPONENT        MAGNITUDE         PHASE
  55.000   70.000            3.7568E-15         2.2585E-01         1.3559E-10         2.2585E-01     -105.6185
  60.000   70.000            4.3113E-15         2.3482E-01         1.3577E-10         2.3482E-01     -126.9069
  65.000   70.000            2.2204E-15         2.6542E-01         1.2966E-10         2.6542E-01     -146.1865
  70.000   70.000            2.9790E-15         3.0349E-01         1.1648E-10         3.0349E-01     -160.5297
  75.000   70.000            2.2542E-15         3.2599E-01         9.6042E-11         3.2599E-01     -170.6136
  80.000   70.000            6.6905E-16         3.0741E-01         6.8868E-11         3.0741E-01     -178.1229
  85.000   70.000            4.4674E-16         2.1669E-01         3.6218E-11         2.1669E-01      175.2634
  90.000   70.000            9.6187E-25         1.8271E-11         2.1774E-21         1.8271E-11      -12.7325
       0   80.000            2.3936E-15         1.0500E-11         5.9548E-11         6.0467E-11       63.7878
   5.000   80.000            4.5912E-15         2.9725E-02         4.6350E-11         2.9725E-02      -50.0658
  10.000   80.000            4.3356E-15         6.6577E-02         5.2825E-11         6.6577E-02      -49.9520
  15.000   80.000            3.1421E-15         1.0802E-01         6.0444E-11         1.0802E-01      -50.4334
  20.000   80.000            4.4367E-15         1.5074E-01         6.9440E-11         1.5074E-01      -51.5265
  25.000   80.000            5.6741E-15         1.9084E-01         7.9897E-11         1.9084E-01      -53.3265
  30.000   80.000            4.0943E-15         2.2405E-01         9.1667E-11         2.2405E-01      -56.0286
  35.000   80.000            5.3660E-15         2.4640E-01         1.0430E-10         2.4640E-01      -59.9795
  40.000   80.000            6.3584E-15         2.5520E-01         1.1701E-10         2.5520E-01      -65.7733
  45.000   80.000            2.5895E-15         2.5050E-01         1.2869E-10         2.5050E-01      -74.3916
  50.000   80.000            3.1735E-15         2.3734E-01         1.3797E-10         2.3734E-01      -87.2402
  55.000   80.000            1.7798E-15         2.2751E-01         1.4334E-10         2.2751E-01     -105.3279
  60.000   80.000            2.2315E-15         2.3577E-01         1.4334E-10         2.3577E-01     -126.6769
  65.000   80.000            2.3604E-15         2.6595E-01         1.3671E-10         2.6595E-01     -146.0572
  70.000   80.000            1.6012E-15         3.0380E-01         1.2267E-10         3.0380E-01     -160.4761
  75.000   80.000            1.7841E-15         3.2613E-01         1.0104E-10         3.2613E-01     -170.6016
  80.000   80.000            1.3184E-16         3.0742E-01         7.2398E-11         3.0742E-01     -178.1313
  85.000   80.000            6.7132E-16         2.1664E-01         3.8057E-11         2.1664E-01      175.2460
  90.000   80.000            5.0965E-25         1.8267E-11         2.2872E-21         1.8267E-11      -12.7633
      .0   90.000            2.3936E-15         3.0859E-22         6.0467E-11         6.0467E-11     -116.2122
   5.000   90.000            4.0945E-15         2.9790E-02         4.7144E-11         2.9790E-02      -50.0526
  10.000   90.000            5.1182E-15         6.6817E-02         5.3791E-11         6.6817E-02      -49.9312
  15.000   90.000            4.2855E-15         1.0850E-01         6.1595E-11         1.0850E-01      -50.4073
  20.000   90.000            4.0762E-15         1.5150E-01         7.0795E-11         1.5150E-01      -51.4956
  25.000   90.000            4.2422E-15         1.9183E-01         8.1474E-11         1.9183E-01      -53.2905
  30.000   90.000            5.7732E-15         2.2522E-01         9.3479E-11         2.2522E-01      -55.9863
  35.000   90.000            6.6798E-15         2.4764E-01         1.0635E-10         2.4764E-01      -59.9291
  40.000   90.000            7.7557E-15         2.5638E-01         1.1927E-10         2.5638E-01      -65.7118
  45.000   90.000            3.6621E-15         2.5152E-01         1.3113E-10         2.5152E-01      -74.3155
  50.000   90.000            2.6820E-15         2.3811E-01         1.4053E-10         2.3811E-01      -87.1485
  55.000   90.000            5.0096E-15         2.2799E-01         1.4593E-10         2.2799E-01     -105.2309
  60.000   90.000            1.6012E-15         2.3600E-01         1.4585E-10         2.3600E-01     -126.5998
  65.000   90.000            2.3604E-15         2.6602E-01         1.3904E-10         2.6602E-01     -146.0137
  70.000   90.000            3.2024E-15         3.0377E-01         1.2471E-10         3.0377E-01     -160.4581
  75.000   90.000            1.8453E-15         3.2603E-01         1.0269E-10         3.2603E-01     -170.5975
  80.000   90.000            8.9207E-16         3.0727E-01         7.3556E-11         3.0727E-01     -178.1341
  85.000   90.000            6.6844E-16         2.1651E-01         3.8659E-11         2.1651E-01      175.2402
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1  2 MONOPOLES 5/8 WAVELENGTH -- 1/3 WAVELENGTH APART -- EXAMPLE 2

DIELECTRIC CONSTANT =   1.5000E+01 AND CONDUCTIVITY =   1.0000E-02 FOR FAR FIELD CALCULATIONS.

  OBSERVATION ANGLES    ELECTRIC FIELD
    THETA     PHI            R-COMPONENT         THETA-COMPONENT      PHI-COMPONENT          MAGNITUDE          PHASE
   90.000   90.000              3.5213E-27            1.8255E-11          2.3236E-21          1.8255E-11         -12.7637
```

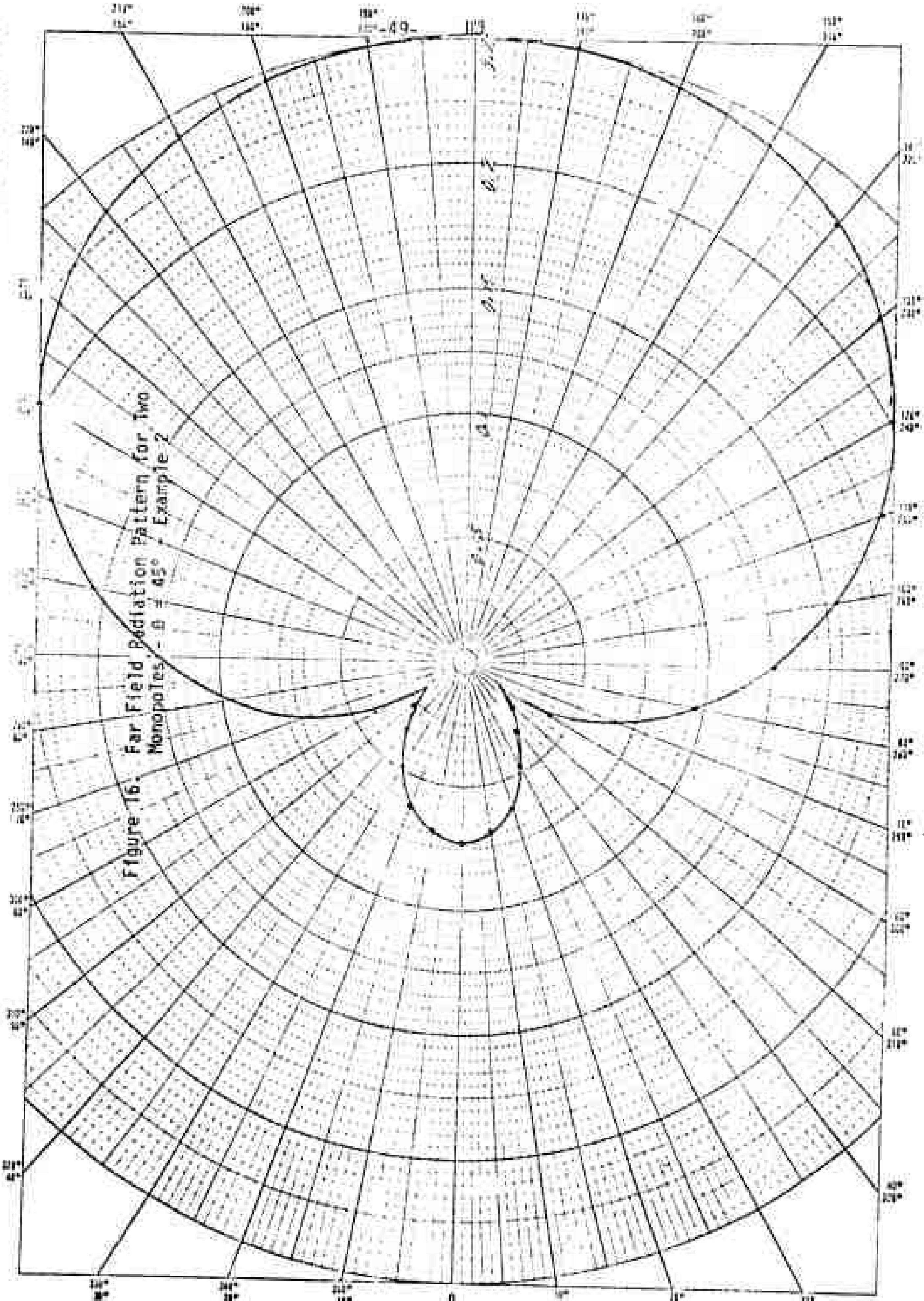

Figure 16. Far Field Radiation Pattern for Two Monopoles, θ = 45° Example 2

Example 3 - Top Loaded Monopole - As a third example we will model the antenna shown in Figure 17. This antenna, used for LORAN-C, has a high degree or rotational symmetry. It also has an element on the axis of rotational symmetry and a multiple junction of elements. We will model this antenna over a radial wire ground screen, and compute the electric field from one of the top-loaded radials to ground for a normalized input pcwer of 1 watt.

The input data deck for this antenna shown in Figure 18 is similar to those of the previous examples, however, the following points should be noted.

Card 2: We select a ground screen, near field and normalization of input power.

Card 3: The input frequency of this antenna is 100 kHz, and the ground media parameters are needed.

Card 4 —— 30 are used to describe the antenna. Note that the NCON1 value of all the top-load radials is given a value of -1000 to designate that it is a multiple junction of wires and that the NCON2 value of each top load radial is 0 since they are unconnected. A catenary model is used to specify the physical droop of the wires, and thus a wire weight of 1.586 pounds/metre and a wire tension of 1000 pounds is specified. The last element specified is the tower which is on the axis of symmetry and note that its base is grounded, so that NCON1 of the tower element is 97 and NCON2 of the tower is -1000 since it connects with the top-load radials.

Card 31: Specifies the structure symmetry. Note that 24 sectors of rotational symmetry actually exist on this structure, but since the program limits the user to 12 sectors, two top load radials are included in each of the 12 allowed sectors. Four segments are used for each radial load, and four segments are used for the tower, so NP = 8 and NX = 4. The total number of segments used equals 100, which is the limit of this version of WAMP.

Card 32: Specifies that the base segment, Number 97, of the monopole is driven, and card 33 specifies that 180 radials of #8 AWG wire are used for the ground screen.

Card 34: is the last card, and it specifies that we want to compute the near field from the ground up to the vicinity of one of the top-load radials. 41 points will be evaluated along the path between the two points, and the electric field tangent to the path will be integrated to give the potential between the two end points.

The complete data deck is shown in Figure 18 and the computed results are shown in Figure 19.

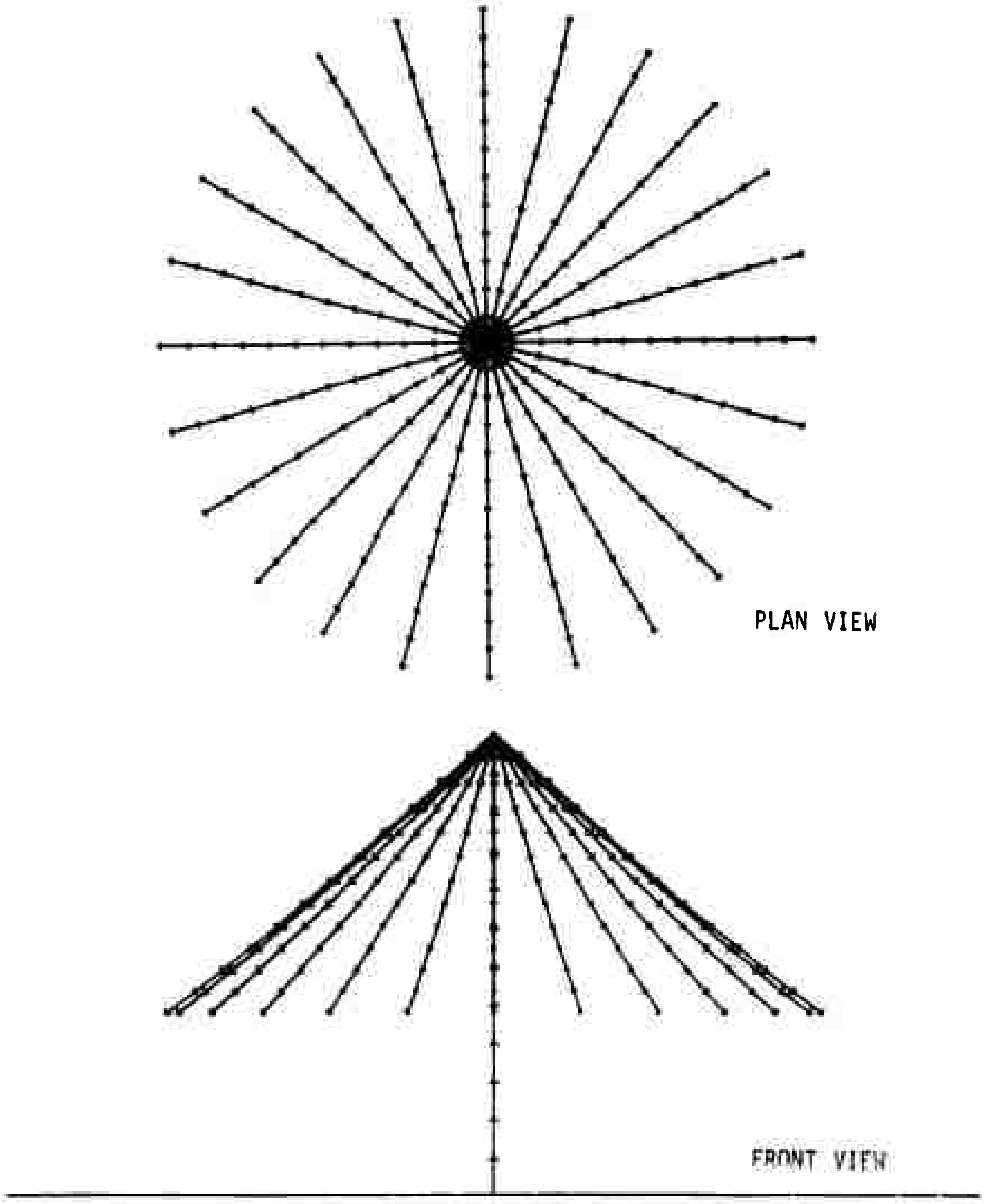

Figure 17. Computer Drawn Model of U. S. Coast Guard Top Loaded Monopole (Note: More segments are shown than actually used in example.)

```
USCG TOP LOADED MONOPOLE ANTENNA -- EXAMPLE 3
  1    0    0    1    1    0    1
 .00010         0.    1    2        15.         .01
      .0        .0 192.94   -1000 140.21            .0  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 135.43587  36.29681  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 121.42163  70.10009  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000  99.14901  99.14923  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 70.079962 121.42179  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000  36.29651 135.43595  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000   -.00031 140.21     75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -36.29711 135.43579  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -70.10036 121.42148  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -99.14945  99.14879  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000-121.42194 70.079955  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000-135.43603  36.29621  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000-140.21       -.00062  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000-135.43571 -36.29741  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000-121.42132 -70.10063  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -99.14857 -99.14967  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -70.07992 -121.4221  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 -36.29591-135.43611  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000    .00093-140.21     75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000  36.29771-135.43563  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000  70.10089-121.42117  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000  99.14989 -99.14835  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 121.42225 -70.07990  75.90       0
  4     .00914    1.586 1000.0           0.
      .0        .0 192.94   -1000 135.43619 -36.29561  75.90       0
  4     .00914    1.586 1000.0           0.
     0.         0.          0.   97         0.          0.     192.94-1000
 -4      .3048        0.         0.         0.
  8    4
 97          1.       0.    0
180     .00163
   140.3        0.          0.       140.3          0.       75.85   40    0
```

Figure 18. Data Deck for Example 3.

```
1****************************

 WIRE ANTENNA MODELING PROGRAM

 ****************************


  USCG TOP LOADED MONOPOLE ANTENNA -- EXAMPLE 3

    1     0     0     1     1     0     1

 FREQUENCY                 =  1 00000E-04
 FREQUENCY INCREMENT       =         0E+00
 NO. FREQUENCY STEPS       =    1
 WAVELENGTH  (METERS)      =  2 99793E+03


 GROUND PLANE AT Z = 0
 DIELECTRIC CONSTANT       =  1 50000E+01
 CONDUCTIVITY              =  1 00000E-02



1 DATA GENERATOR INPUT DATA CARDS


          .0          .0 192.94000-1000 140 21000           0  75.90000      0
    4      .00914     1 586001000 00000          0
           0          .0 192 94000-1000 135 43587  36 29681  75.90000      0
    4      .00914     1.586001000 00000          0
          .0           0 192 94000-1000 121.42163  70 10009  75.90000      0
    4      .00914     1 586001000 00000          0
          .0          .0 192 94000-1000  99.14901  99 14923  75.90000      0
    4      .00914     1.586001000 00000         .0
          .0           0 192 94000-1000  70 07998 121 42179  75.90000      0
    4      .00914     1.586001000.00000          0
          .0           0 192.94000-1000  36.29651 135 43595  75.90000      0
    4      .00914     1 586001000 00000          0
          .0          .0 192.94000-1000   - 00031 140 21000  75 90000      0
    4      .00914     1 586001000.00000          0
          .0          .0 192.94000-1000 -36 29711 135 43579  75 90000      0
    4      .00914     1.586001000 00000          0
          .0          .0 192 94000-1000 -70.10036 12  42148  75.90000      0
    4      .00914     1.586001000 00000          0
           0          .0 192.94000-1000 -99 14945  99 14879  75 90000      0
    4      .00914     1.586001000 00000          0
          .0          .0 192.94000-1000-121 42194  70 07996  75.90000      0
    4      .00914     1 586001000.00000          0
          .0          .0 192 94000-1000-135 43603  36 29621  75 90000      0
    4      .00914     1 586001000 00000          0
           0           0 192.94000-1000-140 21000     00062  75 90000      0
    4       00914     1.586001000 00000          0
           0          .0 192 94000-1000-135 43571  36 29741  75 90000      0
    4      .00914     1.586001000 00000          0
          .0          .0 192 94000-1000-121 42132  70 10063  75 90000      0
    4      .00914     1.586001000.00000          0
          .0           0 192 94000-1000 -99 14857 -99 14967  75 90000      0
    4       00914     1.586001000.00000          0
           0          .0 192.94000-1000 -70 07992-121 42210  75 90000      0
    4      .00914     1.586001000 00000          0
          .0           0 192.94000-1000 -36 29591-135 43611  75 90000      0
    4      .00914     1.586001000 00000          0
          .0           0 192 94000-1000      00093-140 21000  75 90000      0
    4      .00914     1.586001000 00000          0
          .0           0 192.94000-1000  36 29771-135 43563  75 90000      0
    4       00914     1.586001000 00000          0
           0           0 192.94000-1000  70 10089-121 42117  75 90000      0
    4       00914     1.586001000 00000          0
          .0          .0 192.94000-1000  99 14989 -99 14835  75 90000      0
    4      .00914     1.586001000 00000          0
          .0          .0 192 94000-1000 121 42225 -70 07990  75 90000      0
    4      .00914     1.586001000 00000          0
          .0          .0 192.94000-1000 135 43619 -36 29561  75.90000      0
    4      .00914     1 586001000 00000          0
          .0          .0         0   97          0           0 192 94000-1000
   -4      .30480          0         0           0


NUMBER OF SEGMENTS    = 100
NO. SEG. IN A SECTOR =   8
NO. SEG. ON AXIS OF ROTATION =     4
```

```
1 STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

 COORDINATES OF SEG. CENTER     SEG.      WIRE      ORIENTATION ANGLES   CONNECTION DATA
     X          Y          Z    LENGTH    RADIUS      ALPHA       BETA    I-      I    I+
   .00585       .0      .05899   .01587 .00000305   -42.556          0-1000     1     2
    01754       .0      .04858   .01544 .00000305   -40.779          0    1     2     3
   .02923       .0      .03882   .01502 .00000305   -38 902         .0    2     3     4
   .04092       .0      .02971   .01462 .00000305   -36.920         .0    3     4     0
   .00565     .00151    .05899   .01587  00000305   -42.555    15.003-1000     5     6
   .01694     .00454    .04858   .01544 .00000305   -40.778    15.003    5     6     7
   .02824     .00757    .03882   .01502 .00000305   -38.901    15.003    6     7     8
   .03953     .01058    .02971   .01463 .00000305   -36 918    15.003    7     8     0
   .00506     .00292    .05899   .01587  00000305   -42.557    29.999-1000     9    10
    01519     .00877    .04858   .01544 .00000305   -40.780    29.999    9    10    11
   .02531     .01461    .03882   .01502 .00000305   -38.903    29.999   10    11    12
   .03544     .02046     02971    01462 .00000305   -36 921    29.999   11    12     0
   .00413     .00413    .05899   .01587 .00000305   -42.555    45.000-1000    13    14
   .01240     .01240    .04858   .01544 .00000305   -40.778    45.000   13    14    15
   .02067     .02067    .03882   .01502 .00000305   -38.900    45.000   14    15    16
   .02894     .02894    .02971   .01463 .00000305   -36.918    45.000   15    16     0
   .00292     .00506    .05899   .01587  00000305   -42.559    60.008-1000    17    18
   .00877     .01519    .04858   .01544 .00000305   -40.782    60.008   17    18    19
    01461     .02531    .03882   .01502 .00000305   -38.905    60 008   18    19    20
   .02045     .03544    .02971    01462 .00000305   -36.923    60.008   19    20     0
   .00151     .00565    .05899   .01587 .00000305   -42 555    74.997-1000    21    22
   .00454     .01694    .04858    01544 .00000305   -40 778    74.997   21    22    23
   .00757     .02824    .03882   .01502 .00000305   -38.901    74.997   22    23    24
   .01058     .03953    .02971   .01463 .00000305   -36.918    74.997   23    24     0
  -.00000     .00585    .05899   .01587 .00000305   -42.556    90.000-1000    25    26
  -.00000     .01754     04858    01544 .00000305   -40 779    90.000   25    26    27
  -.00000     .02923    .03882   .01502 .00000305   -38.902    90.000   26    27    28
  -.00000     .04092    .02971   .01462 .00000305   -36.920    90.000   27    28     0
  -.00151     .00565    .05899   .01587  00000305   -42.555   105.003-1000    29    30
  -.00454     .01694    .04858   .01544 .00000305   -40.778   105.003   29    30    31
  -.00757     .02824    .03882   .01502 .00000305   -38.901   105.003   30    31    32
  -.01059     .03953    .02971   .01463 .00000305   -36 918   105 003   31    32     0
  -.00292     .00506    .05899    01587  00000305   -42.557   119.999-1000    33    34
  -.00877     .01519    .04858   .01544 .00000305   -40.780   119.999   33    34    35
  -.01461     .02531    .03882    01502 .00000305   -38.903   119.999   34    35    36
  -.02046     .03544    .02971   .01462  00000305   -36.921   119.999   35    36     0
  -.00413     .00413    .05899   .01587 .00000305   -42.555   135.000-1000    37    38
  -.01240     .01240    .04858   .01544 .00000305   -40.778   135.000   37    38    39
  -.02067     .02067    .03882   .01502 .00000305   -38.900   135.000   38    39    40
  -.02894      02894    .02971   .01463 .00000305   -36.918   135.000   39    40     0
  -.00506     .00292    .05899   .01587 .00000305   -42.559   150.008-1000    41    42
  -.01519     .00877    .04858   .01544 .00000305   -40.782   150.008   41    42    43
  -.02531     .01461    .03882   .01502 .00000305   -38.905   150.008   42    43    44
  -.03544     .02045    .02971   .01462 .00000305   -36.923   150.008   43    44     0
  -.00565     .00151    .05899   .01587 .00000305   -42.555   164.998-1000    45    46
```

```
1 STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

 COORDINATES OF SEG. CENTER        SEG.      WIRE     ORIENTATION ANGLES    CONNECTION DATA
      X          Y          Z        LENGTH    RADIUS      ALPHA       BETA      I-      I     I+
  -.01694     .00454     .04858     .01544   00000305   -40.778    164 998     45     46     47
  -.02824      00757      03882     .01502   00000305   -38 901    164.998     46     47     48
  -.03953      01059      02971     .01463   00000305   -36 918    164.998     47     48      0
  -.00585    -.00000      05899      01587   00000305   -42 556   -180 000-1000     49     50
  -.01754    -.00000      04858      01544   00000305    40 779   -180 000     49     50     51
  -.02923    - 00000     .03882      01502   00000305   -38 902   -180 000     50     51     52
  -.04092    - 00000     .02971      01462   00000305    36 920    180 000     51     52      0
  -.00565    -.00151      05899      01587   00000305   -42.555    164 997-1000     53     54
  -.01694    - 00454      04858      01544   00000305    40 778    164 997     53     54     55
  -.02824    -.00757      03882      01502   00000305    38 901    164 997     54     55     56
  -.03953    -.01059      02971      01463   00000305    36 918    164 997     55     56      0
  -.00506    -.00292      05899      01587   00000305    42 557    150 001-1000     57     58
  -.01519    - 00877      04858      01544   00000305    40 780    150 001     57     58     59
  -.02531    - 01461      03882      01502   00000305    38 903    150 001     58     59     60
  -.03544    - 02046      02971      01462   00000305    36 921    150 001     59     60      0
  - 00413    -.00413      05899      01587   00000305    42 555    135 000 1000     61     62
  -.01240    - 01240      04858      01544   00000305    40 778   -135 000     61     62     63
  -.02067    - 02067      03882      01502   00000305    38 900   -135.000     62     63     64
  -.02894    - 02894      02971      01463   00000305    36 918    135 000     63     64      0
  -.00292    -.00506      05899      01587   00000305   -42 559    119.992-1000     65     66
  -.00877    -.01519      04858      01544   00000305    40 782   -119 992     65     66     67
  -.01461    - 02531     .03882      01502   00000305    38 905   -119 992     66     67     68
  -.02045    -.03544     .02971      01462   00000305    36 923   -119 992     67     68      0
  - 00151    -.00565      05899      01587   00000305   -42 555    105.002-1000     69     70
  -.00454    -.01694      04858      01544   00000305    40 778   -105 002     69     70     71
  -.00757    -.02824      03882      01502   00000305    38 901   -105.002     70     71     72
  -.01059    -.03953      02971      01463  .00000305   -36 918   -105 002     71     72      0
   .00000    -.00585      05899      01587   00000305   -42 556    -90.000-1000     73     74
   .00000    -.01754     .04858      01544   00000305   -40 779    -90 000     73     74     75
   .00000    -.02923     .03882      01502   00000305   -38 902    -90 000     74     75     76
   .00000    -.04092      02971      01462   00000305   -36 920    -90 000     75     76      0
   .00151    -.00565      05899      01587   00000305   -42 555    -74.997-1000     77     78
   .00454    -.01694     .04858     .01544   00000305    40 778    -74.997     77     78     79
   .00757    -.02824     .03882      01502  .00000305   -38 901    -74 997     78     79     80
   .01059    - 03953     .02971      01463   00000305   -36 918    -74 997     79     80      0
   .00292    -.00506     .05899      01587   00000305    42 557     60 001 1000     81     82
   .00877    -.01519      04858      01544   00000305   -40 780    -60 001     81     82     83
   .01461    -.02531     .03882      01502   00000305   -38 903    -60.001     82     83     84
    02046    -.03544      02971      01462   00000305   -36 921    -60 001     83     84      0
   .00413    -.00413      05899      01587   00000305   -42 555    -45 000-1000     85     86
   .01240    -.01240      04858      01544   00000305   -40 778    -45 000     85     86     87
   .02067    - 02067     .03882      01502   00000305   -38 900    -45 000     86     87     88
   .02894    -.02894     .02971      01463   00000305   -36 918    -45.000     87     88      0
   .00506    -.00292     .05899      01587   00000305   -42 559    -29 992-1000     89     90
   .01519    -.00877     .04858      01544   00000305   -40 782    -29 992     89     90     91
```

```
1 STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)

 COORDINATES OF SEG. CENTER     SEG.      WIRE    ORIENTATION ANGLES   CONNECTION DATA
     X          Y         Z     LENGTH    RADIUS     ALPHA       BETA    I-     I    I+
   .02531   -.01461    .03882   .01502 .00000305   -38.905    -29.982   90    91   92
   .03544   -.02045    .02971   .01462 .00000305   -36.923    -29.982   91    92    0
   .00585   -.00151    .05099   .01587 .00000305   -42.555    -15.002-1000    93   94
   .01694   -.00454    .04858   .01544 .00000305   -40.778    -15.002   93    94   95
   .02824   -.00757    .03882   .01502 .00000305   -38.901    -15.002   94    95   96
   .03853   -.01059    .02971   .01463 .00000305   -36.918    -15.002   95    96    0
  -.00000        .0    .00804   .01609 .00010167    90.000         .0   97    97   98
  -.00000        .0    .02413   .01609 .00010167    90.000         .0   97    98   99
  -.00000        .0    .04022    01609 .00010167    90.000         .0   98    99  100
  -.00000        .0    .05631   .01609 .00010167    90.000         .0   99   100-1000

 TOTAL WIRE LENGTH    = 1.52746229115E+00

 ANTENNA SOURCE DISTRIBUTIONS
   SEG.         VOLTAGE
   NO.     MAG.         PHASE
   97    1.00000          .0    0


 A RADIAL GROUND SCREEN OF   180 RADIALS WITH A WIRE RADIUS OF   5.4371E-07 WAVELENGTH WAS USED.
```

```
1 SEGMENT EXCITATION (VOLTS/WAVELENGTH)
 SEG NUMBER   REAL PART   IMAGINARY PART

    97      -6.215E+01       -.0E+00
```

```
ISEG.   CURRENT-
NO.     REAL         IMAGINARY    MAGNITUDE        PHASE
  1     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
  2     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
  3     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
  4     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
  5     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
  6     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
  7     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
  8     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
  9     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 10     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 11     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 12     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 13     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 14     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 15     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 16     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 17     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 18     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 19     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 20     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 21     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 22     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 23     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 24     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 25     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 26     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 27     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 28     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 29     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 30     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 31     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 32     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 33     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 34     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 35     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 36     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 37     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 38     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 39     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 40     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 41     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 42     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 43     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 44     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 45     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
```

```
SEG     CURRENT -
 NO.     REAL         IMAGINARY    MAGNITUDE        PHASE
 51     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 52     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 53     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 54     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 55     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 56     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 57     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 58     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 59     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 60     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 61     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 62     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 63     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 64     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 65     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 66     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 67     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 68     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 69     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 70     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 71     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 72     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 73     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 74     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 75     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 76     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 77     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 78     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 79     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 80     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 81     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 82     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 83     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 84     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 85     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 86     6.3467E-04   2.9568 -03   3.02412874E-03   77.885
 87     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 88     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 89     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 90     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 91     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
 92     1.7951E-04   8.5059E-04   8.69322332E-04   78.083
 93     7.6233E-04   3.5174E-03   3.59909304E-03   77.772
 94     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 95     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
```

```
ISEG    CURRENT-
NO.     REAL         IMAGINARY    MAGNITUDE        PHASE
 46     6.3467E-04   2.9568E-03   3.02412874E-03   77.885
 47     4.4518E-04   2.0932E-03   2.14003639E-03   77.993
 48     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 49     7.6227E-04   3.5172E-03   3.59882600E-03   77.772
 50     6.3462E-04   2.9566E-03   3.02391799E-03   77.885
 51     4.4515E-04   2.0931E-03   2.13989524E-03   77.993
```

```
SEG     CURRENT -
 NO.     REAL         IMAGINARY    MAGNITUDE        PHASE
 96     1.7953E-04   8.5064E-04   8.69382102E-04   78.083
 97     1.8351E-02   8.4925E-02   8.68847318E-02   77.806
 98     1.8364E-02   8.4784E-02   8.67496522E-02   77.779
 99     1.8393E-02   8.4832E-02   8.68025469E-02   77.767
100     1.8422E-02   8.4954E-02   8.69280175E-02   77.765
```

```
   ADMIT=   1.8351E-02   8.4925E-02          ZPED=   2.4310E+00  -1.1250E+01
     8.6885E-02        77.806                 1.1510E+01       -77.806
```

```
I  I      AR          AI           BR          BI           CR          CI
   1   5.2288E-04  4.6061E-04  -1.2878E-03 -5.5573E-03  2.3939E-04  3.0566E-03
   2  -6.3994E-03 -3.1312E-02  -1.6459E-03 -7.3947E-03  7.0340E-03  3.4268E-02
   3  -8.7956E-03 -4.3852E-02  -2.4253E-03 -1.1227E-02  9.2407E-03  4.5745E-02
   4  -1.4947E-02 -7.3319E-02  -3.5609E-03 -1.6815E-02  1.5126E-02  7.4169E-02
   5   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03  2.4052E-04  3.0614E-03
   6  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03  7.0340E-03  3.4269E-02
   7  -8.7955E-03 -4.3851E-02  -2.4254E-03 -1.1227E-02  9.2406E-03  4.5744E-02
   8  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4172E-02
   9   5.2270E-04  4.5978E-04  -1.2878E-03 -5.5574E-03  2.3957E-04  3.0574E-03
  10  -6.3997E-03 -3.1313E-02  -1.6459E-03 -7.3949E-03  7.0343E-03  3.4270E-02
  11  -8.7960E-03 -4.3854E-02  -2.4253E-03 -1.1227E-02  9.2411E-03  4.5747E-02
  12  -1.4948E-02 -7.3322E-02  -3.5610E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  13   5.2188E-04  4.5640E-04  -1.2879E-03 -5.5575E-03  2.4043E-04  3.0610E-03
  14  -6.3992E-03 -3.1311E-02  -1.6460E-03 -7.3951E-03  7.0339E-03  3.4268E-02
  15  -8.7953E-03 -4.3850E-02  -2.4254E-03 -1.1227E-02  9.2404E-03  4.5743E-02
  16  -1.4947E-02 -7.3320E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4170E-02
  17   5.2240E-04  4.5834E-04  -1.2879E-03 -5.5576E-03  2.3987E-04  3.0588E-03
  18  -6.4003E-03 -3.1318E-02  -1.6460E-03 -7.3952E-03  7.0349E-03  3.4273E-02
  19  -8.7967E-03 -4.3857E-02  -2.4254E-03 -1.1227E-02  9.2418E-03  4.5750E-02
  20  -1.4949E-02 -7.3328E-02  -3.5612E-03 -1.6816E-02  1.5128E-02  7.4178E-02
  21   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03  2.4052E-04  3.0614E-03
  22  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03  7.0340E-03  3.4269E-02
  23  -8.7955E-03 -4.3851E-02  -2.4254E-03 -1.1227E-02  9.2406E-03  4.5744E-02
  24  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  25   5.2288E-04  4.6061E-04  -1.2878E-03 -5.5573E-03  2.3939E-04  3.0566E-03
  26  -6.3994E-03 -3.1312E-02  -1.6459E-03 -7.3947E-03  7.0340E-03  3.4268E-02
  27  -8.7956E-03 -4.3852E-02  -2.4253E-03 -1.1227E-02  9.2407E-03  4.5745E-02
  28  -1.4947E-02 -7.3319E-02  -3.5609E-03 -1.6815E-02  1.5126E-02  7.4169E-02
  29   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03  2.4052E-04  3.0614E-03
  30  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03  7.0340E-03  3.4269E-02
  31  -8.7955E-03 -4.3851E-02  -2.4254E-03 -1.1227E-02  9.2406E-03  4.5744E-02
  32  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  33   5.2270E-04  4.5978E-04  -1.2878E-03 -5.5574E-03  2.3957E-04  3.0574E-03
  34  -6.3997E-03 -3.1313E-02  -1.6459E-03 -7.3949E-03  7.0343E-03  3.4270E-02
  35  -8.7960E-03 -4.3854E-02  -2.4253E-03 -1.1227E-02  9.2411E-03  4.5747E-02
  36  -1.4948E-02 -7.3322E-02  -3.5610E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  37   5.2188E-04  4.5640E-04  -1.2879E-03 -5.5575E-03  2.4043E-04  3.0610E-03
  38  -6.3992E-03 -3.1311E-02  -1.6460E-03 -7.3951E-03  7.0339E-03  3.4268E-02
  39  -8.7953E-03 -4.3850E-02  -2.4254E-03 -1.1227E-02  9.2404E-03  4.5743E-02
  40  -1.4947E-02 -7.3320E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4170E-02
  41   5.2240E-04  4.5836E-04  -1.2879E-03 -5.5576E-03  2.3987E-04  3.0588E-03
  42  -6.4003E-03 -3.1318E-02  -1.6460E-03 -7.3952E-03  7.0349E-03  3.4273E-02
  43  -8.7967E-03 -4.3857E-02  -2.4254E-03 -1.1227E-02  9.2418E-03  4.5750E-02
  44  -1.4949E-02 -7.3328E-02  -3.5612E-03 -1.6816E-02  1.5128E-02  7.4178E-02
  45   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03  2.4052E-04  3.0614E-03
  46  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03  7.0340E-03  3.4269E-02
  47  -8.7955E-03 -4.3851E-02  -2.4254E-03 -1.1227E-02  9.2406E-03  4.5744E-02
  48  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  49   5.2288E-04  4.6061E-04  -1.2878E-03 -5.5573E-03  2.3939E-04  3.0566E-03
  50  -6.3994E-03 -3.1312E-02  -1.6459E-03 -7.3947E-03  7.0340E-03  3.4268E-02
  51  -8.7956E-03 -4.3852E-02  -2.4253E-03 -1.1227E-02  9.2407E-03  4.5745E-02
  52  -1.4947E-02 -7.3319E-02  -3.5609E-03 -1.6815E-02  1.5126E-02  7.4169E-02
  53   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03  2.4052E-04  3.0614E-03
  54  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03  7.0340E-03  3.4269E-02
  55  -8.7955E-03 -4.3851E-02  -2.4254E-03 -1.1227E-02  9.2406E-03  4.5744E-02
  56  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  57   5.2270E-04  4.5978E-04  -1.2878E-03 -5.5574E-03  2.3957E-04  3.0574E-03
  58  -6.3997E-03 -3.1313E-02  -1.6459E-03 -7.3949E-03  7.0343E-03  3.4270E-02
  59  -8.7960E-03 -4.3854E-02  -2.4253E-03 -1.1227E-02  9.2411E-03  4.5747E-02
  60  -1.4948E-02 -7.3322E-02  -3.5610E-03 -1.6816E-02  1.5127E-02  7.4172E-02
  61   5.2188E-04  4.5640E-04  -1.2879E-03 -5.5575E-03  2.4043E-04  3.0610E-03
  62  -6.3992E-03 -3.1311E-02  -1.6460E-03 -7.3951E-03  7.0339E-03  3.4268E-02
  63  -8.7953E-03 -4.3850E-02  -2.4254E-03 -1.1227E-02  9.2404E-03  4.5743E-02
```

```
 64  -1.4947E-02 -7.3320E-02  -3.5611E-03 -1.6816E-02   1.5127E-02  7.4170E-02
 65   5.2241E-04  4.5838E-04  -1.2879E-C3 -5.5576E-03   2.3986E-04  3.0588E-03
 66  -6 4003E-03 -3.1316E-02  -1.6460E-03 -7.3952E-03   7 0349E-03  3 4273E-02
 67  -8.7967E-03 -4.3657E-02  -2.4254E-03 -1.1227E-02   9.2418E-03  4.5750E-02
 68  -1.4949E-02 -7.3327E-02  -3.5612E-03 -1.6816E-02   1.5128E-02  7.4178E-02
 69   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03   2.4052E-04  3.0614E-03
 70  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03   7.0340E-03  3.4268E-02
 71  -8.7955E-03 -4.3651E-02  -2.4254E-03 -1.1227E-02   9.2406E-03  4.5744E-02
 72  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1 6816E-02   1.5127E-02  7.4172E-02
 73   5.2288E-04  4.6061E-04  -1.2878E-03 -5.5573E-03   2.3939E-04  3.0566E-03
 74  -6.3994E-03 -3.1312E-02  -1.6459E-03 -7.3947E-03   7.0340E-03  3.4268E-02
 75  -8.7956E-03 -4.3652E-02  -2 4253E-03 -1.1227E-02   9.2407E-03  4.5745E-02
 76  -1.4947E-02 -7.3319E-02  -3.5609E-03 -1 6815E-02   1.5126E-02  7.4169E-02
 77   5.2181E-04  4.5601E-04  -1.2879E-03 -5.5575E-03   2.4052E-04  3 0614E-03
 78  -6.3994E-03 -3.1312E-02  -1.6460E-03 -7.3952E-03   7.0340E-03  3.4269E-02
 79  -8.7955E-03 -4.3651E-02  -2.4254E-03 -1.1227E-02   9.2406E-03  4.5744E-02
 80  -1.4948E-02 -7.3321E-02  -3.5611E-03 -1.6816E-02   1.5127E-02  7.4172E-02
 81   5.2270E-04  4 5978E-04  -1.2878E-03 -5.5574E-03   2.3957E-04  3 0574E-03
 82  -6.3997E-0_ -3.1313E-02  -1.6459E-03 -7.3949E-03   7.0343E-03  3.4270E-02
 83  -8.7960E-03 -4.3654E-02  -2.4253E-03 -1.1227E-02   9.2411E-03  4.5747E-02
 84  -1.4948E-02 -7.3322E-02  -3.5610E-03 -1.6816E-02   1.5127E-02  7.4172E-02
 85   5.2189E-04  4.5840E-04  -1.2879E-03 -5.5575E-03   2.4043E-04  3.0610E-03
 86  -6.3992E-03 -3.1311E-02  -1.6460E-03 -7 3951E-03   7.0339E-03  3 4268E-02
 87  -8.7953E-03 -4.3650E-02  -2.4254E-03 -1.1227E-02   9.2404E-03  4 5743E-02
 88  -1.4947E-02 -7.3320E-02  -3.5611E-03 -1.6816E-02   1 5127E-02  7.4170E-02
 89   5.2241E-04  4.5840E-04  -1.2879E-03 -5.5576E-03   2.3986E-04  3.0588E-03
 90  -6.4003E-03 -3.1316E-02  -1.6460E-03 -7.3952E-03   7 0349E-03  3 4273E-02
 91  -8.7967E-03 -4.3657E-02  -2.4254E-03 -1.1227E-02   9.2418E-03  4 5750E-02
 92  -1.4949E-02 -7.3327E-02  -3.5612E-03 -1.6816E-02   1 5128E-02  7 4178E-02
 93   5.2181E-04  4.5601E-04  -1.2879E-03 -5 5575E-03   2.4052E-04  3 0614E-03
 94  -6.3994E-03 -3 1312E-02  -1.6460E-03 -7 3952E-03   7.0340E-03  3.4269E-02
 95  -8.7955E-03 -4.3651E-02  -2.4254E-03 -1.1227E-02   9.2406E-03  4.5744E-02
 96  -1.4948E-02 -7 3321E-02  -3.5611E-03 -1.6816E-02   1.5127E-02  7 4172E-02
 97   1.9552E-02  7.1130E-02   6.0744E-05 -6.9786E-04  -1.2007E-03  1.3795E-02
 98   2.0033E-02  1.0326E-01   2.0595E-04 -4.6118E-04  -1 6696E-03 -1.8473E-02
 99   1.8392E-02  9.2104E-02   2.9034E-04  8.4128E-04   1.3485E-06 -7 2728E-03
100   2.9727E-03  1.9711E-02  -4.9131E-04 -2.0914E-03   1.5449E-02  6.5243E-02




1 * * * * * * * * * * * * * * * * * * * *

    VOLTAGE TO DRIVE ANTENNA AT 1-WATT =      10.43954

      ALL FIELDS ARE NORMALIZED TO THIS INPUT POWER

  * * * * * * * * * * * * * * * * * * * *
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1  E-FIELD FROM   140.3000          .0          .0 METERS TO   140.3000          .0   75.8500 METERS

 POSITION ON PATH (METERS)      E-TANGENT (V/M)      TOTAL E-FIELD (V/M)

                .0E+00          5.17051E-01         5.20094E-01
          1.89625E+00          5.20804E-01         5.23061E-01
          3.79250E+00          5.24430E-01         5.26118E-01
          5.68875E+00          5.27996E-01         5.29327E-01
          7.58500E+00          5.31554E-01         5.32740E-01
          9.48125E+00          5.35146E-01         5.36400E-01
          1.13775E+01          5.38810E-01         5.40344E-01
          1.32737E+01          5.42576E-01         5.44606E-01
          1.51700E+01          5.46474E-01         5.49214E-01
          1.70662E+01          5.50528E-01         5.54200E-01
          1.89625E+01          5.54765E-01         5.59591E-01
          2.08587E+01          5.59209E-01         5.65418E-01
          2.27550E 01          5.63884E-01         5 71710E-01
          2.46512E+01          5.68817E-01         5.78500E 01
          2.65475E+01          5.74035E-01         5.85824E-01
          2.84437E+01          5.79568E-01         5.93721E-01
          3.03400E+01          5.85449E-01         6.02234E-01
          3.22362E+01          5.91715E-01         6.11413E-01
          3.41325E+01          5.98411E-01         6.21318E-01
          3.60287E+01          6.05586E-01         6.32014E-01
          3.79250E+01          6.13302E-01         6.43583E-01
          3.98212E+01          6.21634E-01         6 56124E-01
          4.17175E+01          6.30674E-01         6.69753E-01
          4.36137E+01          6.40538E-01         6.84621E-01
          4.55100E+01          6.51377E-01         7.00915E-01
          4.74062E+01          6.63388E-01         7.18876E-01
          4.93025E+01          6.76832E-01         7.38820E-01
          5.11987E+01          6.92068E-01         7.61171E-01
          5.30950E+01          7.09592E-01         7.86505E-01
          5.49912E+01          7.30105E-01         8.15627E-01
          5.68875E+01          7.54607E-01         8.49663E-01
          5.87837E+01          7.84644E-01         8.90360E-01
          6.06800E+01          8.22537E-01         9.40301E-01
          6.25762E+01          8.72026E-01         1.00364E+00
          6.44725E+01          9 39431E-01         1.08740E+00
          6.63687E+01          1.03620E+00         1.20430E+00
          6.82650E+01          1.18535E+00         1.38004E+00
          7.01612E+01          1.44027E+00         1.67458E+00
          7.20575E+01          1.95912E+00         2.26672E+00
          7.39537E+01          3.50338E+00         4.02825E+00
          7.58500E+01          3.44369E+01         6.31509E+01

THE INTEGRAL OF THE E-FLD TANGENT TO THE PATH IS      9.10214E+01 VOLTS.   41 POINTS USED TO EVALUATE INTEGRAL.
```

VI. MODELING GUIDELINES AND SPECIAL CALCULATIONS

Experience with the WAMP antenna modeling program has proven the old adage that "Garbage in equals garbage out" is applicable. If care in setting up the numerical model is not taken, completely erroneously results may be realized. In this section, I will try to cover a few important modeling rules which can help to achieve good numerical results. It is always important to carefully question numerical results for reasonability, and if possible, compare with experimental data.

Segmentation - Often the key to a good numerical model lies in the segmentation of the physical structure. Miller, et al. (1971) established some fundamental segmentation guidelines for a variety of structures. Typically, at least six segments per wavelength must be used for reasonable accuracy. At the other extreme, one must not over segment a structure such that "pancake" segments are formed --- this violates the thin-wire approximations.

Multiple junctions and segment length discontinuities, particularly in regions near sources, can lead to troubles. A good rule of thumb is to make all segments at a multiple wire junction of equal length. (Often times this is difficult to achieve when a limited number of segments are available due to computer core-size limitations and execution times.)

The data generator in the WAMP code has a provision for modeling elements with variable length segments. The factor TAU, read in by the DATAGN allows for an exponential increase or decrease in segment length on an element. For an element of N segments, the segment lengths vary by the relation (30):

$$L_i = L_0(1 + \tau)^{(i-1)} \qquad (30)$$

If we know the initial length we need, L_0, the total length of the element, L, and the number of segments available to model the element, N, Table I of Appendix B can be used to find the proper value of TAU.

Miller and Deadrick (1973) have studied in greater detail the consequences of segment length discontinuities and the possible remedies available to achieve good numerical impedance data. These techniques, i.e. accurate near field integrations, however, are expensive in terms of computer times, and should be avoided whenever possible.

Near Field Anomalies - the near electric field subroutine in the WAMP code has been thoroughly checked and found to give good, consistent, numerical results. If one evaluates the near field at the surface of the wire segements, however, large field perturbations may be found near segment ends. These field perturbations are due to segment current discontinuities at segment junctions; a result of the current interpolation method used WAMP. Care should be exercised in interpreting near field results in these regions, particularly if you are trying to evaluate the voltage across a gap region used to model an insulator.

Horizontal Elements Near the Interface - The reflection coefficient approach used to model structures in the vicinity of an imperfectly conducting halfspace has been found (Miller, et al. (1972)) to give stable numerical results for horizontal structures whose height above the interface is greater than 0.1 wavelength. Below this height, the results may become invalid to the point of producing negative input impedances. Long horizontal elements of several wavelengths near the interface can exhibit growing currents. One approximation which has proven to "cure" some of the above limitations has been to fix the angle of incidence of the reflected wave to $\pi/2$. This may be accomplished by setting the variable CTH = 1.0 in the subroutine CMSETUP.

Radial Wire Ground Screen Model - The model used to simulate a radial wire ground screen is relatively simple in form in this program. (A radially varying screen impedance is modeled in parallel with the normal ground plane wave impedance.) The results with this model are quite good, except for vertical structures located at the center of the radial system. In this case the screen appears to the program as a perfect ground, and other techniques, i.e., application of the compensation theorem, (Maley, et al, 1963) must be employed.

Special Calculations - The WAMP code may be used to compute many antenna parameters which often times are difficult to experimentally measure. Listed below are some of the procedures required to compute some of these special quantities.

Bandwidth-Efficiency - The bandwidth efficiency product is of interest to the designers of pulsed Loran systems. Equation (31) defines this parameter

$$\eta_{BW} = \frac{2R_r}{\frac{dx}{df} + \frac{|x|}{f}} \qquad (31)$$

where R_r is the antenna radiation resistance and X and $\frac{dx}{df}$ are the reactance and rate of change of reactance at a frequency f. A calculation of this quantity is easily performed by determining the input resistance and reactance for the antenna over a perfect ground (no losses in ground), and then computing the input reactance for two different frequencies to compute $\Delta X/\Delta f$.

Insulator Modeling - Often times it is necessary to access the potential across support insulators to estimate breakdown problems. Several ways have been found to model insulators. One can impedance load a segment with a very high value of resistance, solve for the segment current and compute an IR drop across the segment. Another technique is to model the insulator as a physical gap and use the near field routine to integrate the fields across the gap. This technique has been found to give somewhat high results, while if you take the E-field at the center of the gap and multiply it by the gap length, you can get a lower bound estimate. These techniques allow an estimation of the insulator voltage drops. One can either reference the drops to a 1 volt input, or normalize the antenna power to 1 watt. See Miller and Deadrick (1973) for more details on insulator modeling.

Corona Discharge Assessment - By using the near-field subroutine to follow a path along the surface of the antenna wire, one may examine the potential for corona discharge. The coordinates of the field evaluation path should be displaced a wire radius away, and sufficient points should be evaluated to resolve the segment end near field discontinuities mentioned above. Again, the fields may be referenced to a 1 volt input source or normalized to a 1 watt input.

Catenary Model - A special feature of the DATAGN subroutine in this program is the inclusion of a catenary model to account for the drop in long length wires used in some of the large LORAN antennas. The catenary curve is modeled by a series of straight line segments which approximate the catenary curve of the form shown in Figure 20.

Number of Segments Limitation

This version of WAMP is designed to operate specifically on the CDC 3300 hardware configuration for the U. S. Coast Guard headquarters in Washington, D. C., and as such, limits have been placed on the number of segments which may be used to model an antenna structure. A total of 100 segments may be used, and in one sector of symmetry, only 22 segments may be used. This means that if no structure symmetry is employed, only 22 segments are allowed. The number of segments in one sector of symmetry plus the number of segments on the axis of symmetry must be less than or equal to 22. The program allows up to 12 sectors of rotational symmetry maximum. To illustrate this point, see example 3.

In order to adapt this program to larger machines, one must increase the size of the arrays and also check to see that the error checking limits in the MAIN program are modified accordingly. The structure array; CM (N,N) is a complex element array, and as such uses two floating point variables for each entry. It is the primary user of core in this program. The EINC array and the P array of common block /2/ are the excitation vector to the system, and an array of pivotals respectively used by the factor and solve routines.

EQUATION OF CATENARY:

$$Z=Z_2 - (X_2-X)[W/2T\ (X-X_1) + (Z_2-Z_1)/(X_2-X_1)]$$

W=WIRE WEIGHT/M
T=WIRE TENSION

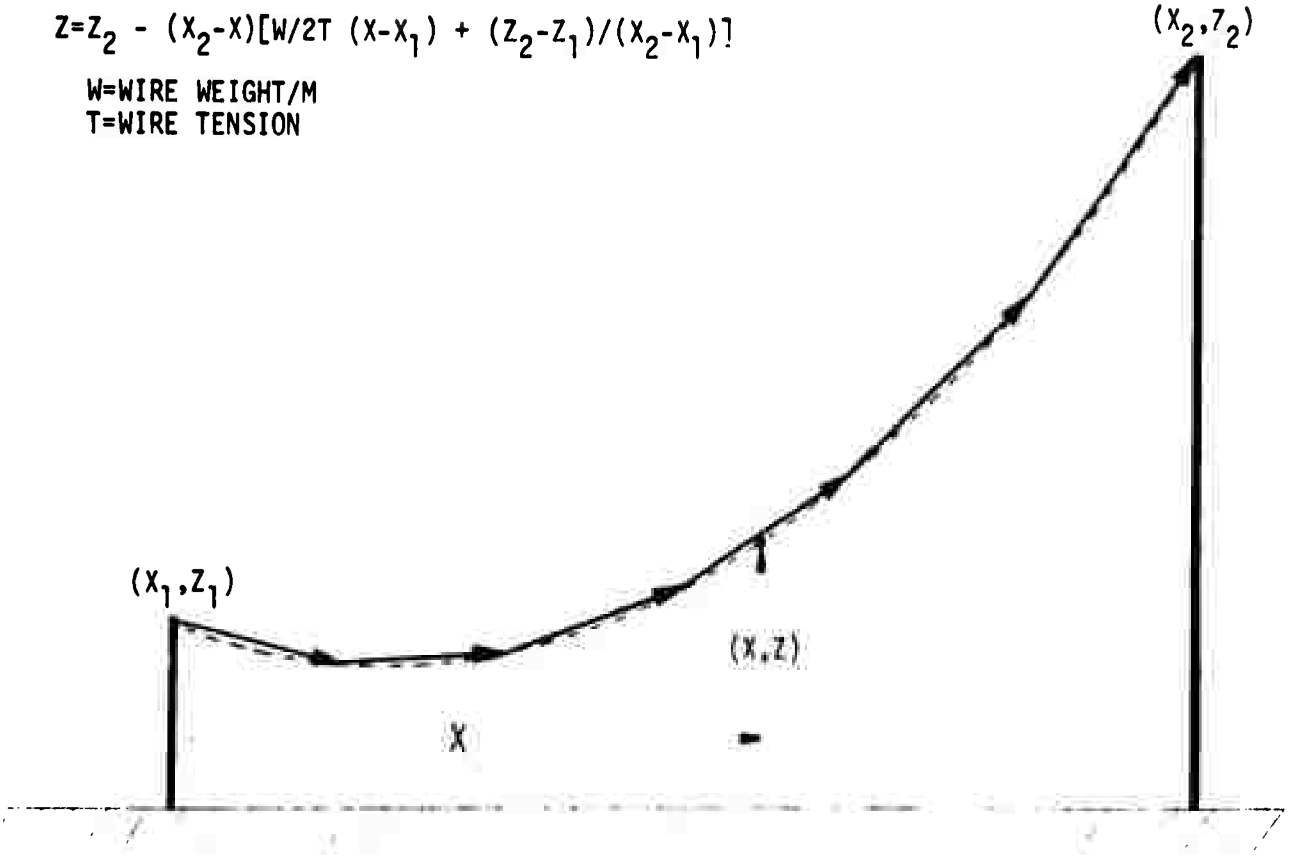

Figure 20. Catenary Element Modeled by Subroutine DATAGN.

Common block /1/ contains the physical description of the structure in terms of wavelength dimensions and direction angles, plus the electrical interconnection data.

Common block /3/ contains the direction cosines for each of the N segments.

Common block /4/ is used to hold data on multiple junctions set up by subroutine TRIO and JUNC. Presently, the program limits multiple junctions to 25 segments at a point, however, this is easily expanded.

Common block /SCRATM/ is used as a temporary scratch location by the factor and solve routines, and should be set by the size of the CM matrix.

Common block /SMAT/ is a square scratch matrix used by the symmetric factor and solve routines. Its dimensions are of the order of the number of symmetric sectors allowed, i.e., 12 x 12 in this version.

Dimensioned variables, CURR, CURI, ZLR, ZLI, ZLC, AIR, AII, BIR, BII, CIR, CII in the main program and NEFLD subroutine must also be expanded to the appropriate size of the maximum structure allowed.

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APPENDIX A   WAMP PROGRAM LISTING

```
      PROGRAM WAMP
C
      INTEGER P
      COMPLEX ZRATI,ADMIT,ZPED,RRV,RRH,ZRSIN,RRD,ERX,ERY,ERZ,EPX,EPY
      COMPLEX CM,FJ,EINC,EXA,CIX,CIY,CIZ,ERC
      DIMENSION CURR(100), CURI(100), ZLR(22), ZLI(22), ZLC(22), COM(10)
      DIMENSION THETR(5), PHYR(5), ETAR(5), DTHR(5), DPHR(5), NTHR(5), N
     1PHR(5)
      DIMENSION AIR(100), AII(100), BIR(100), BII(100), CIR( 00), CII(10
     10)
      DIMENSION ISEG(13), ENCR(12), ENCI(12)
      DIMENSION CME(2,22,100)
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      COMMON /2/ CM(22,100),EINC(100),P(100)
      COMMON /3/ CAB(100),SAB(100),SALP(100)
      COMMON /4/ NCOX,JOX(25),NCIX,JIX(25),NCOZ,JOZ(25),NCIZ,JIZ(25)
      EQUIVALENCE (CM,CME)
      NROW=22
      NCOL=100
      NRPAGE=45
      FJ=CMPLX(0.,1.)
      ZZ=376.72727
      PI=3.14159265
      TP=2.*PI
      TA=.01745329252
      TD=57.29577951
      CONST=ZZ/(2 *TP)
C
C     **********RUN COMMENTS**********
C
C     READ IN 1ST DATA CARD--80 COLUMNS OF RUN COMMENTS
C
 1    READ (60,68) (COM(I),I=1,10)
      IF (EOF,60) 65,2
C
C     **********RUN OPTIONS**********
C     READ 2ND DATA CARD TO SELECT RUN OPTIONS
C       NPRINT = SELECTS LEVEL OF DIAGNOSTIC PRINTOUTS:  0 TO 2
C       ILOAD  = SELECTS LOADED ELEMENT OPTION. =0 FOR NO LOAD, =1 LOAD
C       IPGND  = SELECTS A PERFECT GROUND FOR IPGND = 1, = 0 FOR FINITE
C       IGSCRN = SELECTS A RADIAL GROUND SCREEN OPTION IN CMSETUP
C       INEAR  = SELECTS NEAR-FIELD CALCULATION IF = 1, = 0 FOR NO CALC
C       IFAR   = SELECTS FAR-FIELD CALCULATION IF = 1, = 0 FOR NO CALC
C       NPWR   = A,B,C CURRENTS AND FIELD CALC ARE NORMALIZED TO 1 WATT
C
 2    READ (60,69) NPRINT,ILOAD,IPGND,IGSCRN,INEAR,IFAR,NPWR
C
C     **********FREQUENCY AND GROUND**********
C
C     READ IN 3RD DATA CARD
C       GHZ    = ANTENNA FREQUENCY IN GIGA-HERTZ
C       GR     = DELTA-FREQ IN GHZ IF NFS  GT 1 -- FREQ = GHZ + GR STEPS
C       NFS    = NUMBER OF FREQUENCY STEPS TO CALC--GREATER OR = 1
C       KSYMP  = FREE SPACE ANTENNA = 1, OVER GROUND = 2
C       EPSR   = RELATIVE DIELECTRIC CONSTANT OF GROUND
C       SIG    = CONDUCTIVITY OF GROUND -- MHOS/METER
C
      READ (60,70) GHZ,GR,NFS,KSYMP,EPSR,SIG
      COLAM=0.299793/GHZ
      IF (KSYMP.EQ.2) GO TO 3
      EPSR= .
      SIG=0.
      KSYMP=1
```

```
    3 WRITE (61,71)
      WRITE (61,72)
      WRITE (61,73)
      WRITE (61,74) (COM(I),I=1,10)
      WRITE (61,69) NPRINT,ILOAD,IPGND,IOSCRN,INEAR,IFAR,NPWR
      WRITE (61,75) GHZ,OR,NFS,COLAM
      IF (IPGND.EQ.1) WRITE (61,102)
      IF (KSYMP.EQ.2.AND.IPGND.EQ 0) WRITE (61,76) EPSR,SIG
      IF (KSYMP.EQ.1) WRITE (61,66)
C
C     BEFORE READING IN MORE DATA CARDS IN THE MAIN PROGRAM, CALL THE
C     DATA GENERATOR TO FILL UP THE GEOMETRY ARRAYS -- THE DATAGN
C     WILL REQUIRE THE NEXT-N-DATA CARDS--SEE THE APPROPRIATE DATA GN
C     SUBROUTINE FOR ADDITIONAL DETAILS.
C
C
      CALL DATAGN
C
C     **********STRUCTURE SYMMETRY**********
C
C     NEXT READ IN NP AND NX TO SET UP SYMMETRY CALCULATIONS
C     NP=NUMBER OF SEGMENTS IN A ROTATIONALLY SYMMETRIC SECTION
C     NX=NUMBER OF SEGMENTS ON THE AXIS OF ROTATION
C     NOTE THAT THE PROGRAM WILL WORK IF NP=N AND NX=0
C
      READ (60,69) NP,NX
      WRITE (61,77) N,NP,NX
      NSIZE=NP+NY
      NCOLSYM=N NX
C
C     IF NSIZE IS GREATER THAN 22, TOO MANY SEGMENTS PER SECTOR ARE USED
C     AND IERR=1.
C
      IF (NSIZE.LE.22) GO TO 4
      IERR=1
      GO TO 64
    4 IP=NRPAGE
      SLEN=0.
      DO 8 I=1,N
      IF (NPRINT+1) 7,5,5
    5 AP=ALP(I)*TD
      BT=BET(I)*TD
      IP=IP+1
      IF (IP.LE.NRPAGE) GO TO 6
      WRITE (61,78)
      IP=1
    6 WRITE (61,79) X(I),Y(I),Z(I),SI(I),BI(I),AP,BT,ICON1(I),I,ICON2(I)
    7 ALPI=ALP(I)
      BETI=BET(I)
      CALP=COS(ALPI)
      SALP(I)=SIN(ALPI)
      CAB(I)=CALP*COS(BETI)
      SAB(I)=CALP*SIN(BETI)
      SLEN=SLEN+SI(I)
      IF (SI(I).GT.0.0) GO TO 8
      WRITE (61,80) I
      STOP
    8 CONTINUE
      WRITE (61,81) SLEN
      ISEG(13)=0
      DO 9 K=1,12
      ISEG(K)=0
      ENCR(K)=0.0
    9 ENCI(K)=0.0
```

```
      IM=0
      WRITE (61,82)
C
C     **********SOURCE EXCITATION**********
C     READ N+5TH DATA CARD FOR THE SOURCE TO DRIVE ANTENNA
C       IS      = EXCITED SEGMENT NUMBER
C       ECM     = MAGNITUDE OF SEGMENT EXCITATION--VOLTS
C       ECA     = PHASE OF EXCITATION IN DEGREES
C       NFLD    = NFLD=1 IF MORE SEGMENTS ARE TO BE EXCITED, =0 TO END
C     USE 1.0 VOLT AT 0 DEG PHAZE FOR CORRECT INPUT IMPEDANCE CALC
C     1 TO 12 SEGMENTS MAY BE SIMULTANEOUSLY EXCITED.
C
 10   READ (60,83) IS,ECM,ECA,NFLD
      WRITE (61,83) IS,ECM,ECA,NFLD
      IF (1.LE.IS.AND.IS.LE.N) GO TO 11
C
C     IERR=2 IF SOURCE SEGMENT IS LT 1 OR GREATER THAN NUM OF SEGS USED
C
      IERR=2
      GO TO 64
 11   K=ISEG(13)+1
      IF (K.LE.12) GO TO 12
C
C     IERR=3 IF TOO MANY SEGMENTS ARE SELECTED FOR SOURCES
C
      IERR=3
      GO TO 64
 12   ISEG(13)=K
      ISEG(K)=IS
      ECA=ECA*TA
      ENCR(K)=ECM*COS(ECA)
      ENCI(K)=ECM*SIN(ECA)
      IF (NFLD.NE.0) GO TO 10
      IF (ILOAD) 13,18,13
 13   DO 14 I=1,NP
      ZLC(I)=0.0
      ZLR(I)=0.0
 14   ZLI(I)=0.0
C
C     **********SEGMENT LOADING**********
C     IF ILOAD = 1, THEN READ IN SEGMENT LOAD PARAMETERS
C       ZR      = RESISTANCE IN OHMS ON EACH OF THE SPECIFIED SEGMENTS
C       ZI      = INDUCTANCE IN HENRYS ON EACH OF THE SPECIFIED SEGMENTS
C       ZC      = CAPACITANCE IN FARADS ON EACH OF THE SPECIFIED SEGMENTS
C       I1      = LOADS ARE CONNECTED FROM
C       I2      = SEGMENTS I1 TO I2 INCLUSIVE
C       NFLD    = 1 FOR MORE LOAD CARDS, =0 FOR END OF LOAD INPUT DATA
C
C     NOTE  IF SYMMETRY IS EMPLOYED AND A ROTATIONALLY SYMMETRIC SEGMENT
C     IS LOADED, THEN ALL LIKE SYMMETRIC SEGMENTS WILL ALSO BE LOADED.
C
 15   READ (60,85) ZR,ZI,ZC,I1,I2,NFLD
      IF (I2.EQ.0) I2=I1
      WRITE (61,86) I1,I2,ZR,ZI,ZC
      IF (I2.LT.I1) GO TO 17
      IF (I1.LE.NCOLSYM) I1=MOD(I1,NP)
      IF (I2.LE.NCOLSYM) I2=MOD(I2,NP)
      IF (I1.GT.NCOLSYM) I1=MOD(I1,NCOLSYM)+NP
      IF (I2.GT.NCOLSYM) I2=MOD(I2,NCOLSYM)+NP
      DO 16 I=I1,I2
      ZLC(I)=ZLC(I)+ZC
      ZLR(I)=ZLR(I)+ZR
 16   ZLI(I)=ZLI(I)+ZI
 17   CONTINUE
```

```
      IF (NFLD.NE.0) GO TO 15
C
C     **********BEGIN FREQUENCY DO LOOP**********
C
 18   DO 63 MKS=1,NFS
      FR=(GHZ+DR)/GHZ
      IF (MKS.EQ.1) FR=1.
      GHZ=GHZ*FR
      COLAM=0.299793/GHZ
C
C     ZRATI = THE RATIO OF THE HALF-SPACE TO FREE-SPACE PLANE WAVE IMPED
C
      ZRATI=CSQRT(1./(EPSR-FJ*SIG*COLAM*59.92))
      IF (MKS.EQ.1) GO TO 23
      IF (NPRINT) 20,19,19
 19   WRITE (61,87) GHZ
 20   DO 22 I=1,N
      X(I)=X(I)*FR
      Y(I)=Y(I)*FR
      Z(I)=Z(I)*FR
      SI(I)=SI(I)*FR
      BI(I)=BI(I)*FR
      IF (NPRINT) 22,21,21
 21   WRITE (61,87) X(I),Y(I),Z(I),SI(I),BI(I)
 22   CONTINUE
 23   CONTINUE
C
C     CMSETUP IS USED TO SET UP THE COMPLEX IMPEDANCE MATRIX
C
      CALL CMSETUP (ZRATI,KSYMP,IPGND,IGSCRN)
C
C     NOW ADD IN THE IMPEDANCE LOADING ON THE SELF TERMS.
C
      IF (ILOAD.EQ.0) GO TO 25
      DO 24 I=1,NSIZE
      J=I
      IF (I.GT.NP) J=NCOLSYM+I-NP
      IF (ZLC(I).GT.0) CM(I,J)=CM(I,J)+FJ/(TP*GHZ*1.E+9*ZLC(I)*SI(I))

 24   CM(I,J)=CM(I,J)-ZLR(I)/SI(I)-FJ*TP*GHZ*1.E+9*ZLI(I)/SI(I)
 25   IF (NPRINT-1) 28,28,26
 26   CONTINUE
      DO 27 I=1,NSIZE
 27   WRITE (61,88) I,((CME(KAY,I,J),KAY=1,2),J=1,N)
C
C     **********SOLUTION OF THE MATRIX EQUATION**********
C
 28   CONTINUE
C
C     FACTOR THE IMPEDANCE MATRIX
C
C
C     NOP=NUMBER OF SYMETRIC SECTIONS--MUST BE .LE. 12
C
      NOP=(N-NX)/NP
      CALL FACTRCS (NP,NOP,NX,CM,P,NROW,NCOL,1)
C
C     SET UP THE EXCITATION SOURCE VECTOR.  ANY OF THE N SEGMENTS MAY
C     BE EXCITED.
C
      DO 29 I=1,N
 29   EINC(I)=CMPLX(0.,0.)
      ISEGL=ISEG(13)
      DO 30 I=1,ISEGL
```

```
      IS=ISEG(I)
   30 EINC(IS)=-CMPLX(ENCR(I),ENCI(I))/SI(IS)
      IF (NPRINT.LT.0) GO TO 32
      WRITE (61,90)
      DO 31 IP=1,N
      X1=REAL(EINC(IP))
      X2=AIMAG(EINC(IP))
      IF (X1.NE.0 .OR.X2.NE.0.) WR'TE (61,89) IP,X1,X2
   31 .ONTINUE
   32 CONTINUE
C
C     SOLVE THE SYSTEM OF EQUATIONS FOR SEGMENT CURRENTS---THE EINC
C       ARRAY IS THE EXCITING SOURCE MATRIX TO THE SOLVE SUBROUTINE
C       AND THE CURRENTS ARE RETURNEP FROM SOLVE IN THIS ARRAY.
C          CURI = INV(CM) * EINC)
C
      CA_L SOLVECS (NP,NOP,NX,CM,P,EINC,NROW,NCOL)
C
C     THE SEGMENT CURRENTS ARE RETURNED THROLGH THE EINC ARRAY
C
      DO 33 I=1,N
      CURR(I)=REAL(EINC(I))
   33 CURI(I)=AIMAG(EINC(I))
      NHALF=(N+1)/2
      IP=NRPAGE
      DO 34 I=1,N
      J=I+NHALF
      IP=IP+1
      CMAG=SQR'(CURR(I)*CURR(I)+CURI(I)*CURI(I))
      PH=TD*AATAN2(CURI(I),CURR(I))
      IF (J.GT.N) GO TO 35
      CMAGP=SQRT(CURR(J)*CURR(J)+CURI(J)*CURI(J))
      PHP=TD*AATAN2(CURI(J),CURR(J))
      IF (IP.LE.NRPAGE) GO TO 34
      WRITE (61,91)
      IP=1
   34 WRITE (61,92) I,CURR(I),CURI(I),CMAG,PH,J,CURR(J),CURI(J),CMAGP,PH
     1P
   35 WRITE (61,92) I,CURR(I),CURI(I),CMAG,PH
C
C     IF MORE THAN 1 SEGMENT IS EXCITED, AN INPUT IMPEDANCE IS NOT CALC
C
C     TO OBTAIN THE CORRECT IN' JT IMPEDANCE THE ANTENNA SEGMENTS
C     MUST BE EXCITED WITH A 1 J VOLT AT 0 DEG PHASE SOURCE.
C
      IF (ISEGL.GT.1) GO TO 36
      ADMIT=CURR(IS.+FJ*CURI(IS)
      ADMAG=CABS(ADMIT)
      ADFAZ=AATAN2(CURI(IS),CURR(IS))*TD
      ZPED=1./ADMIT
      ZMAG=1./ADMAG
      ZFAZ=-ADFAZ
      ADMITR=REAL(ADMIT)
      ADMITI=AIMAG(ADMIT)
      ZPEDR=REAL(ZPED)
      ZPEDI=AIMAG(ZPED)
      WRITE (61,93) ADMITR,ADMITI,ZPEDR,ZPEDI,ADMAG,ADFAZ,ZMAG,ZFAZ
   36 CONTINUE
      IF (NPRINT.GT.0) WRITE (61,94)
C
C     EXPAND THE SOLVED CURRENTS AT SEGMENT CENTERS INTO A CONSTANT PLUS
C      A SINE AND COSINE TERM· I(S) =  A + B*SIN(K*S) + C*COS(K*S)
C
      DO 54 I=1,N
```

```
      CALL TRIO (I,JCO1,JCO2,DIL,DIK)
      S=SI(I)
      CL=TP*DIL
      CK=TP*DIK
      SINL=SIN(CL)
      COSL=COS(CL)
      SINK=SIN(CK)
      COSK=COS(CK)
      SILK=SIN(CL+CK)
      CELLO=SINL+SINK-SILK
      IF (JCO1) 37,42,43
   37 CRLO=0.0
      CILO=0.0
      IF (NCIX.LT.1) GO TO 39
      DO 38 K=1,NCIX
      JIXK=JIX(K)
      CRLO=CRLO+CURR(JIXK)
   38 CILO=CILO+CURI(JIXK)
   39 CONTINUE
      IF (NCOX.LT.1) GO TO 41
      DO 40 K=1,NCOX
      JOXK=JOX(K)
      CRLO=CRLO-CURR(JOXK)
   40 CILO=CILO-CURI(JOXK)
   41 CONTINUE
      GO TO 44
   42 CRLO=0.0
      CILO=0.0
      GO TO 44
   43 CRLO=CURR(JCO1)
      CILO=CURI(JCO1)
   44 CRLL=CURR(I)
      CILL=CURI(I)
      IF (JCO2) 45,50,51
   45 CRLY=0.0
      CILY=0.0
      IF (NCOZ.LT.1) GO TO 47
      DO 46 K=1,NCOZ
      JOZK=JOZ(K)
      CRLY=CRLY+CURR(JOZK)
   46 CILY=CILY+CURI(JOZK)
   47 CONTINUE
      IF (NCIZ.LT.1) GO TO 49
      DO 48 K=1,NCIZ
      JIZK=JIZ(K)
      CRLY=CRLY-CURR(JIZK)
   48 CILY=CILY-CURI(JIZK)
   49 CONTINUE
      GO TO 52
   50 CRLY=0.0
      CILY=0.0
      GO TO 52
   51 CRLY=CURR(JCO2)
      CILY=CURI(JCO2)
   52 AIR(I)=(CRLO*SINK-CRLL*SILK+CRLY*SINL)/CELLO
      AII(I)=(CILO*SINK-CILL*SILK+CILY*SINL)/CELLO
      BIR(I)=(CRLO*(COSK-1.0)+CRLL*(COSL-COSK)+CRLY*(1.0-COSL))/CELLO
      BII(I)=(CILO*(COSK-1.0)+CILL*(COSL-COSK)+CILY*(1.0-COSL))/CELLO
      CIR(I)=-(CRLO*SINK-CRLL*(SINL+SINK)+CRLY*SINL)/CELLO
      CII(I)=-(CILO*SINK-CILL*(SINL+SINK)+CILY*SINL)/CELLO
      IF (NPRINT) 54,54,53
   53 WRITE (61,95) I,AIR(I),AII(I),BIR(I),BII(I),CIR(I),CII(I)
   54 CONTINUE
C     . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
```

```
C
C     IF NPWR=1  NORMALIZE THE ANTENNA'S INPUT POWER TO A REFERENCE
C     1-WATT INPUT.
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF (NPWR.EQ.0) GO TO 57
      PWRSUM=0.
      DO 55 I=1,ISEGL
      IEXCIT=ISEG(I)
      PWR=0.5*REAL((ENCR(I)+FJ*ENCI(I))*(CURR(IEXCIT)-FJ*CURI(IEXCIT)))
      PWRSUM=PWRSUM+PWR
   55 CONTINUE
      WATTI=SQRT(1./PWRSUM)
      WRITE (61,96) WATTI
      DO 56 I=1,N
C
C     NORMALIZE THE ANTENNA CURRENTS TO AN EQUIAVLENT 1 WATT DRIVE FOR
C     FIELD CALCULATIONS.
C
      AIR(I)=AIR(I)*WATTI
      AII(I)=AII(I)*WATTI
      BIR(I)=BIR(I)*WATTI
      BII(I)=BII(I)*WATTI
      CIR(I)=CIR(I)*WATTI
      CII(I)=CII(I)*WATTI
   56 CONTINUE
   57 CONTINUE
C
C     **********NEAR FIELD CALCULATIONS**********
C
      IF (INEAR.EQ.1) CALL NEFLD (AIR,AII,BIR,BII,CIR,CII,ZRATI,KSYMP)
C
C
C     **********FAR FIELD CALCULATIONS**********
C
      K=0
      IF (IFAR.EQ.0) GO TO 63
   58 K=K+1
C
C     FAR FIELD INPUT SELECTIONS--UP TO 5 CARDS MAY BE USED
C       THETR  = INITIAL THETA COORDINATE--DEGREES
C       PHYR   = INITIAL PHI COORDINATE--DEGREES
C       ETAR   = ETA ANGLE--DEGREES
C       DTHR   = DELTA THETA STEP--DEG
C       DPHR   = DELTA PHI STEP--DEG
C       NTHR   = NUMBER OF THETA STEPS
C       NPHR   = NUMBER OF PHI STEPS
C       NFLD   = =0 IF NO MORE FAR-FIELD CARDS, =1 FOR MORE INPUT
C       NEWSIG = =1 IF FAR FIELD CALC OVER DIFFERENT MEDIA, =0 IF NOT
C       SIOFF  = CONDUCTIVITY OF FAR-FIELD MEDIA--MHOS/METER
C       EPSFF  = RELATIVE DIELECTRIC CONSTANT OF FAR-FIELD MEDIA
C
      READ (60,84) THETR(K),PHYR(K),ETAR(K),DTHR(K),DPHR(K),NTHR(K),NPHR
     1(K),NFLD,NEWSIG,SIOFF,EPSFF
      IF (NFLD.NE.0) GO TO 58
      KMR=K
      IP=NRPAGE
      DO 62 KR=1,KMR
      DPHRK=DPHR(KR)
      NPHRK=NPHR(KR)
      THRO=THETR(KR)
      DTHRK=DTHR(KR)
      NTHRK=NTHR(KR)
      SETA=SIN(ETAR(KR)*TA)
```

```
      CETA=COS(ETAR(KR)*TA)
      PHRK=PHYR(KR)-DPHRK
C
C      LOOP THROUGH THE PHI ANGLES
C
      DO 62 KP=1,NPHRK
      PHRK=PHRK+DPHRK
      PHRKA=PHRK*TA
      SPHI=SIN(PHRKA)
      CPHI=COS(PHRKA)
      THRK=THRO-DTHRK
      PKX=-SPHI
      PKY=CPHI
C
C     LOOP THROUGH THE THETA ANGLES
C
      DO 62 KT=1,NTHRK
      THRK=THRK+DTHRK
      THRKA=THRK*TA
      STHET=SIN(THRKA)
      ROX=STHET*CPHI
      ROY=STHET*SPHI
      ROZ=COS(THRKA)
      EIXR=CETA*ROZ*CPHI-SETA*SPHI
      EIYR=CETA*ROZ*SPHI+SETA*CPHI
      EIZR=-CETA*STHET
      IP=IP+1
      CIX=CMPLX(0.,0.)
      CIY=CMPLX(0.,0.)
      CIZ=CMPLX(0.,0.)
C
C     IF YOU WANT TO CALCULATE THE FAR FIELD RADIATION PATTERN OVER A
C     MEDIA WHICH IS DIFFEHENT THAN THE NEAR FIELD, SET NEWSIG=1 AND
C     READ IN THE NEW GROUND PARAMETERS ON THE FAR-FIELD CARD.
C
      IF (NEWSIG.EQ.1) ZRATI=CSQRT(1./(EPSFF-FJ*SIGFF*COLAM*59.92))
      ZRSIN=+CSQRT(1.-ZRATI*ZRATI*STHET*STHET
      RRV=(ROZ-ZRATI*ZRSIN)/(ROZ+ZRATI*ZRSIN)
      RRH=-(ZRATI*ROZ-ZRSIN)/(ZRATI*ROZ+ZRSIN)
      RRD=RRH-RRV
      DO 60 I=1,N
      CABI=CAB(I)
      SABI=SAB(I)
      SALPI=SALP(I)
      RFL=-1.
      DO 60 K=1,KSYMP
      RFL=-RFL
      ARG=X(I)*ROX+Y(I)*ROY+Z(I)*ROZ*RFL
      CARG=COS(TP*ARG)
      SARG=SIN(TP*ARG)
      EXA=CMPLX(CSARG,SARG)
      DODEL=ROX*CABI+ROY*SABI+ROZ*SALPI*RFL
      XODEL=CABI-ROX*DODEL
      YODEL=SABI-ROY*DODEL
      ZODEL=SALPI*RFL-ROZ*DODEL
      OMEGA=-DODEL
      EL=PI*SI(I)
      SILL=OMEGA*EL
      TOP=EL+SILL
      BOT=EL-SILL
      A=(2.0-OMEGA*OMEGA*EL*EL/3.0)*EL
      IF (ABS(OMEGA).GE.1.E-7) A=2.*SIN(SILL)/OMEGA
      TOO=1.0-TOP*TOP/6.0
      IF (ABS(TOP).GE.1.E-9) TOO=SIN(TOP)/TOP
```

```
      BOO=1.0-BOT*BOT/6.0
      IF (ABS(BOT).GE.1.E-9) BOO=SIN(BOT)/BOT
      B=EL*(BOO-TOO)
      C=EL*(BOO+TOO)
      RR=A*AIR(I)+B*BII(I)+C*CIR(I)
      RI=A*AII(I)-B*BIR(I)+C*CII(I)
      RRX=RR*XODEL
      RRY=RR*YODEL
      RRZ=RR*ZODEL
      RIX=RI*XODEL
      RIY=RI*YODEL
      RIZ=RI*ZODEL
      ERX=CMPLX(RRX,RIX)
      ERY=CMPLX(RRY,RIY)
      ERZ=CMPLX(RRZ,RIZ)
      IF (K.NE.2) GO TO 59
      EPY=PKX*ERX+PKY*ERY
      EPX=PKX*EPY
      EPY=PKY*EPY
      ERX=-(RRV*ERX+RRO*EPX)
      ERY=-(RRV*ERY+RRO*EPY)
      ERZ=-RRV*ERZ
   59 CIX=CIX+ERX*EXA
      CIY=CIY+ERY*EXA
   60 CIZ=CIZ+ERZ*EXA
      ERX=CONST*CIX
      ERY=CONST*CIY
      ERZ=CONST*CIZ
      ERC=ERX*EIXR+ERY*EIYR+ERZ*EIZR
      ER=REAL(ERC)
      EI=AIMAG(ERC)
      ERAD=CABS(ERX*STHET*CPHI+ERY*STHET*SPHI+ERZ*ROZ)
      ETHETA=CABS(ERX*ROZ*CPHI+ERY*ROZ*SPHI-ERZ*STHET)
      EPHI=CABS(-ERX*SPHI+ERY*CPHI)
      PHAZE=TD*AATAN2(EI,ER)
      ERMAG=SQRT(ERAD**2+ETHETA**2+EPHI**2)
      IF (IP.LE.NRPAGE) GO TO 61
      WRITE (61,97) (COM(I),I=1,10)
      IF (NEWSIG.EQ.1) WRITE (61,98) EPSFF,SIGFF
      WRITE (61,99)
      IP=1
   61 WRITE (61,100) THRK,PHRK,ERAD,ETHETA,EPHI,ERMAG,PHAZE
   62 CONTINUE
   63 CONTINUE
      GO TO 1
   64 WRITE (61,101) IERR
   65 CONTINUE
      STOP
C
C
C
   66 FORMAT (//33H ANTENNA IS MODELED IN FREE SPACE//)
   67 FORMAT (21H1 FREQUENCY IN GHZ = ,F12.8,//,6X,4HX(I),6X,4HY(I),6X,4
     1HZ(I),5X,5HSI(I),5X,5HBI(I))
   68 FORMAT (10A8)
   69 FORMAT (16I5)
   70 FORMAT (2F10.5,2I5,2F10.5)
   71 FORMAT (///,30H1*****************************)
   72 FORMAT (/,30H WIRE ANTENNA MODELING PROGRAM,/)
   73 FORMAT (30H *****************************)
   74 FORMAT (///,1X,10A8/)
   75 FORMAT (/1X,9HFREQUENCY12X,1H=E13.5/1X,22HFREQUENCY INCREMENT   =E1
     13.5/1X,22HNO. FREQUENCY STEPS   =I4/1X,22HWAVELENGTH  (METERS) =E13
     2.5//)
```

```
76    FORMAT (1X,22HGROUND PLANE AT Z = 0./1X,22HDIELECTRIC CONSTANT  =E  A 576
     113.5/1X,12HCONDUCTIVITY9X,1H=E13.5/)                                A 577
77    FORMAT (///1X,22HNUMBER OF SEGMENTS    =I4/1X,22HNO. SEG. IN A SECTO A 578
     1R =I4/,1X,31HNO. SEG. ON AXIS OF ROTATION = ,I4)                    A 579
78    FORMAT (49H1 STRUCTURE GEOMETRY  (DIMENSIONS IN WAVELENGTHS)//2X,6  A 580
     13HCOORDINATES OF SEG. CENTER      SEG.       WIRE     ORIENTATION AN2 A 581
     22HGLES   CONNECTION DATA  /6X33HX          Y          Z       LENGTH4 A 582
     30H    RADIUS      ALPHA       BETA     I-     I    I+       )        A 583
79    FORMAT (4F10.5,F10.7,2F10.3,3I5)                                    A 584
80    FORMAT (30H NEGATIVE SEGMENT LENGTH.    I=I5)                       A 585
81    FORMAT (/23H TOTAL WIRE LENGTH     =E18 11)                         A 586
82    FORMAT (/29H ANTENNA SOURCE DISTRIBUTIONS/24H    SEG.         VOLTAG A 587
     1E  /26H   NO.      MAG.       PHASE)                                A 588
83    FORMAT (I5,2F10.5,I5)                                               A 589
84    FORMAT (5F10.5,4I5,2F5.1)                                           A 590
85    FORMAT (3E10.3,3I5)                                                 A 591
86    FORMAT (9H SEGMENTS,I4,5H THRU,I4,12H LOADED WITH,E10 3,16H OHMS R  A 592
     1ESISTANCE,E10.3,23H HENRIES INDUCTANCE AND,E10 3,20H FARADS CAPACI  A 593
     2TANCE.)                                                             A 594
87    FORMAT (8F10.5)                                                     A 595
88    FORMAT (/1X,3H I=I3/(1X,10E11 3))                                   A 596
89    FORMAT (/1X,I5,5X,E11.3,3X,E11.3)                                   A 597
90    FORMAT (44H1 SEGMENT EXCITATION (VOLTS/WAVELENGTH)       /41H SEG NU A 598
     1MBER   REAL PART   IMAGINARY PART )                                 A 599
91    FORMAT (5H1SEG.3X,8HCURRENT-,48X,4HSEG 4X,9HCURRENT -/1X,3HNO 5X,4  A 600
     1HREAL.63H          IMAGINARY   MAGNITUDE         PHASE           NO. A 601
     2    RE43HAL          IMAGINARY   MAGNITUDE      PHASE       )        A 602
92    FORMAT (1X,I4,E13.4,E12.4,E16.8,F9.3,9X,I4,E13 4,E12 4,E16.8,F9.3)  A 603
93    FORMAT (4X,6HADMIT=2E12.4,10X,5HZPED=2E12.4/6XE10.4,2XF10.3,18X,E1  A 604
     10.4,2X,F10.3)                                                       A 605
94    FORMAT (4H1  16X,2HAR10X,2HAI11X,2HBR10X,2HBI11X,2HCR10X,2HCI)      A 606
95    FORMAT (1X,I4,3(1X,2E12.4))                                         A 607
96    FORMAT (39H1 * * * * * * * * * * * * * * * * * * *,//,40H   VOLTAG  A 608
     1E TO DRIVE ANTENNA AT 1-WATT = ,F12 5,//,50H      ALL FIELDS ARE NO  A 609
     2RMALIZED TO THIS INPUT POWER//41H* * * * * * * * * * * * * * * * *  A 610
     3 * * *   )                                                          A 611
97    FORMAT (2H1 ,10A8/)                                                 A 612
98    FORMAT (22HDIELECTRIC CONSTANT = ,E12 4,20H AND CONDUCTIVITY = ,E1  A 613
     12.4,29H FOR FAR FIELD CALCULATIONS. //)                             A 614
99    FORMAT (41H  OBSERVATION ANGLES     ELECTRIC FIELD    /4X,5HTHETA,5X A 615
     1,3HPHI,13X,11HR-COMPONENT,7X,15HTHETA-COMPONENT,6X,13HPHI-COMPONEN  A 516
     2T10X,9HMAGNITUDE,10X,6H PHASE)                                      A 617
100   FORMAT (2(1X,F8.3),12X,4(E12 4,8X),F10 4)                           A 618
101   FORMAT (17H STOP   ERROR NO.I5)                                     A 619
102   FORMAT (32H A PERFECT GROUND PLANE AT Z 0   )                       A 620
      END                                                                 A 621
```

```
      FUNCTION AATAN2 (Y,X)
C
C     THIS FUNCTION CORRECTLY COMPUTES THE ARC TANGENT FOR ALL INPUT
C     ARGUMENTS AND RETURNS AN ANSWER IN THE RANGE OF +- PI/2
C
C     TEST INPUT ARGUMENTS
C
      PIO2=1.570796327
      IF (Y.EQ.0.) GO TO 1
      IF (X.EQ.0.) GO TO 2
      AATAN2=ATAN2(Y,X)
      RETURN
 1    AATAN2=0.
      IF (X.LT.0.) AATAN2=2.*PIO2
      RETURN
 2    AATAN2=SIGN(PIO2,Y)
      RETURN
      END
```

```
      SUBROUTINE CHSETUP (ZRATI,KSYMP,IPGND,IGSCRN)
C
C     SUBROUTINE CHSETUP IS USED TO SETUP THE COMPLEX IMPEDANCE MATRIX
C     CH.
C
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      INTEGER P
      COMPLEX ZRATI,REFS,REFPS,ZRSIN
      COMPLEX ZRATIS,ZSCRN,ZFACT
      COMPLEX FJ,CH,EINC
      COMMON /2/ CH(22,100),EINC(100),P(100)
      COMMON /3/ CAB(100),SAB(100),SALP(100)
      COMMON /4/ NCOX,JOX(25),NCIX,JIX(25),NCOZ,JOZ(25),NCIZ,JIZ(25)
      COMMON /REFL/ RHOX,RHOY,RHOZ,CABJ,SABJ,SALPR,PX,PY,REFS,REFPS
      DIMENSION ETR(3), ETI(3)
      FJ=CMPLX(0.,1.)
      PI=3.14159265
      SIGN=-1.
      NR=NP+NX
      NSYM=N-NR
      ZRATIS=ZRATI
      IF (IGSCRN EQ.0) GO TO 1
C
C     IF IGSCRN INPUT IN THE MAIN PROGRAM = 1, A RADIAL WIRE GROUND
C     SCREEN IS SELECTED.  YOU WILL BE REQUIRED TO READ IN THE NUMBER OF
C     OF WIRES---NWIRES AND THE RADIUS OF THE RADIAL WIRES FOR EACH PASS
C     THROUGH THE FREQUENCY DO LOOP.
C
      READ (60,19) NWIRES,COH
C
C     IF A RADIAL GROUND IS SELECTED, COMPUTE SOME PARAMETERS FROM THE
C     NUMBER OF RADIAL WIRES--NWIRES, AND FROM THE RADIUS--COH (METERS)
C
      COH=COH/COLAM
      FLWIRE=NWIRES
      SNFACT=FLWIRE*COH
      W=2.*PI*0.299793*1.E+9/COLAM
      U0=4.*PI*1.E-7
      ZFACT=FJ*U0*W*COLAM/FLWIRE
      ETA0=120.*PI
      WRITE (61,20) NWIRES,COH
 1    CONTINUE
      DO 2 I=1,NR
      DO 2 J=1,N
 2    CH(I,J)=CMPLX(0.,0.)
C
C     J--SOURCE LOOP INDEX
C
      DO 18 J=1,N
      CALL TRIO (J,JCO1,JCO2,DIL,DIK)
      S=SI(J)
      B=BI(J)
      XJ=X(J)
      YJ=Y(J)
      ZJ=Z(J)
      CABJ=CAB(J)
      SABJ=SAB(J)
      SALPJ=SALP(J)
      DO 18 I=1,NR
C
C     I--OSERVATION LOOP INDEX
C
      IX=I
```

```
      IF (I.GT.NP) IX=I+NSYM
      XIJ=X(IX)-XJ
      YIJ=Y(IX)-YJ
      IJ=IX-J
      CABI=CAB(IX)
      SABI=SAB(IX)
      SALPI=SALP(IX)
      RFL=-1.
      DO 10 IP=1,KSYMP
C
C     KSYMP LOOP--WHEN IP=1 DO FREE SPACE, IP=2 DO GROUND IMAGE CALC
C
      RFL=-RFL
C
C     ZP = DISTANCE FROM SOURCE SEGMENT TO OBSERVATION POINE MEAS
C     ALONG THE AXIS OF THE SOURCE SEGMENT AND A LINE PERPENDICULAR
C     TO THE AXIS AND THE OBSERVATION POINT
C
C     RS = SQUARE OF THE DISTANCE BETWEEN THE SOURCE AND THE OBSERVATION
C     POINT.
C
C     RH = PERPENDICULAR DISTANCE BETWEEN OBSERVATION POINT AND AXIS OF
C     SEGMENT.
C
      ZIJ=Z(IX)-RFL*ZJ
      QI=CABI*CABJ+SABI*SABJ+SALPI*SALPJ*RFL
      Q2=XIJ*CABI+YIJ*SABI+ZIJ*SALPI
      ZP=XIJ*CABJ+YIJ*SABJ+ZIJ*SALPJ*RFL
      RS=XIJ*XIJ+YIJ*YIJ+ZIJ*ZIJ
      RH2=RS-ZP*ZP
      IF (RH2.LT.1.E-20) GO TO 3
      RH=SQRT(RH2)
      QP2=(Q2-ZP*QI)/RH
      GO TO 4
 3    QP2=0.
      RH=0.
 4    CONTINUE
C
C     SKIP OVER THE GROUND IMAGE STUFF IF DOING A FREE SPACE CALC.
C
      IF (IP.NE.2) GO TO 10
      SALPR=SALPJ*RFL
      RHOX=XIJ-CABJ*ZP
      RHOY=YIJ-SABJ*ZP
      RHOZ=ZIJ-SALPJ*ZP*RFL
      RMAG=SQRT(RHOX*RHOX+RHOY*RHOY+RHOZ*RHOZ)
      IF (RMAG.GT.1.E-6) GO TO 5
      RHOX=0.
      RHOY=0.
      RHOZ=0.
      GO TO 6
 5    RHOX=RHOX/RMAG
      RHOY=RHOY/RMAG
      RHOZ=RHOZ/RMAG
 6    RMAG=SQRT(YIJ*YIJ+XIJ*XIJ)
C
C     MODIFY THE GROUND IMPEDANCE -- ZRATI -- BY THE RADIAL GROUND
C     SCREEN IMPEDANCE IN PARALLEL WITH THE GROUND IMPEDANCE.
C
      IF (IOSCRN.EQ.0) GO TO 7
      XSPEC=(X(IX)*ZJ+Z(IX)*XJ)/(Z(IX)+ZJ)
      YSPEC=(Y(IX)*ZJ+Z(IX)*YJ)/(Z(IX)+ZJ)
      RHOSPC=SQRT(XSPEC*XSPEC+YSPEC*YSPEC+SNFACT*SNFACT)
      ZSCRN=ZFACT*RHOSPC*ALOG(RHOSPC/SNFACT)
```

```
      ZRATI=(ZRATIS*ZSCRN)/(ETA0*ZRATIS+ZSCRN)
    7 CONTINUE
      IF (RMAG.GT.1.E-6) GO TO 8
      PX=0.
      PY=0.
      CTH=1.
      ZRSIN=CMPLX(1.,0.)
      GO TO 9
    8 PX=YIJ/RMAG
      PY=-XIJ/RMAG
      CTH=ZIJ/SQRT(RS)
      ZRSIN=+CSQRT(1.-ZRATI*ZRATI*(1.-CTH*CTH))
    9 REFS=(CTH-ZRATI*ZRSIN)/(CTH+ZRATI*ZRSIN)
      REFPS=-(ZRATI*CTH-ZRSIN)/(ZRATI*CTH+ZRSIN)
      REFPS=REFPS-REFS
C
C     IF IPGND = 1, A PERFECT GROUND IS MODELED BY FIXING THE REFLECTION
C     COEFFICIENTS AS FOLLOWS
C
      IF (IPGND.EQ.0) GO TO 10
      ZRSIN=CMPLX(1.,0.)
      REFS=CMPLX(1.,0.)
      REFPS=CMPLX(0.,0.)
   10 CONTINUE
C
C     INTEGRATE THE E-FIELD AT OBS POINT DUE TO THE SOURCE SEGMENT
C
      CALL INTG (B,S,RH,ZP,QI,QP2,ETR,ETI,DIL,DIK,IJ,IP)
      IJ=1
      IF (IP.NE.2) GO TO 12
      DO 11 IC=1,3
      ETR(IC)=SIGN*ETR(IC)
   11 ETI(IC)=SIGN*ETI(IC)
   12 IF (JCO1) 13,15,14
   13 CALL JMELS (ETR(1),ETI(1),NCIX,JIX,NCOX,JOX,I)
      GO TO 15
   14 CM(I,JCO1)=CM(I,JCO1)+ETR(1)+FJ*ETI(1)
   15 CM(I,J)=CM(I,J)+ETR(2)+FJ*ETI(2)
      IF (JCO2) 16,18,17
   16 CALL JMELS (ETR(3),ETI(3),NCOZ,JOZ,NCIZ,JIZ,I)
      GO TO 18
   17 CM(I,JCO2)=CM(I,JCO2)+ETR(3)+FJ*ETI(3)
   18 CONTINUE
      ZRATI=ZRATIS
      RETURN
C
C
C
   19 FORMAT (I5,E10.5)
   20 FORMAT (///27H A RADIAL GROUND SCREEN OF ,I5,31H RADIALS WITH A WI
     1RE RADIUS OF ,E12.4,21H WAVELENGTH WAS USED ///)
      END
```

```
      SUBROUTINE DATAGN
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      FACTOR=1./COLAM
      ISEG=1
C
C     READ IN 2 DATA CARDS FOR EACH LINE ELEMENT USED
C     TO MODEL THE ANTENNA.  THE FIRST CARD CONTAINS THE END POINT
C     COORDINATES (IN METERS) AND THE INTERCONNECTION DATA FOR THE LINE
C     ENDS.  THE SECOND CARD SPECIFIES THE NUMBER OF SEGMENTS TO USE TO
C     MODEL THE LINE ELEMENT, THE WIRE RADIUS USED FOR THE ELEMENT AND I
C     DESIRED YOU CAN SPECIFY THAT A CATENARY BE MODELED BY GIVING THE
C     WIRE WEIGHT/METER AND THE WIRE TENSION .  IF AN INCREASING LENGTH
C     SEGMENT LINE IS DESIRED, SPECIFY THE LENGTH EXPANSION FACTOR TAU.
C
      WRITE (61,4)
C
C      DATA GENERATOR INPUTS:
C
C       X1,Y1,Z1 AND X2,Y2,Z2 ARE THE CARTESIAN COORDINATES OF THE TWO
C         END POINTS OF THE LINE ELEMENT
C       NCON1 = END CONNECTION VALUE OF THE NEGATIVE END OF THE LINE (1)
C       NCON2 = END CONNECTION VALUE OF THE POSITIVE END OF THE LINE (2)
C       WIRERAD = WIRE RADIUS IN METERS
C       WT = WIRE WEIGHT IN POUNDS PER METER---NEEDED ONLY FOR CATENARY
C       TENS = WIRE TENSION IN POUNDS---SET=0. IF NO CATENARY
C       TAU = SEGMENT LENGTH EXPANSION FACTOR---SET=0. IF EQUAL LTH SEGS
C
    1 READ (60,2) X1,Y1,Z1,NCON1,X2,Y2,Z2,NCON2
      READ (60,3) NSEGS,WIRERAD,WT,TENS,TAU
C
      WRITE (61,5) X1,Y1,Z1,NCON1,X2,Y2,Z2,NCON2
      WRITE (61,3) NSEGS,WIRERAD,WT,TENS,TAU
C
C     CONVERT THE INPUT UNITS IN METERS TO WAVELENGTHS FOR WAAP
C
      X1=X1*FACTOR
      Y1=Y1*FACTOR
      Z1=Z1*FACTOR
      X2=X2*FACTOR
      Y2=Y2*FACTOR
      Z2=Z2*FACTOR
      WIRERAD=WIRERAD*FACTOR
      MSEGS=IABS(NSEGS)
      CALL LINE (ISEG,MSEGS,TAU,WT,TENS,WIRERAD,X1,Y1,Z1,X2,Y2,Z2)
      ICON1(ISEG)=NCON1
      ISEG=ISEG+MSEGS
      ICON2(ISEG-1)=NCON2
      N=ISEG-1
      IF (NSEGS.LT.0) RETURN
      GO TO 1
C
C
C
    2 FORMAT (3F10.5,I5,3F10.5,I5)
    3 FORMAT (I5,4F10.5)
    4 FORMAT (//,33H1 DATA GENERATOR INPUT DATA CARDS,//)
    5 FORMAT (1X,3F10.4,I5,3F10.4,I5)
      END
```

```
      SUBROUTINE EFLD (B,S,RH,ZP,IJ,EZRS,EZIS,ERRS,ERIS,EZRC,EZIC,ERRC,E
     1RIC,EZRK,EZIK,ERRK,ERIK)
C
C     SUBROUTINE EFLD COMPUTES THE AXIAL AND RADIAL ELECTRIC FIELDS REF
C     TO THE SOURCE SEGMENT AT A SPECIFIED OBSERVATION POINT.
C
C     INPUTS:
C       B = SOURCE RADIUS
C       S = SOURCE LENGTH
C       RH = PERPENDICULAR DISTANCE BETWEEN OBS PT AND SOURCE SEG AXIS
C            AXIS.
C       ZP = AXIAL DISTANCE BETWEEN SOURCE SEG AND RH MEASURED ALONG
C            SOURCE AXIS.
C       IJ = OBSERVATION SEG NUMBER - SOURCE SEG NUMBER
C     OUTPUTS:
C       EZRS = AXIAL FIELD DUE TO SIN TERM--REAL PART
C       EZIS = IMAGINARY PART
C       ERRS = RADIAL FIELD DUE TO SIN TERM--REAL PART
C       ERIS = IMAGINARY PART
C
C       EZRC = AXIAL FIELD DUE TO COS TERM--REAL PART
C       EZIC = IMAGINARY PART
C       ERRC = RADIAL FIELD DUE TO COS TERM--REAL PART
C       ERIC = IMAGINARY PART
C
C       EZRK = AXIAL FIELD DUE TO CONSTANT TERM--REAL PART
C       EZIK = IMAGINARY PART
C       ERRK = RADIAL FIELD DUE TO CONSTANT TERM--REAL PART
C       ERIK = IMAGINARY PART
C
      COMMON /TMI/ ZPK,RKB2,IJX
      DATA ZZ,TP,TP2/188.363635,6.283185308,39.4784176/
      IJX=IJ
      RHK=RH*TP
      ZPK=ZP*TP
      BK=B*TP
      RKB2=RHK*RHK+BK*BK
      RKB=SQRT(RKB2)
      COINC=RHK/RKB
      SKT=TP*S*0.5
      ZD2=ZPK-SKT
      ZD1=ZPK+SKT
      R2KS=RKB2+ZD2*ZD2
      R2K=SQRT(R2KS)
      R1KS=RKB2+ZD1*ZD1
      R1K=SQRT(R1KS)
      SR2=SIN(R2K)/R2K*ZZ
      CR2=COS(R2K)/R2K*ZZ
      SR1=SIN(R1K)/R1K*ZZ
      CR1=COS(R1K)/R1K*ZZ
      SR2R=SR2/R2K
      SR2RR=SR2/R2KS
      CR2R=CR2/R2K
      CR2RR=CR2/R2KS
      SR1R=SR1/R1K
      SR1RR=SR1/R1KS
      CR1R=CR1/R1K
      CR1RR=CR1/R1KS
      CST=COS(SKT)
      SST=SIN(SKT)
      T1=(CR2R-SR2RR)*ZD2
      T2=(CR1R-SR1RR)*ZD1
      T3=(SR2R+CR2RR)*ZD2
      T4=(SR1R+CR1RR)*ZD1
```

```
      T1S=T1*SST
      T2S=-T2*SST
      T3S=T3*SST
      T4S=-T4*SST
      EZRS=(SR2-SR1)*CST+T1S-T2S
      EZIS=(CR2-CR1)*CST-T3S+T4S
      ERRS=-((SR2*ZD2-SR1*ZD1)*CST+(SR2+SR1)*SST+T1S*ZD2-T2S*ZD1)/RKB*CO
     1INC
      ERIS=-((CR2*ZD2-CR1*ZD1)*CST+(CR2+CR1)*SST-T3S*ZD2+T4S*ZD1)/RKB*CO
     1INC
      T1S=T1*CST
      T2S=T2*CST
      T3S=T3*CST
      T4S=T4*CST
      EZRC=(-(SR2+SR1)*SST+T1S-T2S)
      EZIC=(-(CR2+CR1)*SST-T3S+T4S)
      ERRC=-(-(SR2*ZD2+SR1*ZD1)*SST+(SR2-SR1)*CST+T1S*ZD2-T2S*ZD1)/RKB*C
     1OINC
      ERIC=-(-(CR2*ZD2+CR1*ZD1)*SST+(CR2-CR1)*CST-T3S*ZD2+T4S*ZD1)/RKB*C
     1OINC
      ERRK=RKB*(CR2R-SR2RR-CR1R+SR1RR)*COINC
      ERIK=-RKB*(SR2R+CR2RR-SR1R-CR1RR)*COINC
C
C     ONLY THE AXIAL FIELD DUE TO THE CONSTANT CURRENT TERM MUST BE
C     INTEGRATED NUMERICALLY
C
      CALL INTX (-SKT,SKT,RKB2,ZPK,BK,IJ,CINT,SINT)
      EZRK=-ZZ*SINT+T1-T2
      EZIK=-ZZ*CINT-T3+T4
      RETURN
      END
```

```
      SUBROUTINE FACTOR (N,A,P,NDIM)
C
C     SUBROUTINE TO FACTOR A MATRIX INTO A UNIT LOWER TRIANGULAR MATRIX
C     UPPER TRIANGULAR MATRIX USING THE GAUSS-DOOLITTLE ALGORITHM PRESEN
C     PAGES 411-416 OF A. RALSTON--A FIRST COURSE IN NUMERICAL ANALYSIS.
C     BELOW REFER TO COMMENTS IN RALSTONS TEXT.
C
      COMPLEX A,D,DETER
      INTEGER R,P,RM1,RP1,PJ,PR
      DIMENSION A(NDIM,NDIM), P(NDIM)
      COMMON /SCRATM/ D(100)
      IFLG=0
      DO 9 R=1,N
C
C     STEP 1
C
      DO 1 K=1,N
      D(K)=A(K,R)
    1 CONTINUE
C
C     STEPS 2 AND 3
C
      RM1=R-1
      IF (RM1.LT.1) GO TO 4
      DO 3 J=1,RM1
      PJ=P(J)
      A(J,R)=D(PJ)
      D(PJ)=D(J)
      JP1=J+1
      DO 2 I=JP1,N
      D(I)=D(I)-A(I,J)*A(J,R)
    2 CONTINUE
    3 CONTINUE
    4 CONTINUE
C
C     STEP 4
C
      DMAX=D(R)*CONJG(D(R))
      P(R)=R
      RP1=R+1
      IF (RP1.GT.N) GO TO 6
      DO 5 I=RP1,N
      ELMAG=D(I)*CONJG(D(I))
      IF (ELMAG.LT.DMAX) GO TO 5
      DMAX=ELMAG
      P(R)=I
    5 CONTINUE
    6 CONTINUE
      IF (DMAX.LT.1.E-10) IFLG=1
      PR=P(R)
      A(R,R)=D(PR)
      D(PR)=D(R)
C
C     STEP 5
C
      IF (RP1.GT.N) GO TO 8
      DO 7 I=RP1,N
      A(I,R)=D(I)/A(R,R)
    7 CONTINUE
    8 CONTINUE
      IF (IFLG.EQ.0) GO TO 9
      WRITE (61,10) R,DMAX
      IFLG=0
    9 CONTINUE
```

```
      RETURN                                                            F  65
C                                                                       F  66
C                                                                       F  67
C                                                                       F  68
 10   FORMAT (7H PIVOT(,I3,2H)=,E16.8)                                  F  69
      END                                                               F  70-
```

```
      SUBROUTINE FACTORS (N,NOP,A,P,NROW,NCOL)
C
C     SUBROUTINE FACTORS IS USED TO SET-UP THE FACTORIZATION OF THE
C     SYMMETRIC PART OF THE IMPEDANCE MATRIX
C
      COMPLEX A,D,DETER,S
      INTEGER P
      COMMON /SMAT/ S(12,12)
      DIMENSION A(NROW,NCOL), P(NCOL)
      COMMON /SCRATM/ D(100)
      IF (NOP.EQ.1) GO TO 6
      PHAZ=6.2831853072/NOP
      DO 1 I=2,NOP
      DO 1 J=1,NOP
      ARG=PHAZ*(I-1)*(J-1)
      XXX=COS(ARG)
      YYY=SIN(ARG)
      S(I,J)=CMPLX(XXX,YYY)
1     S(J,I)=S(I,J)
      DO 5 I=1,N
      DO 5 J=1,N
      DO 2 K=1,NOP
      KA=J+(K-1)*N
      D(K)=A(I,KA)
2     CONTINUE
      DETER=D(1)
      DO 3 KK=2,NOP
3     DETER=DETER+D(KK)
      A(I,J)=DETER
      DO 5 K=2,NOP
      KA=J+(K-1)*N
      DETER=D(1)
      DO 4 KK=2,NOP
4     DETER=DETER+D(KK)*S(K,KK)
5     A(I,KA)=DETER
6     DO 7 KK=1,NOP
      KA=(KK-1)*N+1
      CALL FACTOR (N,A(1,KA),P(KA),NROW)
7     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FACTRCS (N,NOP,M,A,P,NROW,NCOL,MODE)
C
C     SUBROUTINE FACTRCS TAKES CARE OF FACTORIZATION OF MATRICIES
C     WITH SEGMENTS ON AXIS OF ROTATION
C
      COMPLEX A,SUM
      INTEGER P
      DIMENSION A(NROW,NCOL), P(NCOL)
      NA=N*NOP
      NAP=NA+1
      NT=NA+M
      FNOP=NOP
      GO TO (1,2,4), MODE
    1 CALL FACTORS (N,NOP,A,P,NROW,NCOL)
      IF (M.EQ.0) GO TO 7
    2 DO 3 I=1,M
      NAI=NA+I
    3 CALL SOLVE (N,A,P,A(1,NAI),NROW)
    4 DO 6 I=1,M
      IND=I+N
      DO 6 J=1,M
      JND=J+NA
      SUM=CMPLX(0.,0.)
      DO 5 K=1,N
    5 SUM=SUM+A(IND,K)*A(K,JND)
    6 A(IND,JND)=A(IND,JND)-SUM*FNOP
      CALL FACTOR (M,A(N+1,NAP),P(NAP),NROW)
    7 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE GF (ZK,CO,SI)
C
C     SUBROUTINE GF PROVIDES THE FUNCTION TO BE NUMERICALLY INTEGRATED
C     BY INTX.  THE FORM IS: EXP(I*K*R)/K*R.  THE REAL PART IS RETURNED
C     THROUGH CO AND THE IMAGINARY PART OF THE INTEGRAND IS SI.
C
      COMMON /THI/ ZPK,RKB2,IJ
      ZDK=ZK-ZPK
      RK=SQRT(RKB2+ZDK*ZDK)
      SI=SIN(RK)/RK
      IF (IJ) 1,2,1
 1    CO=COS(RK)/RK
      RETURN
C
C     WHEN I=J, SUBTRACT OUT A SINGULAR (1/RK) POINT--IT WILL BE
C     INCLUDED AT A LATER POINT IN SUBROUTINE INTX
C
 2    CO=(COS(RK)-1.)/RK
      RETURN
      END
```

```
      SUBROUTINE ON (EZR,EZI,ERR,ERI)
C
C     SUBROUTINE ON MODIFIES THE PERFECT IMIAGE FIELDS BY THE
C     APPROPRIATE REFLECTION COEFFICIENTS EVALUATED AT THE SPECULAR
C     POINTS.
C
      COMPLEX EZ,ER,ERX,ERY,ERZ,EPX,EPY,REFS,REFPS
      COMMON /REFL/ RHOX,RHOY,RHOZ,CABJ,SABJ,SALPR,PX,PY,REFS,REFPS
      EZ=CMPLX(EZR,EZI)
      ER=CMPLX(ERR,ERI)
      ERX=RHOX*ER+CABJ*EZ
      ERY=RHOY*ER+SABJ*EZ
      ERZ=RHOZ*ER+SALPR*EZ
      EPY=PX*ERX+PY*ERY
      EPX=PX*EPY
      EPY=PY*EPY
      ERX=REFS*ERX+REFPS*EPX
      ERY=REFS*ERY+REFPS*EPY
      ERZ=REFS*ERZ
      EZ=ERX*CABJ+ERY*SABJ+ERZ*SALPR
      ER=ERX*RHOX+ERY*RHOY+ERZ*RHOZ
      EZR=REAL(EZ)
      EZI=AIMAG(EZ)
      ERR=REAL(ER)
      ERI=AIMAG(ER)
      RETURN
      END
```

```
      SUBROUTINE INTG (B,S,RH,ZP,Q1,QP2,ETR,ETI,DIL,DIK,IJ,IP)
C
C     SUBROUTINE INTG IS USED IN COMPUTING THE ENTRIES FOR THE CM MATRIX
C     IT COMPUTES THE E-FIELD AT AN OBSERVATION SEGMENT DUE TO A UNIT
C     CURRENT ON THE SOURCE SEGMENT.  THE SUBROUTINE RETURNS THE
C     INTERPOLATED TANGENTIAL FIELDS FOR THE SEGMENTS AS FOLLOWS:
C       ETR(1) AND ETI(1) ARE THE FIELDS FOR SEGMENTS CONNECTED TO THE
C         NEGATIVE END OF THE SOURCE SEGMENT.
C       ETR(2) AND ETI(2) ARE THE FIELDS FOR THE OBSERVATION POINT SEG
C       ETR(3) AND ETI(3) ARE THE FIELDS FOR SEGMENTS CONNECTED TO THE
C         POSITIVE END OF THE SOURCE SEGMENT.
C
      DIMENSION ETR(3), ETI(3)
      DATA TP/6.283185308/
C
C      COMPUTE THE E-FIELDS REFERENCED TO THE SOURCE SEGMENT.
C
      CALL EFLD (B,S,RH,ZP,IJ,EZRS,EZIS,ERRS,ERIS,EZRC,EZIC,ERRC,ERIC,EZ
     1RK,EZIK,ERRK,ERIK)
      IF (IP.NE.2) GO TO 1
C
C     IF COMPUTATION IS PERFORMED FOR THE IMAGE FIELDS, MODIFY THE
C     PERFECT GROUND IMAGE FIELDS BY THE APPROPRIATE REFLECTION COEFF
C
      CALL GN (EZRS,EZIS,ERRS,ERIS)
      CALL GN (EZRC,EZIC,ERRC,ERIC)
      CALL GN (EZRK,EZIK,ERRK,ERIK)
C
C     TAKE A DOT PRODUCT OF THE SOURCE FIELDS TO COMPUTE THE TANGENTAL
C     FIELDS AT THE OBSERVATION POINT.
C
  1   ETRS=EZRS*Q1+ERRS*QP2
      ETIS=EZIS*Q1+ERIS*QP2
      ETRC=EZRC*Q1+ERRC*QP2
      ETIC=EZIC*Q1+ERIC*QP2
      ETRK=EZRK*Q1+ERRK*QP2
      ETIK=EZIK*Q1+ERIK*QP2
      CL=TP*DIL
      CK=TP*DIK
      SINL=SIN(CL)
      COSL=COS(CL)
      SINK=SIN(CK)
      COSK=COS(CK)
      SILK=SIN(CL+CK)
      CONS=SINL+SINK-SILK
      ETR(1)=(SINK*ETRK+(COSK-1.)*ETRS-SINK*ETRC)/CONS
      ETI(1)=(SINK*ETIK+(COSK-1.)*ETIS-SINK*ETIC)/CONS
      ETR(2)=(-SILK*ETRK+(COSL-COSK)*ETRS+(SINL+SINK)*ETRC)/CONS
      ETI(2)=(-SILK*ETIK+(COSL-COSK)*ETIS+(SINL+SINK)*ETIC)/CONS
      ETR(3)=(SINL*ETRK+(1.-COSL)*ETRS-SINL*ETRC)/CONS
      ETI(3)=(SINL*ETIK+(1.-COSL)*ETIS-SINL*ETIC)/CONS
      RETURN
      END
```

```
      SUBROUTINE INTX (EL1,EL2,RKB2,ZPK,B,IJ,SGR,SGI)
C
C     INTX IS AN ADAPTIVE RHOMBERG INTEGRATION SCHEME
C
C
C     REFERENCE:  JOURNAL OF COMPUTATIONAL PHYSICS  5, PP 265-279
C     1970-- A VARIABLE INTERVAL WIDTH QUADRATURE TECHNIQUE BASED ON
C     RHOMBERG'S METHOD , E. K. MILLER, ET AL
C
      DATA NX,NM,NTS,RX/1,65536,4,1.E-4/
      Z=EL1
      ZE=EL2
      IF (IJ.EQ.0) ZE=0.
      S=ZE-Z
      EP=10*NM
      EP=S/EP
      ZEND=ZE-EP
      SGR=0.0
      SGI=0.0
      NS=NX
      NT=0
C
C     GF IS THE FUNCTION TO BE NUMERICALLY INTEGRATED
C
      CALL GF (Z,G1R,G1I)
 1    DZ=S/NS
      DZOT=DZ*0.5
      ZP=Z+DZ
      IF (ZP-ZE) 3,3,2
 2    DZ=ZE-Z
      IF (ABS(DZ)-EP) 17,17,3
 3    DZOT=DZ/2.
      ZP=Z+DZOT
      CALL GF (ZP,G3R,G3I)
      ZP=Z+DZ
      CALL GF (ZP,G5R,G5I)
 4    T00R=(G1R+G5R)*DZOT
      T00I=(G1I+G5I)*DZOT
      T01R=(T00R+DZ*G3R)*0.5
      T01I=(T00I+DZ*G3I)*0.5
      T10R=(4.0*T01R-T00R)/3.0
      T10I=(4.0*T01I-T00I)/3.0
      TE1R=TEST(T01R,T10R)
      TE1I=TEST(T01I,T10I)
      IF (TE1I-RX) 5,5,6
 5    IF (TE1R-RX) 8,8,6
 6    ZP=Z+DZ*0.25
      CALL GF (ZP,G2R,G2I)
      ZP=Z+DZ*0.75
      CALL GF (ZP,G4R,G4I)
      T02R=(T01R+DZOT*(G2R+G4R))*0.5
      T02I=(T01I+DZOT*(G2I+G4I))*0.5
      T11R=(4.0*T02R-T01R)/3.0
      T11I=(4.0*T02I-T01I)/3.0
      T20R=(16.0*T11R-T10R)/15.0
      T20I=(16.0*T11I-T10I)/15.0
      TE2R=TEST(T11R,T20R)
      TE2I=TEST(T11I,T20I)
      IF (TE2I-RX) 7,7,14
 7    IF (TE2R-RX) 9,9,14
 8    SGR=SGR+T10R
      SGI=SGI+T10I
      NT=NT+2
      GO TO 10
```

```
 9    SGR=SGR+T20R
      SGI=SGI+T20I
      NT=NT+1
 10   Z=Z+DZ
      IF (Z-ZEND) 11,17,17
 11   G1R=G5R
      G1I=G5I
      IF (NT-NTS) 1,12,12
 12   IF (NS-NX) 1,1,13
 13   NS=NS/2
      NT=1
      GO TO 1
 14   NT=0
      IF (NS-NM) 16,15,15
 15   WRITE (61,20) Z
      GO TO 9
 16   NS=NS*2
      DZ=S/NS
      DZOT=DZ*0.5
      G5R=G3R
      G5I=G3I
      G3R=G2R
      G3I=G2I
      GO TO 4
 17   CONTINUE
C
C     IF I=J AN ANALYTIC DIFFERENCE TERM IN THE INTEGRAND
C     IS NOW INCLUDED IN THE CONTRIBUTION
C
      IF (IJ) 19,18,19
 18   SGR=2.*(SGR+ALOG((SQRT(B*B+S*S)+S)/B))
      SGI=2.*SGI
 19   CONTINUE
      RETURN
C
C
C
 20   FORMAT (24H STEP SIZE LIMITED AT Z=F10.5)
      END
```

```
      SUBROUTINE JMELS (ETR,ETI,NCP,JP,NCM,JM,I)
C
C     JMELS HANDLES THE STUFFING OF THE COMPLEX IMPEDANCE MATRIX--CM.
C     THE SUBROUTINE IS CALLED ONLY WHEN AN ICON VALUE IS NEGATIVE--
C     INDICATING EITHER A MULTIPLE JUNCTION OR A CHANGE IN REF POLARITY.
C
C     INPUTS:
C       I   = OBSERVATION POINT SEGMENT
C       ETR = TANGENTIAL ELECTRIC FIELD (REAL) AT SEGMENT I
C       ETI = TANGENTIAL ELECTRIC FIELD (IMAG) AT SEGMENT I
C       NCP = NUMBER OF SEGMENTS CONNECTED TO POSITIVE END OF JTH SEG
C       JP  = ARRAY OF SEGMENT NUMBERS CONNECTED TO POS END OF JTH SEG
C       NCM = NUMBER OF SEGMENTS CONNECTED TO NEGATIVE END OF JTH SEG
C       JM  = ARRAY OF SEGMENT NUMBERS CONNECTED TO NEG END OF JTH SEG
C
      INTEGER P
      COMPLEX CM,FJ,EINC
      COMMON /2/ CM(22,100),EINC(100),P(100)
      DIMENSION JP(25), JM(25)
      FJ=CMPLX(0.,1.)
      IF (NCP.LT.1) GO TO 2
      DO 1 J=1,NCP
      JPJ=JP(J)
    1 CM(I,JPJ)=CM(I,JPJ)+ETR+FJ*ETI
    2 CONTINUE
      IF (NCM.LT.1) GO TO 4
      DO 3 J=1,NCM
      JMJ=JM(J)
    3 CM(I,JMJ)=CM(I,JMJ)-ETR-FJ*ETI
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE JUNC (J,JNO,NC1,NSEG1,NC2,NSEG2,D)
C
C     SUBROUTINE JUNC IS USED TO CHECK SEGMENT ENDS FOR MULTIPLE
C     JUNCTIONS.  THIS SUBR IS ONLY CALLED IF AN ICON VALUE IS NEGATIVE.
C      INPUTS:
C        J     = SEGMENT NUMBER TO BE TESTED
C        JNO   = ICON VALUE OF J-TH SEGMENT TO BE CHECKED
C      OUTPUTS:
C        NC1   = NUMBER OF SEGMENTS WHOSE NEG END IS CONNECTED TO JNO
C        NC2   = NUMBER OF SEGMENTS WHOSE POS END IS CONNECTED TO JNO
C        NSEG1 = ARRAY OF SEG NUMBERS WHOSE NEG END IS CONNECTED TO JNO
C        NSEG2 = ARRAY OF SEG NUMBERS WHOSE POS END IS CONNEC ED TO JNO
C        D     = AVG LENGTH OF J-TH SEG AND AVG OF ALL OTHER CONN SEGS.
C
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      DIMENSION NSEG1(25), NSEG2(25)
      NC1=0
      NC2=0
      SNC=0.0
C
C     CHECK FOR NEG ENDS CONNECTED TO JNO
C
      DO 4 I=1,N
      IF (ICON1(I)-JNO) 2,1,2
 1    IF (I.EQ.J) GO TO 2
      NC1=NC1+1
      IF (NC1.GT.25) GO TO 5
      NSEG1(NC1)=I
      SNC=SNC+SI(I)
C
C     CHECK FOR POS ENDS CONNECTED TO JNO
C
 2    IF (ICON2(I)-JNO) 4,3,4
 3    IF (I.EQ.J) GO TO 4
      NC2=NC2+1
      IF (NC2.GT.25) GO TO 5
      NSEG2(NC2)=I
      SNC=SNC+SI(I)
 4    CONTINUE
      FC=NC1+NC2
C
C     COMPUTE AN AVERAGE SEGMENT LENGTH FOR THE MULTIPLE JUNCTION
C
      D=(SI(J)+SNC/FC)/2.0
      RETURN
 5    WRITE (61,6) JNO
      STOP
C
C
C
 6    FORMAT (41H ERROR - TOO MANY CONNECTIONS TO JUNCTION14)
      END
```

```
      SUBROUTINE LINE (I,NS,TAU,WT,TENS,WRAD,X1,Y1,Z1,X2,Y2,Z2)
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
C
C     THIS SUBROUTINE IS USED TO CALCULATE THE GEOMETRIC COORDINATES OF
C     EACH MAJOR ANTENNA ARM.  THE DATA GENERATED BY THIS SUBROUTINE IS
C     X,Y,Z COORDINATE OF THE CENTER OF A SEGMENT PLUS THE ALPHA AND BET
C     ORIENTATION ANGLES OF EACH POINT.  INTERCONNECTION DATA IS ALSO GE
C     EACH OF THE SEGMENTS.  BY SPECIFYING THE PROPER PARAMETERS IN THE
C     CALL ONE HAS THE CHOICE OF USING A TAPERED SEGMENT LENGTH WITH  A
C     CATENARY FORM OR A LINEAR FORM.
C
C     IF TENS =0. THEN DONT MODEL A CATENARY
      IF (TENS.LE.1.) TENS=1.E100
      XINC=X2-X1
      YINC=Y2-Y1
      ZINC=Z2-Z1
      RHO=SQRT(XINC**2+YINC**2+ZINC**2)
      RHOXY=SQRT(XINC**2+YINC**2)
      BETA=AATAN2(YINC,XINC)
      EXPSUM=0.
      NEXP=-1
C
C     CALCULATE SEGMENT LENGTH SLO.  IF TAPERED SEG IS USED SPECIFY TAU
C
      DO 1 LS=1,NS
    1 EXPSUM=EXPSUM+(1.+TAU)**(LS-1)
      SLO=RHO/EXPSUM
C
C     CALC AN APPROX VALUE FOR THE ALPHA ANGLE USING ST LINE SEG.  ALFA
C     WILL BE USED TO DETERMINE THE INCREMENTAL X AND Y STEP
C
      ALFA=AATAN2(ZINC,RHOXY)
      CA=COS(ALFA)
      SA=SIN(ALFA)
      CAB=CA*COS(BETA)
      SAB=CA*SIN(BETA)
C
C     SET UP SEGMENT PARAMETERS.  IF WIRE WEIGHT IS SPECIFIED, CATENARY
C     BE CALCULATED.  FOR VERTICAL ELEMENTS NO CATENARY WILL BE USED
C
      NEND=NS+I-1
      XX1=X1
      YY1=Y1
      ZZ1=Z1
      CAT=WT*COLAM/(2.*TENS)
      DO 4 M=I,NEND
      NEXP=NEXP+1
      SL=SLO*(1.+TAU)**NEXP
      SLX=SL*CAB
      SLY=SL*SAB
      XX2=XX1+SLX
      YY2=YY1+SLY
      XPRIME=SQRT((XX2-X1)**2+(YY2-Y1)**2)
      IF (ABS(ALFA).LE.1.5) GO TO 2
      ZZ2=ZZ1+SL*SA
      GO TO 3
    2 ZZ2=Z2-(RHOXY-XPRIME)*(CAT*XPRIME+ZINC/RHOXY)
    3 XY=SQRT(SLX**2+SLY**2)
      ALPHA=AATAN2((ZZ2-ZZ1),XY)
      X(M)=(XX1+XX2)/2
      Y(M)=(YY1+YY2)/2
      Z(M)=(ZZ1+ZZ2)/2.
      SI(M)=SQRT(XY**2+(ZZ2-ZZ1)**2)
```

```
      BI(M)=WRAD
      ALP(M)=ALPHA
      BET(M)=BETA
      ICON1(M)=M-1
      ICON2(M)=M+1
      XX1=XX2
      YY1=YY2
      ZZ1=ZZ2
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE NEFLD (AIR,AII,BIR,BII,CIR,CII,ZRATI,KSYMP)
C
C     SUBROUTINE NEFLD IS USED TO CALCULATE THE NEAR ELECTRIC FIELD
C     AT A SELECTION OF OBSERVATION POINTS.  THE INPUTS ARE THE INITIAL
C     POINT: X0,Y0,AND Z0 AND THE FINAL POINT X1,Y1 AND Z1.  NXY+1 POINTS
C     ARE EVALUATED, AND AN INTEGRAL OF THE TANGENTIAL E-FIELD IS EVALUA
C     TO GIVE A VOLTAGE DROP ALONG THE PATH.  INPUT POSITIONS ARE GIVEN
C     IN METERS AND THE FIELD VALUES ARE RETURNED IN VOLTS/METER.
C
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      COMPLEX ZRATI,REFS,REFPS,ZRSIN
      COMMON /3/ CAB(100),SAB(100),SALP(100)
      COMMON /REFL/ RHOX,RHOY,RHOZ,CABJ,SABJ,SALPR,PX,PY,REFS,REFPS
      DIMENSION AIR(100), AII(100), BIR(100), BII(100), CIR(100), CII(10
     10)
      COMPLEX FJ,EZP,ERHO,EX,EY,EZ,EP,SUM,ET
      FJ=CMPLX(0.,1.)
      PI=3.14159265
      TP=2.*PI
      TA=PI/180.
      FACTOR=1./COLAM
C
C     READ IN INITIAL AND FINAL POINT COORDINATES---DIM ARE IN METERS
C
    1 READ (60,15) X0,Y0,Z0,X1,Y1,Z1,NXY,NFLD
      WRITE (61,16) X0,Y0,Z0,X1,Y1,Z1
      WRITE (61,17)
C
C     CALCULATE DIRECTION COSINES FOR OBSERVATION VECTOR
C
      RHOXY=SQRT((X1-X0)**2+(Y1-Y0)**2)
      RHOXYZ=SQRT(RHOXY**2+(Z1-Z0)**2)
      BETA=AATAN2((Y1-Y0),(X1-X0))
      ALPHA=AATAN2((Z1-Z0),RHOXY)
      COSALPO=COS(ALPHA)
      SALPO=SIN(ALPHA)
      CABO=COSALPO*COS(BETA)
      SABO=COSALPO*SIN(BETA)
C
C     CONVERT DIMENSIONS FROM METERS TO WAVELENGTHS FOR THE PROGRAM
C
      DX=FACTOR*(X1-X0)/NXY
      DY=FACTOR*(Y1-Y0)/NXY
      DZ=FACTOR*(Z1-Z0)/NXY
      XOB=X0*FACTOR
      YOB=Y0*FACTOR
      ZOB=Z0*FACTOR
      DRHOXYZ=RHOXYZ/NXY
      PATH=0.
      SUM=CMPLX(0.,0.)
C
C     MAIN LOOP TO CALC NEAR FIELDS ALONG SPECIFIED PATH
C
      NXY=NXY+1
      DO 14 I=1,NXY
      EX=CMPLX(0.,0.)
      EY=CMPLX(0.,0.)
      EZ=CMPLX(0.,0.)
      DO 11 J=1,N
      S=SI(J)
      B=0.
      XJ=X(J)
      YJ=Y(J)
```

```
      ZJ=Z(J)
      CABJ=CAB(J)
      SABJ=SAB(J)
      SALPJ=SALP(J)
      XIJ=XOB-XJ
      YIJ=YOB-YJ
      RFL=-1.
      DO 11 IP=1,KSYMP
      RFL=-RFL
      ZIJ=ZOB-ZJ*RFL
      ZP=XIJ*CABJ+YIJ*SABJ+ZIJ*SALPJ*RFL
      RS=XIJ*XIJ+YIJ*YIJ+ZIJ*ZIJ
      RH2=RS-ZP*ZP
      IF (RH2.LT.1.E-20) GO TO 2
      RH=SQRT(RH2)
      GO TO 3
2     RH=0.
3     CONTINUE
      SALPR=SALPJ*RFL
      RHOX=XIJ-CABJ*ZP
      RHOY=YIJ-SABJ*ZP
      RHOZ=ZIJ-SALPJ*ZP*RFL
      RMAG=SQRT(RHOX*RHOX+RHOY*RHOY+RHOZ*RHOZ)
      IF (RMAG.GT.1.E-6) GO TO 4
      RHOX=0.
      RHOY=0.
      RHOZ=0.
      GO TO 5
4     RHOX=RHOX/RMAG
      RHOY=RHOY/RMAG
      RHOZ=RHOZ/RMAG
5     RMAG=SQRT(YIJ*YIJ+XIJ*XIJ)
      IF (IP.NE.2) GO TO 8
      IF (RMAG.GT.1.E-6) GO TO 6
      PX=0.
      PY=0.
      CTH=1.
      ZRSIN=CMPLX(1.,0.)
      GO TO 7
6     PX=YIJ/RMAG
      PY=-XIJ/RMAG
      CTH=ZIJ/SQRT(RS)
      ZRSIN=+CSQRT(1.-ZRATI*ZRATI*(1.-CTH*CTH))
7     REFS=(CTH-ZRATI*ZRSIN)/(CTH+ZRATI*ZRSIN)
      REFPS=-(ZRATI*CTH-ZRSIN)/(ZRATI*CTH+ZRSIN)
      REFPS=REFPS-REFS
8     CONTINUE
      CALL EFLD (B,S,RH,ZP,1,EZRS,EZIS,ERRS,ERIS,EZRC,EZIC,ERRC,ERIC,EZR
     1K,EZIK,ERRK,ERIK)
      IF (IP.NE.2) GO TO 9
      CALL GN (EZRS,EZIS,ERRS,ERIS)
      CALL GN (EZRC,EZIC,ERRC,ERIC)
      CALL GN (EZRK,EZIK,ERRK,ERIK)
9     EZP=EZRK*AIR(J)-EZIK*AII(J)+EZRS*BIR(J)-EZIS*BII(J)+EZRC*CIR(J)-EZ
     1IC*CII(J)+FJ*(EZRK*AII(J)+EZIK*AIR(J)+EZRS*BII(J)+EZIS*BIR(J)+EZRC
     2*CII(J)+EZIC*CIR(J))
      ERHO=ERRK*AIR(J)-ERIK*AII(J)+ERRS*BIR(J)-ERIS*BII(J)+ERRC*CIR(J)-E
     1RIC*CII(J)+FJ*(ERRK*AII(J)+ERIK*AIR(J)+ERRS*BII(J)+ERIS*BIR(J)+ERR
     2C*CII(J)+ERIC*CIR(J))
      IF (IP.NE.2) GO TO 10
      EZP=-EZP
      ERHO=-ERHO
10    EX=EX+EZP*CABJ+ERHO*RHOX
      EY=EY+EZP*SABJ+ERHO*RHOY
```

```
      EZ=EZ+EZP*SALPJ*RFL+ERHO*RHOZ
   11 CONTINUE
C
C     EX,EY AND EZ ARE THE COMPLEX E-FIELDS IN THE CARTESIAN
C     COORDINATE DIRECTIONS AT THE OBSERVATION POINT.
C
      ETOTAL=SQRT(CABS(EX)**2+CABS(EY)**2+CABS(EZ)**2)/COLAM
      ET=(EX*CABO+EY*SABO+EZ*SALPO)/COLAM
      ETANG=CABS(ET)
      IF (I.EQ.1) GO TO 12
      IF (I.EQ.NXY) GO TO 12
      SUM=SUM+ET
      GO TO 13
   12 SUM=SUM+ET/2.
   13 CONTINUE
      XOB=XOB+DX
      YOB=YOB+DY
      ZOB=ZOB+DZ
      WRITE (61,18) PATH,ETANG,ETOTAL
      PATH=PATH+DRHOXYZ
   14 CONTINUE
C
C     THE TANGENTIAL E-FIELD IS INTEGRATED VIA THE TRAPEZOINDAL
C     RULE TO COMPUTE THE VOLTAGE DROP ALONG THE SPECIFIED PATH
C
      VDROP=CABS(SUM)*DRHOXYZ
      WRITE (61,19) VDROP,NXY
      IF (NFLD.NE.0) GO TO 1
      RETURN
C
C
   15 FORMAT (6F10.4,2I5)
   16 FORMAT (16H1  E-FIELD FROM ,3F10.4,11H METERS TO ,3F10.4,7H METERS
     1)
   17 FORMAT (//,46H POSITION ON PATH (METERS)      E-TANGENT (V/M),24H
     1   TOTAL E-FIELD (V/M),//)
   18 FORMAT (3E20.5)
   19 FORMAT (//,50H THE INTEGRAL OF THE E-FLD TANGENT TO THE PATH IS ,E
     115.5,7H VOLTS.,I5,34H POINTS USED TO EVALUATE INTEGRAL.,//)
      END
```

```
      SUBROUTINE SOLVE (N,A,P,B,NDIM)
C
C     SUBROUTINE TO SOLVE THE MATRIX EQUATION LU*X=B WHERE L IS A UNIT L
C     TRIANGULAR MATRIX AND U IS AN UPPER TRIANGULAR MATRIX BOTH OF WHIC
C     IN A.  THE RHS VECTOR B IS INPUT AND THE SOLUTION IS RETURNED THRO
C
      COMPLEX A,B,Y,SUM
      INTEGER P,PI
      DIMENSION A(NDIM,NDIM), P(NDIM), B(NDIM)
      COMMON /SCRATM/ Y(100)
C
C     FORWARD SUBSTITUTION
C
      DO 3 I=1,N
      PI=P(I)
      Y(I)=B(PI)
      B(PI)=B(I)
      IP1=I+1
      IF (IP1.GT.N) GO TO 2
      DO 1 J=IP1,N
      B(J)=B(J)-A(J,I)*Y(I)
    1 CONTINUE
    2 CONTINUE
    3 CONTINUE
C
C     BACKWARD SUBSTITUTION
C
      DO 6 K=1,N
      I=N-K+1
      SUM=CMPLX(0.,0.)
      IP1=I+1
      IF (IP1.GT.N) GO TO 5
      DO 4 J=IP1,N
      SUM=SUM+A(I,J)*B(J)
    4 CONTINUE
    5 CONTINUE
      B(I)=(Y(I)-SUM)/A(I,I)
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLVECS (N,NOP,M,A,P,B,NROW,NCOL)
C     SUBROUTINE SOLVECS TAKES CARE OF SOLUTION OF PROBLEMS WITH SEGMENT
C     ON AXIS OF ROTATION
C
      COMPLEX A,B,SUM
      INTEGER P
      DIMENSION A(NROW,NCOL), P(NCOL), B(NCOL)
      NA=N*NOP
      NAP=NA+1
      NT=NA+M
      CALL SOLVES (N,NOP,A,P,B,NROW,NCOL)
      IF (M.EQ.0) GO TO 6
      DO 2 I=1,M
      IND=I+N
      INDX=I+NA
      SUM=CMPLX(0.,0.)
      DO 1 K=1,NA
    1 SUM=SUM+A(IND,K)*B(K)
    2 B(INDX)=B(INDX)-SUM
      CALL SOLVE (M,A(N+1,NAP),P(NAP),B(NAP),NROW)
      DO 5 I=1,N
      SUM=CMPLX(0.,0.)
      DO 3 K=NAP,NT
    3 SUM=SUM+A(I,K)*B(K)
      DO 4 K=1,NOP
      IND=I+(K-1)*N
    4 B(IND)=B(IND)-SUM
    5 CONTINUE
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLVES (N,NOP,A,P,B,NROW,NCOL)
C
C     SUBROUTINE SOLVES SOLVES ROTATIONALLY SYMMETRIC MATRICIES
C
      COMPLEX A,B,Y,SUM,S
      INTEGER P
      COMMON /SMAT/ S(12,12)
      DIMENSION A(NROW,NCOL), P(NCOL), B(NCOL)
      COMMON /SCRATM/ Y(100)
      IF (NOP.EQ.1) GO TO 5
      FNORM=1./NOP
      DO 4 I=1,N
      DO 1 K=1,NOP
      IA=I+(K-1)*N
    1 Y(K)=B(IA)
      SUM=Y(1)
      DO 2 K=2,NOP
    2 SUM=SUM+Y(K)
      B(I)=SUM*FNORM
      DO 4 K=2,NOP
      IA=I+(K-1)*N
      SUM=Y(1)
      DO 3 J=2,NOP
    3 SUM=SUM+Y(J)*CONJG(S(K,J))
    4 B(IA)=SUM*FNORM
    5 DO 6 KK=1,NOP
      IA=(KK-1)*N+1
      CALL SOLVE (N,A(1,IA),P(IA),B(IA),NROW)
    6 CONTINUE
      IF (NOP.EQ.1) RETURN
      DO 10 I=1,N
      DO 7 K=1,NOP
      IA=I+(K-1)*N
    7 Y(K)=B(IA)
      SUM=Y(1)
      DO 8 K=2,NOP
    8 SUM=SUM+Y(K)
      B(I)=SUM
      DO 10 K=2,NOP
      IA=I+(K-1)*N
      SUM=Y(1)
      DO 9 J=2,NOP
    9 SUM=SUM+Y(J)*S(K,J)
   10 B(IA)=SUM
      RETURN
      END
```

```
      FUNCTION TEST (F1,F2)
C
C     FUNCTION TEST IS USED BY INTX TO COMPUTE THE RELATIVE ERROR OF THE
C     NUMERICAL SUB INTEGRATION.
C
      IF (ABS(F2)-1.0E-40) 2,2,1
    1 TEST=ABS((F1-F2)/F2)
      RETURN
    2 TEST=0.
      RETURN
      END
```

```
      SUBROUTINE TRIO (J,JCO1,JCO2,DIL,DIK)
C
C     SUBROUTINE TRIO IS USED TO DETERMINE THE TYPE OF JUNCTION USED AT
C     THE SEGMENT ENDS.  THREE TYPES OF SEGMENT END JUNCTIONS ARE ALLOW
C     --IF ICON IS 0, SEGMENT END IS OPEN--IF ICON EQUALS SEGMENT NUMBER
C     THEN SEG END IS GROUNDED--IF ICON IS NEG THEN A CHECK IS MADE FOR
C     MULTIPLE JUNCTIONS.  TRIO RETURNS AN EQUIVALENT DISTANCE (DIL,DIK)
C     WHICH IS USED FOR INTERPOLATING CURRENTS FROM 1 SEG TO THE NEXT.
C      INPUTS:
C        J      = SEGMENT NUMBER TO BE CHECKED
C      OUTPUTS:
C        JCO1   = ICON VALUE OF J-TH SEG NEG END
C        JCO2   = ICON VALUE OF J-TH SEG POS END
C        DIL    = AVG DISTANCE FOR CURRENT INTERPOLATION ON SEG NEG END
C        DIK    = AVG DISTANCE FOR CURRENT INTERPOLATION ON SEG POS END
C
      COMMON /1/ N,NP,X(100),Y(100),Z(100),SI(100),BI(100),ALP(100),BET(
     1100),ICON1(100),ICON2(100),COLAM,NX
      COMMON /4/ NCOX,JOX(25),NCIX,JIX(25),NCOZ,JOZ(25),NCIZ,JIZ(25)
      S=SI(J)
      JCO1=ICON1(J)
      JCO2=ICON2(J)
C
C     **********CHECK SEGMENT NEGATIVE END**********
C
      IF (JCO1) 1,2,3
C
C     MULTIPLE JUNCTION
C
    1 CALL JUNC (J,JCO1,NCOX,JOX,NCIX,JIX,DIL)
      GO TO 4
C
C     OPEN CIRCUIT--FREE END -- INTERPOLATE ONLY TO END OF SEGMENT
C
    2 DIL=S/2.0
      GO TO 4
C
C     NORMAL JUNCTION CONNECTION--SIMPLE JUNCTION OR GROUNDED SEGMENT
C
    3 DIL=(SI(JCO1)+S)/2.0
C
C     **********CHECK SEGMENT POSITIVE END**********
C
    4 IF (JCO2) 5,6,7
C
C     MULTIPLE JUNCTION
C
    5 CALL JUNC (J,JCO2,NCOZ,JOZ,NCIZ,JIZ,DIK)
      GO TO 8
C
C     OPEN CIRCUIT--FREE END
C
    6 DIK=S/2.0
      GO TO 8
C
C     NORMAL JUNCTION CONNECTION--SIMPLE JUNCTION OR GROUNDED SEGMENT
C
    7 DIK=(SI(JCO2)+S)/2.0
    8 CONTINUE
      RETURN
      END
```

APPENDIX B TABLE I SEGMENT EXPANSION COEFFICIENTS (TAU)

L/L0	NUMBER OF SEGMENTS--N 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	0	-39	-.46	-.49	-50	-50	-50	-50	-50	-50	-50	50	-50	50	50	50	50	50	50
3	1.00	0	-19	-.26	-30	-31	-32	-33	-33	-33	-34	-34	-34	34	34	34	34	34	34
4	2.00	.30	0	-12	-17	-20	-22	-23	-24	24	-25	25	25	25	25	25	25	25	25
5	3.00	56	15	0	-08	-12	-15	16	-17	-18	-19	-19	-19	20	20	20	20	20	20
6	4.00	79	28	09	0	-06	-09	-11	13	-14	-14	15	15	16	16	16	16	17	17
7	5.00	1.00	39	17	06	0	-04	-07	-09	-10	-11	-12	12	13	13	13	14	14	14
8	6.00	1.19	49	24	11	04	0	-03	06	-07	-08	09	10	10	11	11	11	12	12
9	7.00	1.37	58	30	16	08	03	0	-03	-05	-06	07	08	08	09	09	10	10	10
10	8.00	1.54	66	35	20	12	06	03	0	-02	-04	05	06	07	07	08	08	08	09
11	9.00	1.70	74	40	24	15	09	05	02	0	-02	03	04	05	06	06	07	07	07
12	10.00	1.85	81	45	28	18	11	07	04	02	0	02	03	04	04	05	06	06	06
13	11.00	2.00	88	49	31	20	14	09	06	03	01	0	02	03	03	04	05	05	05
14	12.00	2.14	94	53	34	23	16	11	07	05	03	01	0	01	02	03	04	04	04
15	13.00	2.27	1.00	.57	37	25	17	12	09	06	04	02	01	0	01	02	03	03	04
16	14.00	2.41	1.06	61	39	27	19	14	10	07	05	03	02	01	0	01	02	02	03
17	15.00	2.53	1.11	64	42	29	21	15	11	08	06	04	03	02	01	0	01	02	02
18	16.00	2.65	1.16	67	44	31	22	17	13	09	07	05	04	03	02	01	0	01	02
19	17.00	2.77	1.22	70	46	33	24	18	14	10	08	06	05	03	02	01	01	0	01
20	18.00	2.89	1.26	73	48	34	25	19	15	11	09	07	05	04	03	02	01	01	0
21	19.00	3.00	1.31	76	50	36	27	20	16	12	10	08	06	05	04	03	02	01	01
22	20.00	3.11	1.36	79	52	37	28	21	17	13	10	08	07	05	04	03	02	02	01
23	21.00	3.22	1.40	.82	.54	39	29	22	18	14	11	09	07	06	05	04	03	02	01
24	22.00	3.32	1.44	.84	56	40	30	23	18	15	12	10	08	06	05	04	03	03	02
25	23.00	3.42	1.48	.87	58	.42	31	24	19	15	13	10	08	07	06	05	04	03	02
26	24.00	3.52	1.53	.89	60	43	.32	25	20	16	13	11	09	07	06	05	04	03	03
27	25.00	3.62	1.56	.91	61	44	33	26	21	17	14	11	10	08	07	06	05	04	03
28	26.00	3.72	1.60	.94	63	.45	34	27	22	.18	14	12	10	08	.07	06	05	04	.03
29	27.00	3.82	1.64	96	.64	.47	35	28	.22	18	15	13	10	09	07	06	05	04	04
30	28.00	3.91	1.68	.98	66	48	36	28	23	19	16	13	11	09	08	.07	06	05	04
31	29.00	4.00	1.71	1.00	67	.49	.37	29	24	19	16	13	11	.10	.08	07	06	05	.04
32	30.00	4.09	1.75	1.02	69	50	38	30	24	20	17	14	12	.10	09	07	06	05	05
33	31.00	4.18	1.78	1.04	.70	.51	39	31	25	.20	17	14	12	10	09	.08	07	.06	.05
34	32.00	4.27	1.81	1.06	71	52	40	31	.25	.21	18	15	.13	11	.09	.08	07	06	.05
35	33.00	4.35	1.85	1.08	73	53	40	32	26	22	18	15	13	11	10	08	07	06	.06
36	34.00	4.44	1.88	1.10	74	.54	41	33	27	.22	18	.16	13	.12	10	09	08	07	.06
37	35.00	4.52	1.91	1.11	75	.55	42	33	27	23	19	16	14	12	10	.09	08	07	.06
38	36.00	4.60	1.94	1.13	76	56	43	.34	.28	.23	19	16	14	.12	11	09	08	07	.06
39	37.00	4.68	1.97	1.15	77	.57	.43	.35	28	.23	20	17	14	13	.11	.10	.08	07	07
40	38.00	4.76	2.00	1.17	.79	.57	.44	35	29	.24	.20	17	15	.13	.11	.10	.09	.08	.07
41	39.00	4.84	2.03	1.18	.80	.58	45	36	29	.24	21	.18	15	.13	.12	10	.09	.08	.07
42	40.00	4.92	2.06	1.20	.81	.59	.46	.36	.30	.25	21	18	15	.13	.12	.10	09	.08	.07
43	41.00	5.00	2.09	1.21	.82	.60	46	.37	30	.25	21	.18	16	.14	.12	.11	09	08	.07
44	42.00	5.08	2.11	1.23	.83	.61	.47	.37	31	.26	22	.19	16	.14	.12	11	10	09	08
45	43.00	5.15	2.14	1.24	84	.62	.47	.38	31	.26	22	19	16	.14	13	.11	10	09	.08
46	44.00	5.23	2.17	1.26	.85	.62	.48	38	32	26	22	.19	.17	15	13	11	10	.09	.08
47	45.00	5.30	2.19	1.27	.86	.63	49	39	.32	27	23	.20	17	15	13	12	10	09	08
48	46.00	5.37	2.22	1.29	87	.64	49	.39	.32	.27	23	20	17	.15	13	.12	11	.09	08
49	47.00	5.45	2.25	1.30	.88	.65	.50	.40	.33	.28	.23	.20	18	.15	.14	.12	11	10	.09
50	48.00	5.52	2.27	1.32	.89	.65	.50	.40	.33	.28	24	.20	.18	.16	14	12	11	10	.09