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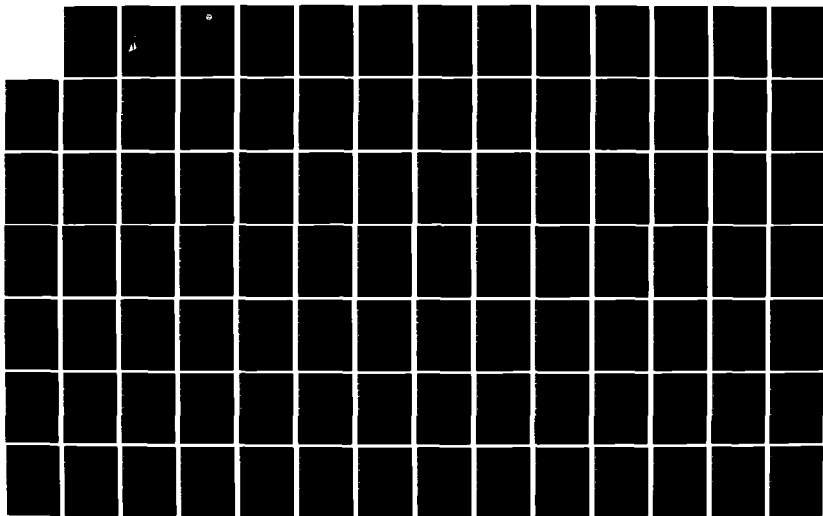
A WKB PROGRAM FOR ELF/VLF EARTH-IONOSPHERE EXCITATION
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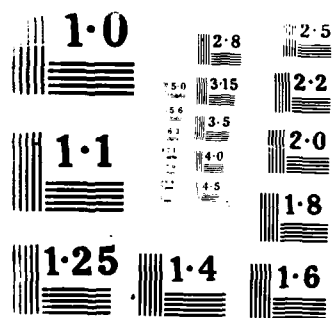
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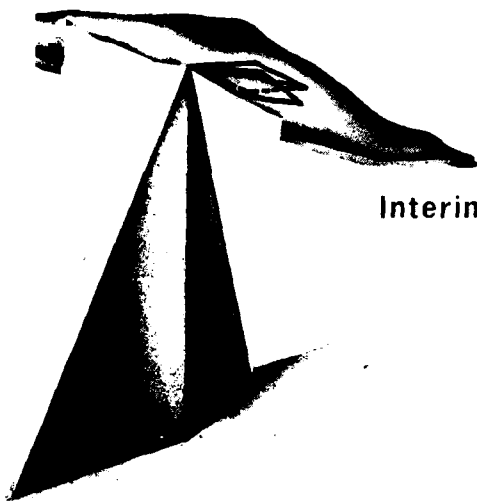
A WKB PROGRAM FOR ELF/VLF EARTH-IONOSPHERE EXCITATION BY SOURCES AT SATELLITE HEIGHTS

R. A. Pappert
L. R. Hitney

September 1982

Interim Report for Period May 1981–September 1982

Prepared for
Defense Nuclear Agency



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JM PATTON, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

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ABSTRACT

This report presents a variation of an earlier program [3] for calculating ELF/VLF excitation of the earth-ionosphere waveguide by point dipoles at satellite heights. The variation consists of implementing WKB formalism developed by Budden [2] for the purpose of speeding up the requisite field integrations. Allowance is made for the following: (1) calculating excitation factors for all electric field components E_x , E_y and E_z ; (2) calculating excitation by both electric and magnetic point dipoles; (3) calculating excitation by vertical, horizontal end-on and horizontal broadside configurations. A mode sum program is also included as an illustration of how the excitation factors are used in field calculations.

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I. INTRODUCTION

In a recent report [1] WKB formalism developed by Budden [2] for an anisotropic medium was used to speed up calculation of ELF/VLF modal height gains in the ionosphere to heights well in excess of the peak of the F layer. Justification for use of the WKB formalism lies in the fact that for altitudes sufficiently high in the ionosphere (i.e., $\gtrsim 110$ km for VLF, $\gtrsim 150$ km for ELF under daytime ionospheres and $\gtrsim 250$ km for ELF under nighttime ionospheres) the electromagnetic field is in the outgoing whistler mode and the ionospheric gradients are sufficiently weak. In this report the WKB method is appended to an earlier program [3] for calculating excitation of the earth-ionosphere waveguide by point dipoles at satellite altitudes. As with the latter program, provision is made for calculating excitation factors for all electric field components generated by both electric and magnetic point dipoles of arbitrary orientation. It can be expected that the present program will reduce the computer cost (Univac 1100) by about a factor of 1/3 in the lower ELF band (~ 75 Hz) and by more than an order of magnitude in the VLF band when the source altitudes are $\gtrsim 500$ km. We summarize in the following paragraphs the features necessary for an understanding of the present work.

All height dependent input quantities are referenced to a Cartesian coordinate system (x, y, z) such that the z axis is taken along the vertical and positive into the ionosphere. The (x, y, z) coordinate system is referred to in this report as the input coordinate system. The transmitter and receiver are located in the x - z plane with $z = 0$ being the ground. The source is taken to be imbedded in a semi-infinite, homogeneous, but anisotropic slab with lower boundary termed WKBHT in the input coordinate system. Thus, reflections from above the source are ignored. The primary plane wave field radiated by the elevated antenna at an earth ionosphere eigenangle, θ_n , is decomposed into downcoming magneto-ionic components and evaluated at $z = \text{WKBHT}$ in the input coordinate system. Next, two independent full wave starting solutions consistent with the condition of downcoming waves are assumed at an altitude termed LWSTHT in the input coordinate system. LWSTHT must be in the isotropic space between the ground and the lowest level of the ionosphere. The two independent solutions are numerically integrated upward to a level

termed TOPHT in the input coordinate system. At TOPHT the two solutions are combined to yield the proper modal polarization and decomposed into the down-coming whistler component. The full wave whistler component is then matched to the corresponding WKB component and the solution propagated to WKBHT via the WKB formulas. Finally, the strength of the full wave solution is determined by matching to the source generated whistler component previously determined at WKBHT.

The present program is a variant of a fields program [4] which necessitated starting the full wave integrations with outgoing wave and subsequent downward integration. That is in contrast with the present requirement of starting the full wave integrations with down-going wave and subsequent upward integration. To achieve this modification the specie profile and collision frequency read in (as was done in reference [3]) is left unaltered and coordinate transformations effected internally in the program. That is, read in of the latter quantities is referenced to what has been referred to previously as the input coordinate system (z axis positive into ionosphere, $z = 0$ at the ground). The profiles are read in from WKBHT down to level LWSTHT (or equivalently D) which is often taken to be ground ($LWSTHT = 0$). The coordinate system and profiles are then transformed by rotating 180° about the x -axis and translating in the z direction by the amount WKBHT. This is referred to as the prime coordinate system and represented by (x', y', z') . Mathematically the transformation is $z' = -z + WKBHT$. This has the effect that $TOPHT' = -LWSTHT + WKBHT$, $LWSTHT' = -TOPHT + WKBHT$ and $WKBHT' = 0$, where the left hand side of the equations are (apart from the ') the program names after the coordinate transformation. The transformation from the (x, y, z) system to the (x', y', z') system is effected internally in the program and achieves the goal that the starting full-wave solutions in the transformed system correspond to upgoing wave and that the full wave integrations proceed as in the original full-wave program [4]. Transformation to the primed system is achieved in the subroutine XINPUT.

Basic inputs to the present program must be supplied from an ELF/VLF earth-ionosphere waveguide program such as that of reference [5]. The inputs include mode eigenangles, derivatives of the modal function evaluated at the eigenangles (or related quantities) and the elements of the plane wave ionospheric reflection matrix as defined in reference [2].

For completeness, Budden's WKB formulas [2] are summarized in section II. Formulas used in matching the full wave and WKB field are given in section III. Principal outputs of the program are the excitation factors defined in section IV. Flow of the program and subroutine descriptions are given in section V. Section VI contains a discussion of the card deck arrangement for input along with discussion of a sample output. Application of the excitation factors for calculating mode sums is discussed in section VII where sample mode sum plots are included. Appendix A contains a listing of the excitation factor program. Appendix B contains a listing of the mode sum program used to generate the results shown in section VII.

II. SUMMARY OF WKB FORMULAS

For plane wave incidence of an rf wave on the ionosphere, Maxwell's equations can be written as [6]

$$e' = -iT e \quad (1)$$

where the prime denotes $(k^{-1} \partial / \partial z)$, with k the free space wave number, T a 4 x 4 matrix given by Budden [2], and e a column matrix composed of components of the electric ($\vec{E}$) and magnetic ($\vec{H}$) fields of the rf wave. The transpose of e is

$$e^T = (E_x, -E_y, Z_0 H_x, Z_0 H_y) \quad (2)$$

where Z_0 is the free space impedance. Henceforth the notation $H_x = Z_0^{-1} H_x$, $H_y = Z_0^{-1} H_y$ and $H_z = Z_0^{-1} H_z$ will be used.

The matrix T has four characteristic roots or eigenvalues, q_i ($i = 1, 2, 3, 4$), which satisfy the characteristic equation

$$\det (T - qI) = 0 \quad (3)$$

where I is the unit 4 x 4 matrix. This equation is the Booker quartic. Corresponding to any root q_i there is an eigencolumn $P = s^{(i)}$ which satisfies

$$T s^{(i)} = q_i s^{(i)} \quad (4)$$

Let S be the 4 x 4 matrix whose columns are $s^{(i)}$. For points where S is nonsingular, the column matrix f can be defined as

$$e = S f \text{ or } f = S^{-1} e \quad (5)$$

and it can be shown [2] that the elements of f satisfy

$$f'_k = -iq_k f_k + \sum_j I_{kj} f_j \quad ; j, k = 1, 4 \quad (6)$$

where

$$\Gamma = -S^{-1}S' \quad (7)$$

The preceding transformation can be carried out only when S is nonsingular. When two roots of the Booker quartic are equal, two of the columns $S^{(i)}$ are usually multiples of each other, and then S is singular. Near such points some of the coupling coefficients Γ_{kj} are very large and the points may be points of reflection or points where coupling between two up-going (or downgoing) waves is very strong. The present program cannot be used in such circumstances.

When the species densities and collision frequencies vary slowly enough with height and where no two of the q_j become nearly equal, the terms of Γ are small quantities and there is an approximate solution for which the non-diagonal elements of Γ are ignored. This solution is associated with one particular root q_j of the Booker quartic. It is [2]

$$f_j = \exp(-ik \int^z q_j dz + k \int^z \Gamma_{jj} dz) \quad (8)$$

and the corresponding field components [in Budden's notation] are

$$\begin{aligned} (E_x, E_y, H_x, H_y) = & (A_j F_j)^{-1/2} (a_3 q_j + a_4, -A_j, q_j A_j, a_5 q_j + a_6) \\ & \times \exp(-ik \int^z q_j dz + k \int^z \Gamma_{jj} dz) \end{aligned} \quad (9)$$

where

$$\begin{aligned} a_1 &= -(T_{11} + T_{44}) & a_4 &= T_{14} T_{42} - T_{12} T_{44} \\ a_2 &= T_{11} T_{44} - T_{14} T_{41} & a_5 &= T_{42} \end{aligned} \quad (10)$$

$$a_3 = T_{12} \quad a_6 = T_{41} T_{12} - T_{11} T_{42} \quad (11)$$

$$A_j = q_j^2 + a_1 q_j + a_2 \quad (12)$$

$$F_j = 2q_j A_j + (q_j^2 - T_{32})(2q_j + a_1) - (a_3 b_5 + b_3 a_5) \quad (13)$$

$$\begin{aligned}
2\Gamma_{jj} = & (A_j F_j)^{-1} \{ q_j^2 (a_3 b_5' - a_3' b_5 + a_5 b_3' - a_5' b_3) \\
& + a_4 b_6' - a_4' b_6 + a_6 b_4' - a_6' b_4 + q_j (a_3 b_6' - a_3' b_6 + a_4 b_5' - a_4' b_5 + a_5 b_4' \\
& - a_5' b_4 + a_6 b_3' - a_6' b_3) \}
\end{aligned} \tag{14}$$

In these equations the T_{ij} 's are the elements of the T matrix given by Budden p 389.

The essence of the program documented in this report is the implementation of equation (9) for altitudes exceeding a height termed TOPHT in the input coordinate system. The mode extracted from the magneto-ionic set is the least attenuated downcoming wave. Runge-Kutta integrations are used to calculate two independent full wave solutions at TOPHT from starting conditions at LWSTHT in the input coordinate system. The full-wave solutions at TOPHT are combined to satisfy the mode polarization condition and decomposed into magneto ionic components. The downcoming whistler component is then matched to the corresponding WKB component and the fields carried to WKBHT via equation (9).

III. FIELD MATCHING

As described in the introduction, it is necessary in the primed coordinate system to integrate two independent field solutions from the level $z' = \text{TOPHT}' = -\text{LWSTHT} + \text{WKBHT}$ to the level $z' = \text{LWSTHT}' = -\text{TOPHT} + \text{WKBHT}$. The initial solution vectors correspond in the prime system (at level TOPHT') to outgoing waves in vacuum and are taken to correspond to vertical and horizontal polarizations. The initial solution vectors are calculated in the subroutine WF INIT and are denoted by the matrix P as shown below

$$\begin{aligned}
 P(1,1) &= E_x = \cos(\theta_n) = C. & P(1,2) &= E_x = 0. \\
 P(2,1) &= -E_y = 0. & P(2,2) &= -E_y = 1. \\
 P(3,1) &= H_x = 0. & P(3,2) &= H_x = \cos(\theta_n) = C. \\
 P(4,1) &= H_y = 1. & P(4,2) &= H_y = 0.
 \end{aligned} \tag{15}$$

where E_j and H_j represent the j^{th} component of the electric and magnetic fields of the rf wave in the prime system and θ_n represents the eigenangle for the n^{th} earth ionosphere waveguide mode. The initial solutions are integrated to the level $z' = \text{LWSTHT}'$ via the Runge-Kutta integration scheme implemented in the subroutine WF INTG. At $z' = \text{LWSTHT}'$ each independent full-wave solution, P_i is decomposed into four magneto-ionic components as follows

$$P_i = \sum_{j=1}^4 \beta(i,j) S(j); i = 1,2 \tag{16}$$

where $S(j)$ are the magneto-ionic solution vectors. Thus,

$$\beta(i,j) = S^{-1}(j)P_i \tag{17}$$

where

$$\begin{aligned}
 S^{-1}(j)S(k) &= 0 \quad j \neq k \\
 &= 1 \quad j = k
 \end{aligned} \tag{18}$$

Because of the sorting achieved in the subroutine WF SORT, the upgoing (in the prime system) whistler mode is S(2). The total whistler component is structured from a linear combination of the components associated with the two independent full wave solutions. The two independent solutions are combined in such a way that they satisfy the modal polarization condition at LWSTHT in the input coordinate system

$$f = \frac{E_y}{H_y} = \frac{1 - {}_{\parallel}R_{\parallel\parallel}\bar{R}_{\parallel\parallel}}{{}_{\perp}R_{\parallel\perp}\bar{R}_{\perp\perp}} = \frac{{}_{\parallel}R_{\perp\parallel}\bar{R}_{\parallel\perp}}{1 - {}_{\perp}R_{\perp\perp}\bar{R}_{\perp\perp}} \quad (19)$$

In this equation R is the plane wave reflection coefficient associated with everything above LWSTHT and $\bar{R}$ is the plane wave reflection coefficient from everything below LWSTHT in the input coordinate system. Consistent with convention, the first subscript on R or $\bar{R}$ applies to the polarization of the incident wave whereas the second subscript applies to the polarization of the reflected wave, with $\parallel$ denoting vertical polarization and $\perp$ denoting horizontal polarization.

The total upgoing (in the prime system) whistler component, $S_T(2)$, obtained from decomposition of the two full wave solutions at $z' = \text{LWSTHT}'$, is then given by

$$S_T(2) = (\beta(1,2) - \beta(2,2)f)S(2) \quad (20)$$

Note that the minus sign before $\beta(2,2)$ follows from the fact that $P(2,2) = -E_y$ (see equation (15)). Equation (9) with $j = 2$ is normalized such that it equals equation (20) at $z' = \text{LWSTHT}'$ and the solution propagated to $z' = \text{WKBHT}' = 0$ via the WKB formula. If the solution at $z' = 0$ is denoted by $[(\beta(1,2) - \beta(2,2)f)S(2)]_{z'=0}$, then the strength and final unknown, A_m , of the full wave solution is determined by [7, 8]

$$A_m = \frac{BP_m(1,2)e^{ikQ(2)Z'_0}}{(Q(2) - Q(1))(Q(2) - Q(3))(Q(2) - Q(4))[(\beta(1,2) - \beta(2,2)f)S(1,2)]_{z'=0}} \quad (21)$$

where $S(I,2)$ ($I = 1,2,3,4$) represents the I^{th} field component of the magneto-ionic mode (i.e., $I = 1 \rightarrow E_x$, $I = 2 \rightarrow -E_y$, $I = 3 \rightarrow H_x$, $I = 4 \rightarrow H_y$). Any of

the field components can be used to determine A_m . The program uses H_y or $I = 4$. The free space wave number is denoted by k , the Q 's are Booker quartic solutions, and z'_0 is the transmitter location in the prime coordinate system. $BP_m(I,J)$ represents an amplitude factor associated with the decomposition of the primary source into an upgoing (in the prime system) magneto-ionic component ($J = 2$) associated with the eigenvalue θ_n . It is determined from equations (17), (22), (24), (25), and (56) of reference [8] and will not be reproduced here. The subscript m on A and BP denotes the source type and configuration in a way which will be described in the following section.

The calculations that have been described in this section are effected in the subroutine `WF BNDY` (or in the entry `DECOMP` in `WF BNDY`).

IV. EXCITATION FACTORS

In this section the excitation factors, λ , which have been programmed are summarized and in section VII their usage in mode sum calculations is discussed. The formulas have been derived in reference [8] and include "height gain" effects associated with transmitter and receiver. In that sense they depart from the conventional definition. The formulas programmed differ from those of reference [8] only in choice of sign and by virtue of using here the complement of the eigenangle used in reference [8]. The formulas are:

$$\begin{aligned}\lambda_1^m &= \frac{2CS^{1/2}}{\partial F/\partial \theta} e^{-i\pi/4} (1 + \bar{R}_{11}) H_y(z_R) ((1 - \bar{R}_{11}) h_y^m + \bar{R}_{11} \bar{R}_{11} e_y^m) \\ \lambda_2^m &= \frac{2C}{S^{1/2} \partial F/\partial \theta} e^{i3\pi/4} (1 + \bar{R}_{11}) E_y(z_R) (\bar{R}_{11} h_y^m + \bar{R}_{11} \bar{R}_{11} e_y^m) \\ \lambda_3^m &= \frac{2C}{S^{1/2} \partial F/\partial \theta} e^{-i\pi/4} (1 + \bar{R}_{11}) E_x(z_R) ((1 - \bar{R}_{11}) h_y^m + \bar{R}_{11} \bar{R}_{11} e_y^m)\end{aligned}\tag{22}$$

In the above, F is the modal function (i.e., the determinant of $1 - R\bar{R}$). The superscript m denotes the source while the subscripts on λ denote the component of the electric field at the receiver for which the excitation factor applies. The convention governing m and j is:

$$\lambda_j^m =$$

$j = 1$ z component

$j = 2$ y component

$j = 3$ x component

$m = 1$ vertical electric dipole

$m = 2$ horizontal electric dipole broadside

$m = 3$ horizontal electric dipole end fire

$m = 4$ vertical magnetic dipole

$m = 5$ horizontal magnetic dipole broadside

$m = 6$ horizontal magnetic dipole end fire

The R and $\bar{R}$ in equation (22) have been defined in the previous section. The quantities h_y^m and e_y^m are the full wave y components of the magnetic and electric fields of the rf wave and are dependent upon the type and location of

the source as indicated by the superscript m . The dependence on altitude of the receiver, z_R , in the input coordinate system is given by the functions $H_y(z_R)$, $E_y(z_R)$ and $E_x(z_R)$. A complete description of these functions is given in reference [3]. Finally, S and C are the sine and cosine, respectively, of an eigenangle, θ_n , and $\partial F/\partial \theta$ is the derivative of the mode function evaluated at θ_n .

V. PROGRAM DESCRIPTION

This section describes the subroutines in the SATELLITE program listed in appendix A. Many of the subroutines are only slight modifications of those given in reference [3]. The subroutines WKB, WKBVAR, QGAMMA and DDKXMT have been added for the purpose of implementing the WKB formalism. Principal output of the program is the excitation factors defined in section IV. A chart showing the essential structure of the SATELLITE program follows on pages 22 through 25.

SUBROUTINE MAIN

MAIN first calls for input of ionic species data in XINPUT and for computation of height gain components and excitation factors via WAVFLD. After executing WAVFLD, excitation factors are available in the array EFIELD (M,J) where M is the source designation and J the field component designation consistent with the convention given in section IV.

SUBROUTINE XINPUT (ISTART, ISTOP)

XINPUT controls read-in of input parameters via NAMELIST statements and ionic species densities and collision frequencies as a function of altitude. Common areas are set up as required. ISTART is set to 1 before the first call to XINPUT and to 0 upon subsequent calls. ISTART = 1 implies all necessary data are to be read in and ISTART = 0 signals that previously read data are to be updated, with all unspecified parameters remaining unchanged. If a value ISTOP = 0 is returned by XINPUT, then more input data are specified in the data deck for subsequent calls to WAVFLD, whereas if a value ISTOP = 1 is returned, the data read were the last data in the data deck, so that XINPUT should not be called again. XINPUT effects the transformation from the input coordinate system (x, y, z) to the prime coordinate system (x', y', z') .

The data deck is divided into several parts, each of which is marked by an identifier card with the identifier DATUMFOL, PROFILE, COLLFREQ, QUIT or STOP. Each of these identifiers is described in the following section.

SUBROUTINE WAVFLD (EX, EY, EZ, HX, HY, HZ)

WAVFLD calls for Runge-Kutta integration of two independent (corresponding to outgoing wave in the prime system at TOPHT') field solutions from TOPHT' to LWSHT' at DELHT increments. The two solutions are combined to satisfy the modal polarization condition and decomposed into magneto-ionic components at LWSHT'. At LWSHT' the full wave whistler component is matched to the corresponding WKB component and the solution carried to WKBHT' via WKB formulas. At WKBHT' the strength of the solution is determined for each source and orientation. WAVFLD then calls for the back substitution of normalizing values which have been saved in WF STOR. The excitation factors are then calculated in WAVFLD and placed in the array EFIELD(M,J). The field components placed at DELHT intervals in the arrays EX, EY, EZ, HX, HY, HZ are extraneous output in the present application.

SUBROUTINE WFINTG (TOPHT', LWSHT', DELHT, IFLAG)

WFINTG performs Runge-Kutta integration of the two solution vectors in P from TOPHT' to LWSHT'. Numerical solutions are saved at DELHT increments. Accuracy is maintained by continually adjusting the step size used in the numerical integration. The current step size (call it h) is used to obtain an estimate of P, and then a better estimate is obtained by using two integrations with step size h/2. If the two solutions agree within an error of PRECSN (an input parameter normally set to 3.D-5), the better estimate is accepted. The step size is automatically decreased to h/2 if the two estimates differ by more than PRECSN, and the integration is repeated. If the error is significantly greater than PRECSN, a step size h/2 is used. If the error is significantly less than PRECSN, the step size 2h is used if it also yields an error less than PRECSN. These tests thus form an automatic step size correction. In this program the call to WFINTG sets IFLAG equal to zero.

ENTRY INIT T

INIT T is an entry in subroutine TMTRX. INIT T sets up height independent values to be used in T matrix calculation. These include the

internally set flag ISO (ISO = 1 for isotropic calculation, 0 otherwise). Also set are the angular radio frequency, the wave number, direction cosines of the geomagnetic field, the complex sine and cosine of THETA.

SUBROUTINE TMTRX(HT')

TMTRX computes the value of the T matrix and a specific height HT' (as usual the prime simply implies that HT is referred to the prime coordinate system). The T matrix depends upon input ionospheric parameters (species density, collision frequency, angle of propagation, magnetic field, etc.). The susceptibility matrix, M, for each species in the ionosphere is computed, the effect of earth curvature is included and the T matrix is computed from the susceptibility matrix elements. The equations used to evaluate M and T are given in Clemmow and Heading [6].

SUBROUTINE WFDENS (HT', EN, COLL)

WFDENS computes the species density (returned in EN) and collision frequency (returned in COLL) at height HT' for up to five species in the ionosphere. EN and COLL are determined from corresponding profiles in the common field WFPF. LHT and MHT are integer values which indicate which profile values are to be interpolated to find values at the height HT'. The EN (or COLL) values are given by logarithmic interpolation of the profile values of heights ENHT(LHT + 1) and ENHT(LHT) or (COLLHT(MHT + 1) and COLLHT(MHT)).

SUBROUTINE WF INIT(P)

WF INIT sets the two starting field vectors P, at TOPHT' subject to the condition of outgoing wave in the prime system. The two starting solutions correspond to TE and TM polarizations.

SUBROUTINE PDERIV(P,DPDH)

PDERIV computes the height derivatives of the two field vectors in P according to Clemmow and Heading [6]. The derivative is returned in DPDH.

SUBROUTINE XFER (A, B, M)

Transfers the N element array A into B.

ENTRY WF STOR

This is an entry in WFSCAL where certain values obtained during integration through the ionosphere are saved for later use. The solution matrix P, the height for which P is a solution and a height integer index are saved along with orthogonalization and normalization values OSUM, APROD and BPROD. In addition, values of the susceptibility matrix elements M31, M32 and M33, which are needed to compute the EZ component of the electric field, are saved at each height.

SUBROUTINE WF STEP (P,DPDH, HT', DELHT, IFLAG)

WF STEP numerically advances the solution matrix P, using the derivative DPDH, from HT' to HT'-DELHT by the Runge-Kutta method. IFLAG, set internally, controls the calculations at intermediate points between HT' and HT'-DELHT at which evaluations are required for comparison of the second and fourth order Runge-Kutta integrations.

SUBROUTINE WF SCAL (PP, IFLAG)

WF SCAL normalizes and orthogonalizes the solution vectors PP according to the formulas of reference [4]. This scaling must later be removed to yield correct unscaled solutions. Control for calculating the quantities needed for removal of the scaling is the internally set IFLAG. Calling WF SCAL sets IFLAG = 0 in this program.

ENTRY DECOMP(HT')

This is an entry in WF BNDY. The two full wave solution vectors, P, are decomposed at HT' = LWSTHT' into upgoing (in the prime system) magneto-ionic components and combined to satisfy the modal polarization condition given in equation (19).

SUBROUTINE EIGVAL (A, SIG)

EIGVAL computes the eigenvalues (returned in SIG) of the arbitrary 4x4 complex matrix A. The characteristic polynomial $P(\lambda)$ of A is determined by explicitly computing $\det(A - \lambda I) = P(\lambda)$. The roots of this quartic polynomial (as computed in closed form, see subroutine QUARTC) are the desired eigenvalues of A. If the ionosphere is isotropic, the eigenvalues of A are computed as the roots of two quadratics.

SUBROUTINE QUARTC (FOUR B3, SIX B2, FOUR B1, B0, Q)

QUARTC computes the four roots of the polynomial $Q^4 + \text{FOUR } B3 * Q^3 + \text{SIX } B2 * Q^2 + \text{FOUR } B1 * Q + B0$ in closed form [9]. Up to ten applications of Newton's iteration are then performed to improve the accuracy of the roots, if necessary.

SUBROUTINE EIGVEC (A, SIG, VEC)

EIGVEC computes the four eigenvectors of A (returned in the four columns of the matrix VEC). The eigenvalues of A are assumed given in SIG. Each eigenvector X_i is computed as the solution of $(A - \sigma_i I)X_i = 0$. Since $\det(A - \sigma_i I) = 0$, this system has a solution if one element of X_i is chosen arbitrarily. In order to reduce the special isotropic case, the first element of X_1 and X_4 are arbitrarily set to A_{23} . The other three elements of each vector are then determined as the solution of a linear system in three unknowns. If the ionosphere is isotropic, the eigenvectors (corresponding to the quadratic roots described previously) are computed in simplified form.

SUBROUTINE WF SORT (Q, A IFAIL)

WF SORT arranges the eigenvalues Q and eigenvectors A of the Booker quartic so that they occur in the order of upgoing fast (evanescent), upgoing slow (travelling or whistler component), downgoing slow, and downgoing fast in the prime coordinate system. If the eigenvalues are too large in magnitude or if they cannot be ordered IFAIL is set to 1 and an error message results.

SUBROUTINE CIMVER (A, AINV, N, NDIM, ERR)

CINVER computes the inverse (returned in AINV) of the $N \times N$ matrix A. NDIM is an integer variable which must be greater than or equal to N. ERR is the estimated relative error of the inverse matrix.

SUBROUTINE CLINEQ (A, B, X, N, NDIM, IFLAG, ERR)

CLINEQ computes the solution of simultaneous linear equations with complex coefficients. That is, it solves the matrix $A * X = B$ for the vector X of length N, given the matrix A of size N by N and the vector B of length N. The matrix A is destroyed by CLINEQ. NDIM is an integer variable which must be greater than or equal to N. IFLAG is an integer variable normally set to 0. ERR indicates the relative error in the computed solution of vector X.

SUBROUTINE RBARS (C, S, RBAR11, RBAR22)

RBARS calculates the plane wave reflection coefficients $\bar{R}_{11} = \text{RBAR11}$ and $\bar{R}_{12} = \text{RBAR22}$ looking towards the ground from LWSTHT in the input system. Evaluations are in terms of modified Hankel functions of order 1/3. The cosine (C) and sine (S) of the eigenvalue, THETA, are used in the $\bar{R}$ determination.

SUBROUTINE MDHNKL (Z, H1, H2, H1PRME, H2PRME)

MDHNKL calculates for argument Z two independent solutions (H1 and H2) and their derivatives (H1PRME, H2PRME) of Stokes' equation by methods described in reference [10]. H1 and H2 are the modified Hankel functions of order 1/3 referred to above.

SUBROUTINE WKB

If STPFLG.NE.1, WKB extends calculation of the solution vector from LWSTHT' to WKBHT' by means of the formulas in section II. Integration of the phase factors q_j and Γ_{jj} (j index for upgoing, in prime system, whistler mode) is performed by Simpson rule routine with fixed step size that can be either input to the program or set internally.

SUBROUTINE WKVAR

If STPFLG.EQ.1, WKBVAR extends calculation of the solution vector from LWSHT' to WKBHT' via the WKB formulas of section II. Although generally requiring more CAU time this is the preferred option since it involves checks on step size. Integration of the phase factors q_j and Γ_{jj} (j index for upgoing, in prime system, whistler mode) is performed by a Simpson rule routine which maintains precision by adjustment of the step size much like the Runge-Kutta step size adjustment in WFINTG.

ENTRY INITDT

This is an entry in DDKXMT where all height independent quantities are initialized before extending field calculations from LWSHT' to WKBHT' via the WKB method.

SUBROUTINE Q GAMMA (HT', DELHT, LWSHT', WKBHT', Q, GAMMA)

Q GAMMA determines the Booker quartic solutions for the least attenuated upgoing (in the prime system) magneto-ionic component at LWSHT' and computes the a_i 's, b_i 's, a_i' 's, b_i' 's, A_i , F_i and Γ_{ij} according to formulas of section II. Full-wave solutions are matched at LWSHT' to the WKB solutions. At other heights and up to WKBHT' coefficients of the exponentials in equation (9) of section II are calculated along with coefficients required for calculating the EZ and HZ fields.

SUBROUTINE DDKXMT

DDKXMT calculates susceptibility matrix elements, M, the T matrix elements and their derivatives with respect to height in the height range $LWSHT' \leq HT' \leq WKBHT'$.

WF BNDY(B)

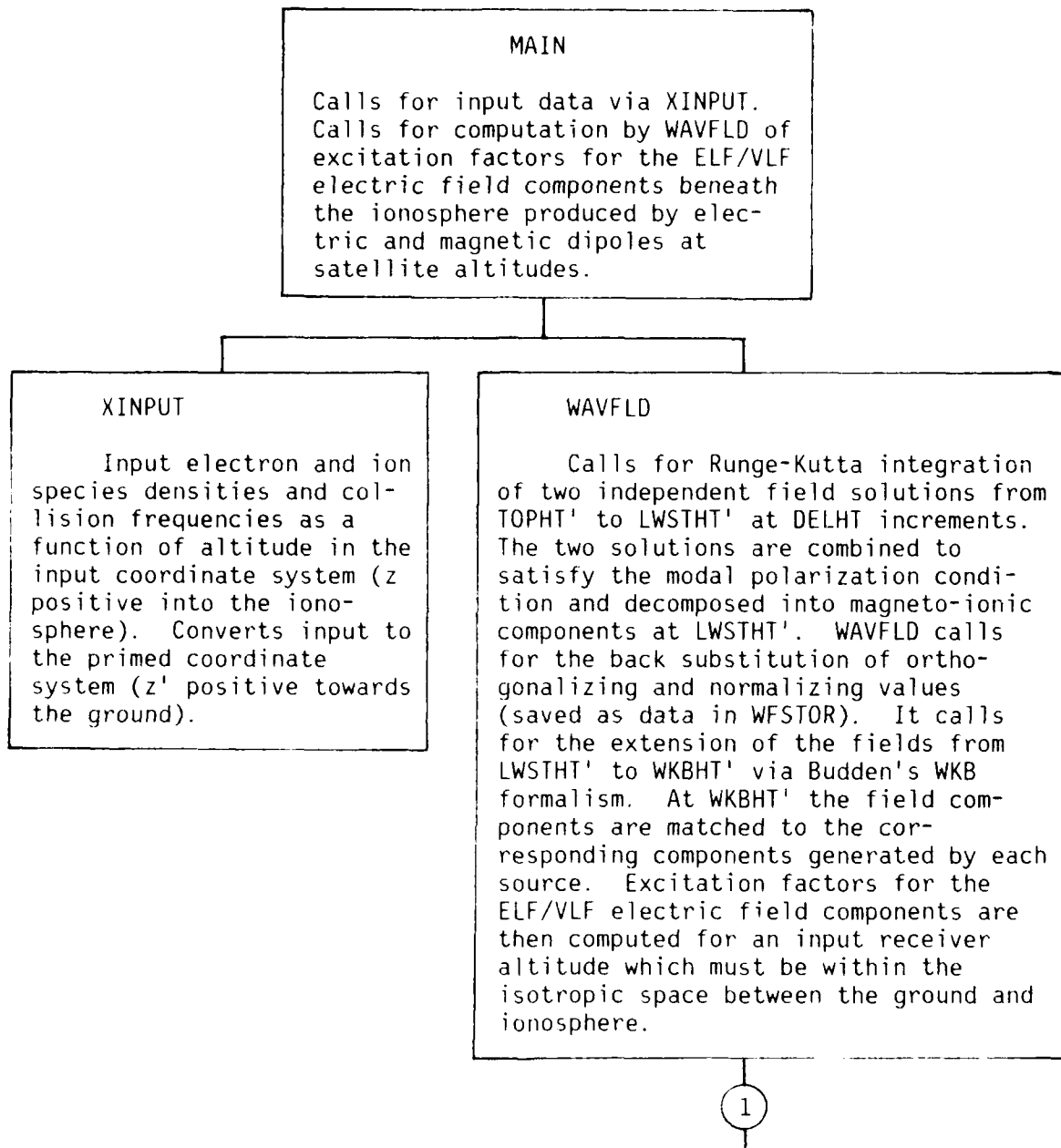
This computes coefficients $BP_m(1,2)$ --see equation (21)--for each source and orientation at WKBHT'. The coefficients are used to determine the strength of the full wave solution which has been carried from within the guide to WKBHT' by the combination of full wave and WKB methods.

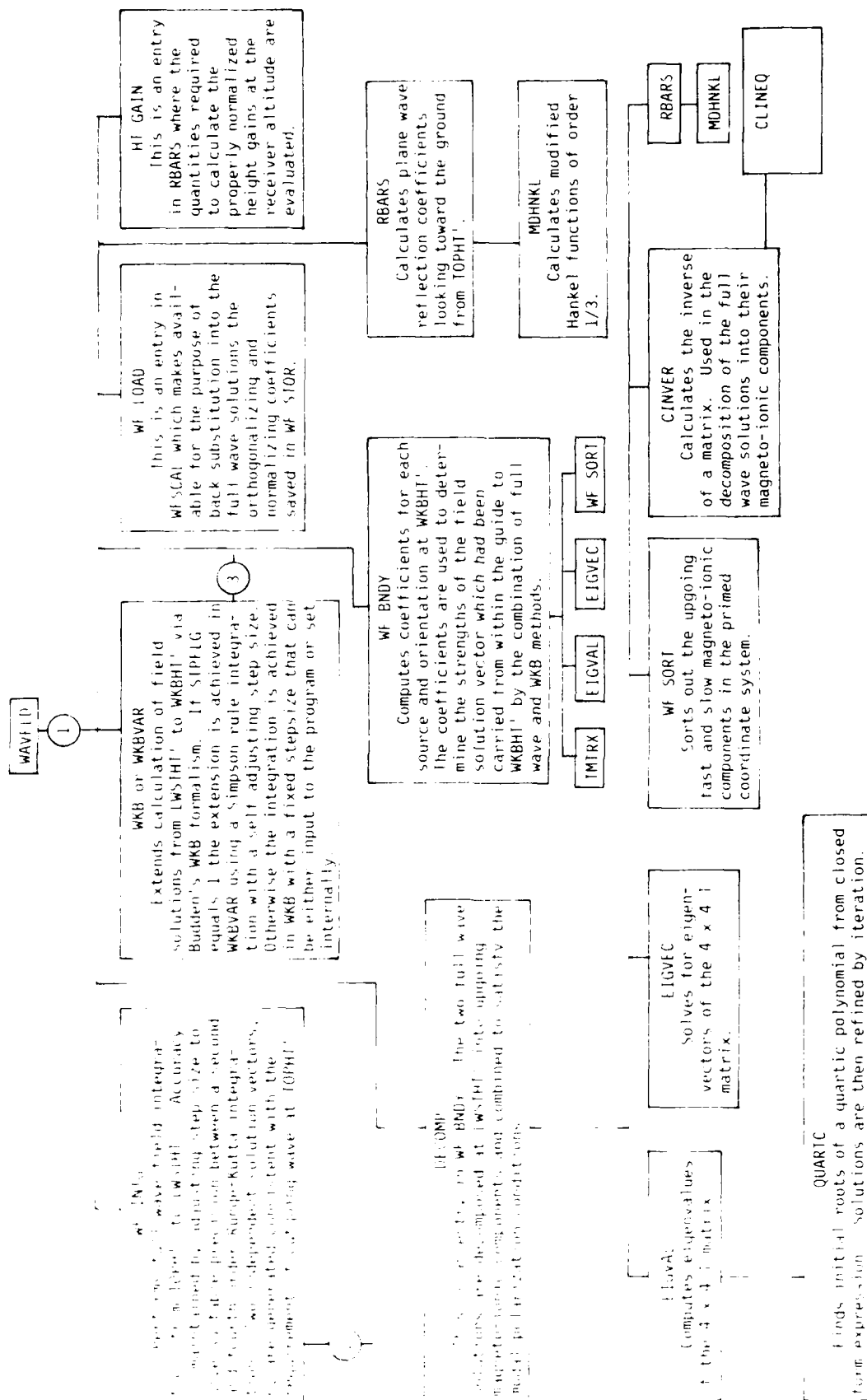
ENTRY WF LOAD

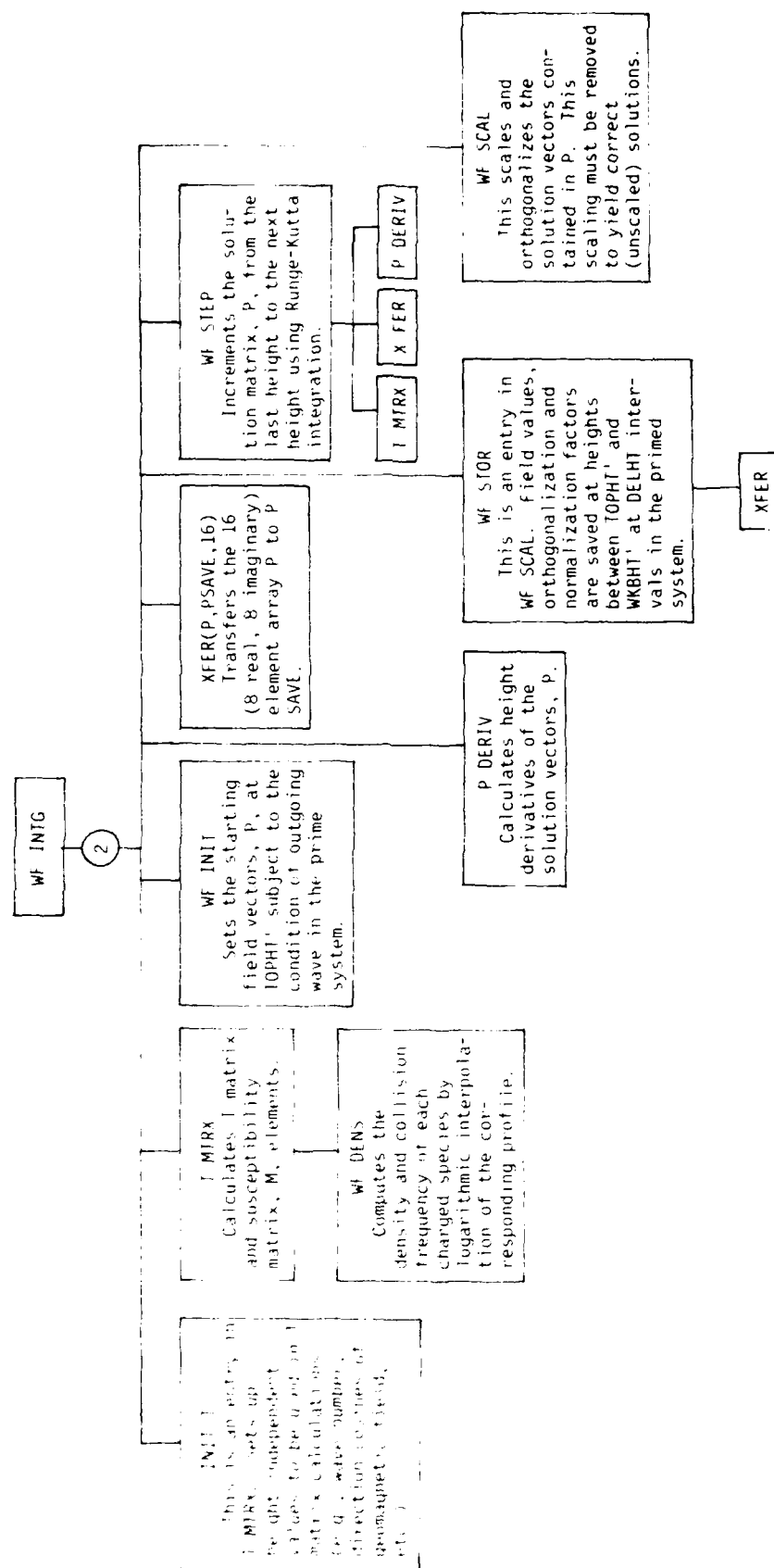
WF LOAD is an entry in WF SCAL which makes available for the purpose of back substitution into the full wave solutions the orthogonalizing and normalizing coefficients saved in WF STOR.

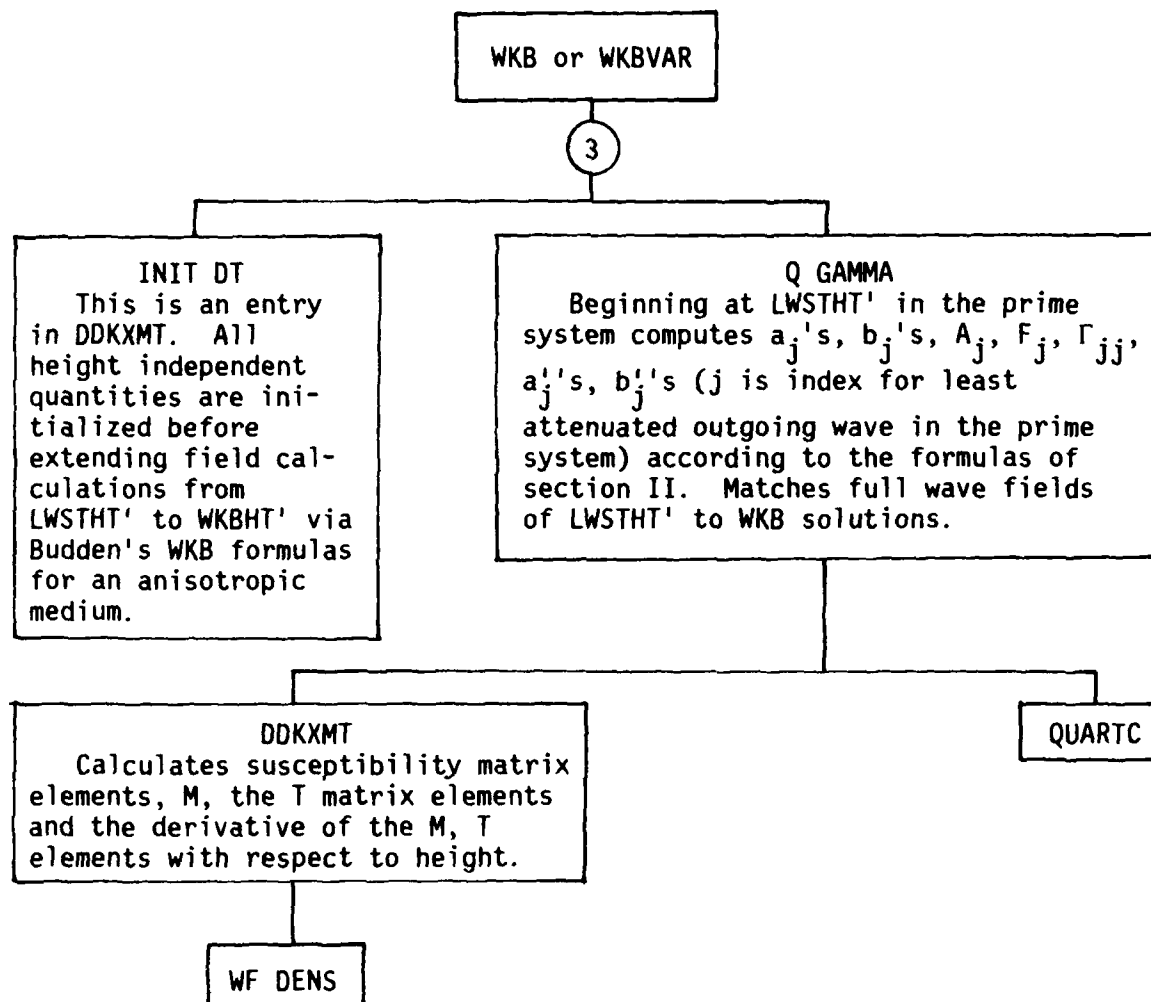
ENTRY HT GAIN

This is an entry in RBARS where the quantities required to calculate the properly normalized height gains at the receiver altitude are evaluated.









VI. SAMPLE INPUT AND OUTPUT

A. INPUT

Altitude independent parameters, species densities and collision frequencies as a function of altitude are supplied via an input data deck on a standard input unit. Read-in occurs in the subroutine XINPUT. The data deck is divided into several parts, each of which is marked by control cards DATUMFOL, PROFILE, COLLFREQ, QUIT, or STOP. Each of these control cards is described below:

(1) DATUMFOL

DATUMFOL - is a control card signifying that input for the namelist DATUM follows.

&DATUM - initiates reading of input data which do not vary with altitude. The data is read in namelist input format. All altitude related quantities are referenced to the input coordinate system (z positive into the ionosphere, ground at $z = 0$). These data are:

THETA - complex angle of incidence in degrees as measured at height H . THETA must be applied from a waveguide program (e.g., ref. [5]).

FREQ - frequency in kHz.

TOPHT - height to which full wave integrations are carried (km).

LWSTHT - beginning height for full wave integrations (km). Also equivalent to level D where mode equation is evaluated.

WKBHT - lower boundary of homogeneous, anisotropic slab in which the transmitter is imbedded (km). Also height to which field solution is propagated via WKB formalism from TOPHT.

DELHT - height increment in km's at which field solutions are saved.

PRECSN - accuracy to be maintained locally in the numerical integrations. Usually taken to be the default value of $3.0E-5$.

AZIM - azimuth of propagation path in degrees, measured clockwise from geomagnetic north.

CODIP - codip of geomagnetic field in degrees.

MAGFLD - geomagnetic field strength in webers/square meter.

COEFNU(5) - coefficient of exponential form of collision frequency (if not specified by profile). Up to five values may be specified. One for each species.

EXPNU(5) - exponent of exponential form of collision frequency (if not specified by profile). Up to five values may be specified. One for each species.

ALPHA - earth curvature coefficient in inverse km. Default is $3.14E-4$.

SIGMA - ground conductivity in siemens/meter. Default value is seawater value of 4.64.

EPSLON - ground permittivity in farads/meter. Default value is $7.172015D-10$. This corresponds to a dielectric constant of 81 for seawater.

- EPSLNO - permittivity of free space ($8.8544\text{E-}12$) in farads/meter.
- H - altitude in km at which modified refractive index is unity. Eigenangles are referenced to this altitude. H must be consistent with the H setting in the waveguide program which supplied the eigenangles.
- TXHT - transmitter altitude (km).
- RXHT - receiver altitude (km).
- ITR - integer flag which should be set to zero in this program.
- RMAG(4) - magnitude of the plane wave reflection elements of R. $R(1) \doteq R_{11}$, $R(2) \doteq R_{12}$, $R(3) \doteq R_{21}$, $R(4) \doteq R_{22}$. These elements are referenced to level D (or equivalently LWSTHT) in the input coordinate system and must be supplied from a waveguide program such as that of reference [5].
- RANG(4) - phase of the plane wave reflection elements of R. These elements are referenced to level D (or equivalently LWSTHT) in the input coordinate system and must be supplied from a waveguide program such as that of reference [5].
- XTRMAG - magnitude of the ground based vertical dipole excitation factor for the vertical electric field, E_z . This, along with XTRANG, is used for the purpose of obtaining the derivative of the modal equation, $dF/d\theta$. XTRMAG must be supplied from a waveguide program such as that of reference [5].

- XTRANG - phase of the ground based vertical dipole excitation factor for the vertical electric field, E_z . This, along with XTRMAG, is used for the purpose of obtaining the derivative of the modal equation, $dF/d\theta$. XTRANG must be supplied from a waveguide program such as that of reference [5].
- NUMDIV - number of divisions into which DELHT is divided when using subroutine WKB (i.e., when STPFLG $\neq$ 1) with fixed input step size. NUMDIV must then be a multiple of 2. If STPFLG $\neq$ 1 and NUMDIV = 0 then the program will determine a constant step size to be used with the Simpson rule integration. It is repeated here that the preferred option is with STPFLG = 1 because of the checks on the adequacy of the step size.
- STPFLG - integer flag which must be set to 1 if the recommended WKBVAR subroutine is to be used to effect the WKB integrations. Other options are discussed above (NUMDIV).
- NRSPEC - number (integer) of species in the ionosphere. Can take on values up to 5. Default value is 1.
- CHARGE(5)- sign of charge of each species in proton units. For an electron, the charge is -1.0. Default values are (-1.0, 1.0, -1.0, 1.0, -1.0).
- RATIOM(5)- mass of each species relative to mass of an electron. Default values are (1.0, 5.8D4, 5.8D4, 5.8D4, 5.8D4).
- &END - signifies end of the DATUM namelist input.

(ii) PROFILE

PROFILE - is a control card initiating reading of the ionospheric profile cards. All altitudes and related quantities are referenced to the input coordinate system (z positive into the ionosphere, ground at $z = 0$). The control card PROFILE is followed by an alpha-numeric card which is used to identify the profile. The profile is input starting at the top of the ionosphere (i.e., WKBHT). The cards must be input in descending order by height. The profile cards contain the height in kilometers and the species densities in particles per cubic centimeter. A maximum of five species can be specified. In the special case of three species, only two are specified on the card. The first is assumed to be electrons and the second is positive ions. The third species, negative ions, is calculated by subtracting the electron density from the positive ion density. All three species are listed on the computer printout. If the value of any species density is less than or equal to zero, it is set in the program to $1.0E-40$. The heights are punched in the form xxx.xx with the decimal point in column 5, and the densities are punched in the form x.xx $D\pm$ xx with the decimal points in column 15, 25, etc. All species data must be specified except for the special case discussed above. The end of the profile is indicated by a dummy height of 999.99.

(iii) COLLREQ

COLLREQ - is a control card initiating reading of the collision frequency profile. All altitudes and related quantities are referenced to the input coordinate system (z positive into the ionosphere, ground at $z = 0$). The control card COLLREQ allows for using nonexponential collision frequencies. A strictly exponential collision frequency may be specified in namelist input by the variables COEFNU and EXPNU. If a collision frequency profile deck is used it overrides COEFNU and EXPNU. Collision frequencies for all species must be input. The card preparation is just as above with the species density values replaced by collision frequency values (in collisions/sec) on the cards. The end of the profile is indicated by a dummy height of 999.99.

(iv) QUIT

QUIT - is a control card which indicates the end of input data for a call to WAVFLD. After calling WAVFLD, XINPUT can be read and used as data for a subsequent call to WAVFLD. This allows several runs to be made with one input deck. Note that only those data which are changed need be specified after the card QUIT.

(v) STOP

STOP - control card which indicates that there are no more input data and that the run is to be terminated after the next call to WAVFLD. Note that if QUIT is encountered ISTOP is set to zero, but if STOP is encountered ISTOP is set to one.

A schematic of an input deck is shown on page 34, and one actual sample input is shown on pages 35 through 37.

B. OUTPUT

The output shown on pages 38 through 41 corresponds to the first DATUMFOL shown on page 36. The output corresponds to the STPFLG = 1 setting. Output corresponding to the additional DATUMFOL have not been shown simply to cut down on the number of pages.

First come NAMELIST and profile printouts in the input coordinate system (z positive into the ionosphere, ground at $z = 0$). Natural logarithms of the profiles in the prime system are also printed. Next follows output which gives the number of Runge-Kutta integration steps used in WAVFLD during the course of integrating from TOPHT' to LWSTHT' as well as the smallest and the average step sizes used in the WKB extension from LWSTHT' to WKBHT'. This is followed by the principal output; two nine element arrays which are the excitation factors for both electric and magnetic dipole transmitters. The column headings indicate excitation factors for the z, y and x electric field components in the input coordinate system. The row labels indicate excitation by vertical (V), horizontal broadside (HB) and horizontal end-on (HE) point dipoles of either electric or magnetic type.

We list below a comparison at 20 kHz between the excitation factors obtained using full wave (FW) methods up to 500 km as opposed to using WKB formalism between 125 km and 500 km. The agreement will be seen to be excellent.

ELECTRIC DIPOLE TRANSMITTER

		Z		Y		X	
		MAG	ANG (RAD.)	MAG	ANG (RAD.)	MAG	ANG (RAD.)
V	WKB	.913-4	-1.504	.118-7	-2.234	.460-7	2.425
	FW	.913-4	-1.485	-.118-7	-2.215	.460-7	2.443
HB	WKB	.809-4	1.358	.104-7	.628	.408-7	-.996
	FW	.808-4	1.377	.104-7	.647	.407-7	-.978
HE	WKB	.816-4	-.243	.105-7	-.973	.412-7	-2.597
	FW	.816-4	-.224	.105-7	-.954	.411-7	-2.579

MAGNETIC DIPOLE TRANSMITTER

		Z		Y		X	
		MAG	ANG (RAD.)	MAG	ANG (RAD.)	MAG	ANG (RAD.)
V	WKB	.785-4	2.928	.101-7	2.198	.396-7	.573
	FW	.785-4	2.946	.101-7	2.216	.396-7	.591
HB	WKB	.279-2	1.358	.360-6	.628	.141-5	-.996
	FW	.279-2	1.377	.360-6	.647	.141-5	-.978
HE	WKB	.279-2	-.212	.360-6	-.942	.141-5	-2.567
	FW	.279-2	-.194	.360-6	-.924	.141-5	-2.549

EXAMPLE OF INPUT DECK

DATUMFØL

&DATUM
(input data)
&END

PRØFILE

(profile cards for each specie)

999.99

CØLLFREQ

(coll. frequency cards for each specie)

999.99

QUIT (end of input for this run)

DATUMFØL

&DATUM
(changes in input data)
&END

PRØFILE

(specify entire new profile deck)

999.99

QUIT (end of input for this run)

DATUMFØL

&DATUM
(changes in input data)
&END

SIØP (end of data deck)

SAMPLE INPUT

```

1  DATUMFOL
2  ADA'UR
3  THETA=18.300,-6.297),
4  RMAG=4537.48488,75127.71191,
5  RANG=19.23390,325.36661,256.47889,265.18541,
6  XTRWAG=2.2393E-3,XTRANG=1.755,
7  FREQ=20.0,
8  ID=2,
9  TOPHT=125.,LWSTHT=0.,WK8HT=500.,DELHT=25.,
10 PRECSN=3E-4,
11 AZIN=238.5,CPIP=39.0,MAGFLD=4.31E-5,
12 SIGMA=1.64,FPSLON=7.172015E-10,
13 EPSLN0=.88,34D-11,
14 TXHT=500.,RXHT=0.,
15 H.O.,
16 RLMDIV=0,
17 STPELG=1,
18 IRSPEC=1,
19 AEND
20 PROFILE 1
21 GLOBAL NIGHTTIME IONOSPHERE (SAT. NIGHT ABOVE 99, H'=87 BELOW 99)
22 500.00 2.00D+05
23 400.00 4.00D+05
24 370.00 4.30D+05
25 350.00 4.40D+05
26 320.00 4.30D+05
27 250.00 1.00D+05
28 225.00 5.00D+03
29 220.00 3.20D+03
30 210.00 1.68D+03
31 200.00 1.00D+03
32 190.00 6.50D+02
33 180.00 4.60D+02
34 170.00 3.45D+02
35 160.00 2.82D+02
36 155.00 2.60D+02
37 150.00 2.50D+02
38 145.00 2.50D+02
39 140.00 2.80D+02
40 130.00 3.70D+02
41 120.00 5.80D+02
42 112.00 1.10D+03
43 100.00 1.30D+03
44 100.00 1.70D+03
45 104.00 1.90D+03
46 102.00 1.98D+03
47 100.00 2.00D+03
48 98.00 1.95D+03
49 0.00 1.83D+12
50 000.00
51 COLLETO
52 500.00 2.00D+02
53 400.00 3.80D+02
54 370.00 3.90D+02

```

SAMPLE INPUT

```

55 3.0000 3.8000E2
56 3.0000 3.5000E2
57 3.0000 2.8000E2
58 2.0000 1.0000E2
59 2.0000 3.5000E1
60 2.0000 3.0000E1
61 2.0000 3.3000E1
62 2.0000 4.5000E1
63 1.0000 1.6000E3
64 1.0000 1.0000E4
65 1.0000 3.0000E4
66 0.00 1.8200E1
67 999.99
68 QUIT
69 DATUMFOL
70 &DATUM
71 THETA=(89.734,-4.985),
72 RMA3=.37608,.50137,.70502,.66571,
73 RMA3=340.94534,267.69431,207.14367,215.38363,
74 XTRMAG=1.2353E-2,XTRANG=1.832,
75 PRECSN=.3E-4,
76 &END
77 QUIT
78 DATUMFOL
79 &DATUM
80 THETA=(86.562,-0.602),
81 RMA3=.31415,.51674,.70714,.66251,
82 RMA3=255.51615,179.85049,128.19374,135.23562,
83 XTRMAG=4.7435E-2,XTRANG=1.553,
84 PRECSN=.3E-4,
85 &END
86 QUIT
87 DATUMFOL
88 &DATUM
89 THETA=(83.728,-0.339),
90 RMA3=.25040,.48057,.70436,.65576,
91 RMA3=211.90089,125.88680,81.77360,87.87696,
92 XTRMAG=2.3667E-2,XTRANG=1.762,
93 PRECSN=.3E-4,
94 &END
95 QUIT
96 DATUMFOL
97 &DATUM
98 THETA=(79.891,-0.477),
99 RMA3=.15081,.49026,.78613,.72446,
100 RMA3=145.66026,22.54322,355.24173,359.06332,
101 XTRMAG=3.5551E-2,XTRANG=1.414,
102 PRECSN=.3E-4,
103 &END
104 QUIT
105 DATUMFOL
106 &DATUM
107 THETA=(77.714,-0.346),
108 RMA3=.10293,.45036,.74700,.68147,
109 RMA3=131.65558,312.34340,298.43223,300.44511,
110 XTRMAG=2.7565E-2,XTRANG=1.854,
111 PRECSN=.3E-4,

```

SAMPLE INPUT

```

112      &END
113      QUIT
114      DATUMFOL
115      &DATUM
116      THETA=(74.296,-0.500),
117      RMAG=.16695,.52330,.77911,.70326,
118      RANG=98.50531,198.50546,203.54697,201.65665,
119      XTRMAG=2.4133E-2,XTRANG=1.212,
120      PRECSN=.3E-4,
121      &END
122      QUIT
123      DATUMFOL
124      &DATUM
125      THETA=(72.241,-0.442),
126      RMAG=.22314,.53869,.73045,.65456,
127      RANG=52.33535,130.93816,144.63344,139.79135,
128      XTRMAG=3.3945E-2,XTRANG=1.887,
129      PRECSN=.3E-4,
130      &END
131      STOP

```


SAMPLE OUTPUT

380.00	6.36+000
370.00	5.91+000
360.00	5.63+000
355.00	5.54+000
350.00	5.52+000
345.00	5.56+000
340.00	5.64+000
330.00	5.84+000
320.00	6.13+000
310.00	6.48+000
300.00	6.91+000
290.00	7.43+000
280.00	8.07+000
275.00	8.52+000
250.00	1.15+001
170.00	1.30+001
150.00	1.30+001
130.00	1.30+001
100.00	1.29+001
.00	1.22+001
COLLFREQ	
500.00	2.00+002
400.00	3.80+002
370.00	3.90+002
350.00	3.80+002
330.00	3.50+002
300.00	2.80+002
250.00	1.05+002
225.00	3.50+001
220.00	3.00+001
210.00	3.30+001
200.00	4.50+001
150.00	1.60+003
120.00	1.00+004
104.00	3.00+004
.00	1.82+011
999.99	
500.00	2.59+001
395.00	1.03+001
380.00	9.21+000
350.00	7.38+000
300.00	3.81+000
290.00	3.50+000
280.00	3.40+000
275.00	3.56+000
250.00	4.65+000
200.00	5.63+000
170.00	5.85+000
150.00	5.94+000
130.00	5.97+000
100.00	5.94+000
.00	5.30+000

QUIT

50 INTEGRATION STEPS, HT = 404.2969
 100 INTEGRATION STEPS, HT = 395.0234
 150 INTEGRATION STEPS, HT = 385.6563
 192 INTEGRATION STEPS USED IN WAVFLD

SAMPLE OUTPUT

SMALLEST INTEGRATION INTERVAL BETWEEN LWSHT' =	375.0 KM AND WKBHT' =	.0 KM IS	.0489 KW
AVERAGE INTEGRATION INTERVAL BETWEEN LWSHT' =	375.0 KM AND WKBHT' =	.0 KM IS	.9665 KW

SAMPLE OUTPUT

ELECTRIC DIPOLE TRANSMITTER

	Z		Y		X	
	MAG	ANG	MAG	ANG	MAG	ANG
V	.599227-005	-.783	.255878-009	3.096	.291676-008	-3.138
HB	.713075-005	1.808	.304493-009	-.596	.347092-008	-.547
HE	.724110-005	.213	.309205-009	-2.191	.352463-008	-2.142

MAGNETIC DIPOLE TRANSMITTER

	Z		Y		X	
	MAG	ANG	MAG	ANG	MAG	ANG
V	.717382-005	-2.904	.306331-009	.974	.349188-008	1.023
HB	.213118-003	1.808	.910042-008	-.596	.103736-006	-.548
HE	.213036-003	.238	.909693-008	-2.167	.103696-006	-2.118

V. MODE SUMS

The excitation factors defined in the previous section are useful for calculating the strengths of the electric field components in the earth-ionosphere guide. In this section explicit expressions are given for calculating those field components. The formulas given are asymptotic and restricted to the range

$$|k\rho\sin\theta_N| \gg 1 \text{ and } |k(\pi a - \rho)\sin\theta_N| \gg 1$$

with k the free space wave number, θ_N the eigenangle for Mode N , a the earth's radius and ρ the transmitter receiver great circle separation. The mode sums are

$$E_j^m(\mu\nu) = \frac{C_1 I \ell f_{\text{kHz}}^{3/2}}{\left(\sin\left(\frac{\rho}{a}\right)\right)^{1/2}} \sum_N \lambda_{jN}^m e^{-ik\rho\sin\theta_N} \quad \begin{matrix} j = 1, 2, 3 \\ m = 1, 2, 3 \end{matrix}$$

$$E_j^m(\mu\nu) = \frac{C_2 I A f_{\text{kHz}}^{5/2}}{\left(\sin\left(\frac{\rho}{a}\right)\right)^{1/2}} \sum_N \lambda_{jN}^m e^{-ik\rho\sin\theta_N} \quad \begin{matrix} j = 1, 2, 3 \\ m = 4, 5, 6 \end{matrix}$$

where the sum is over the number of modes and

$$C_1 = 2.86 \times 10^{-3}$$

$$C_2 = 5.98 \times 10^{-8}$$

$$f_{\text{kHz}} = \text{frequency in kHz}$$

$$I \ell = \text{electric dipole current moment - Amp-m}$$

$$I A = \text{magnetic dipole current moment - Amp-m}^2$$

$$\lambda_j^m = \text{excitation factors defined in previous section.}$$

The field strengths E_j^m are in terms of microvolts per meter. A program for computing and plotting the mode sums is included in appendix B. The latter takes punched output from the excitation factor program given in appendix A. Results of the mode sum program are shown in figures 1 through 3 for electric dipole (ED) and magnetic dipole (MD) excitation of EX, EY and EZ. The dipole moments in this example have been chosen to correspond to one kilowatt free space radiation.

Fig. 1

HAWAII TO SAN DIEGO GLOBAL NIGHT PROFILE

FREQ=20.000 KHZ TXHT=500.0 KM RXHT=10.0 KM

AZIM=58.5 DEGREES CODIP=39.0 DEGREES

MAGFLD= 4.31×10^{-5} W/M² SIGMA= 4.64×10^{-3} /M EPSR= 81.0

IL= 1.69×10^4 A-M

IA= 4.03×10^4 A-M

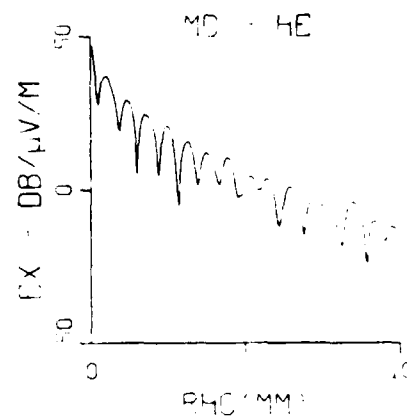
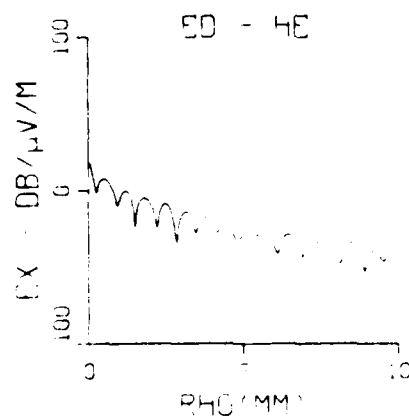
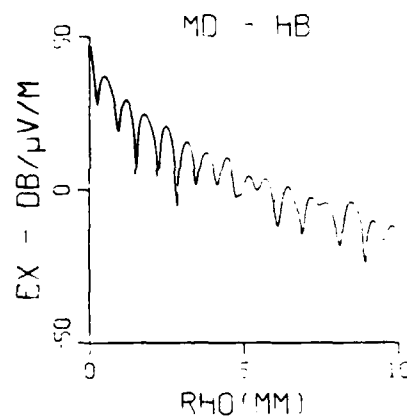
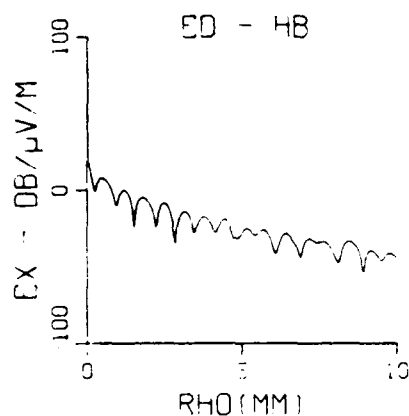
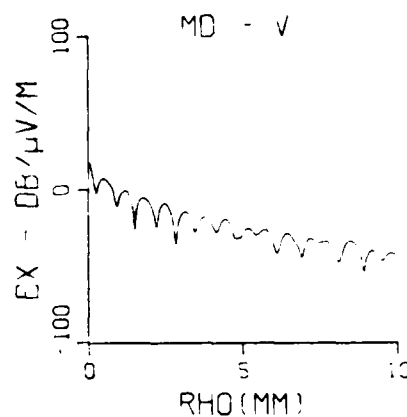
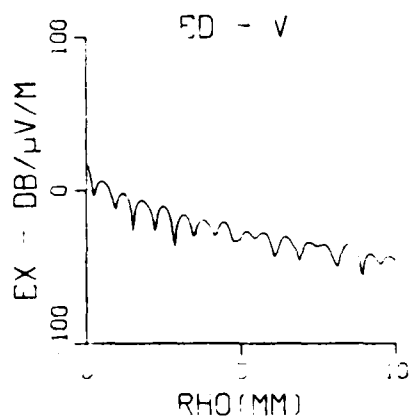


Fig. 2

HAWAII TO SAN DIEGO GLOBAL NIGHT PROFILE

FREQ=20.000 KHZ TXHT=500.0 KM RXHT=10.0 KM

AZIM=58.5 DEGREES CODIP= 39.0 DEGREES

MAGFLD= 4.31×10^{-5} W/M² SIGMA= 4.64×10^0 S/M EPSR= 81.0

IL= 1.69×10^4 A-M

IA= 4.03×10^4 A-M²

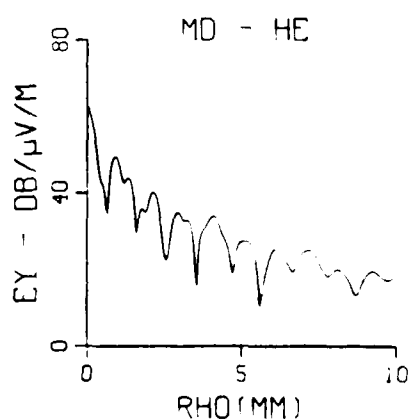
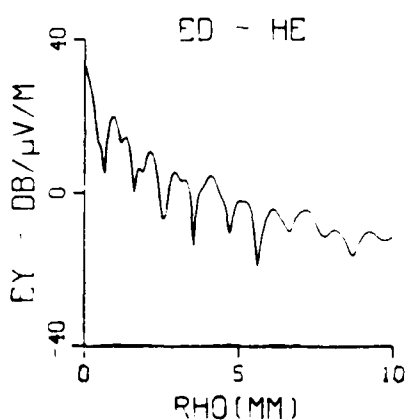
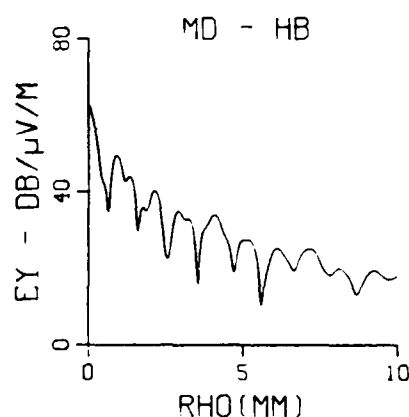
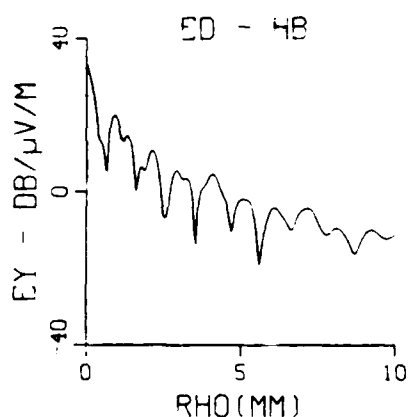
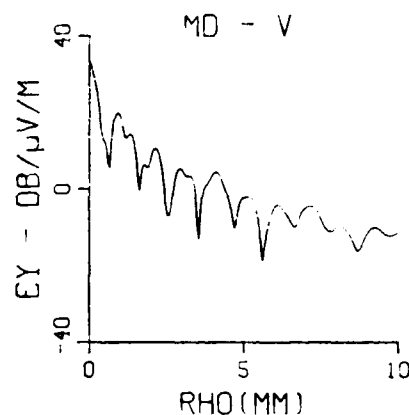
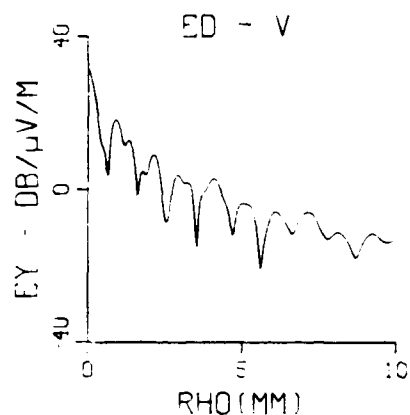


Fig. 3

HAWAII TO SAN DIEGO GLOBAL NIGHT PROFILE

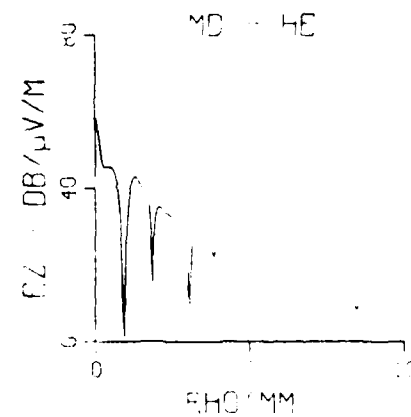
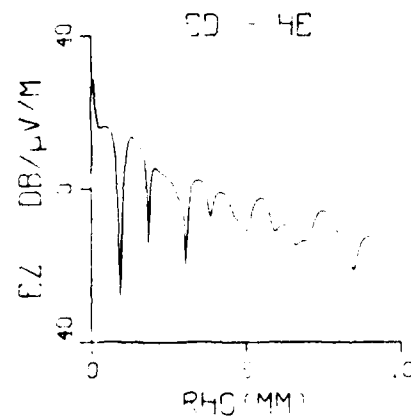
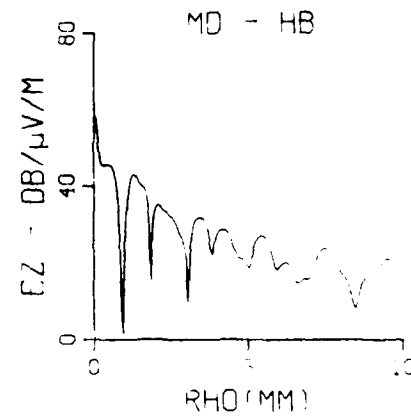
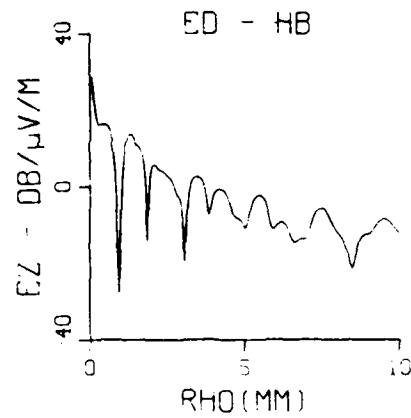
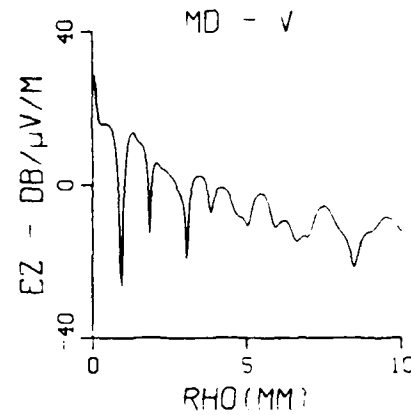
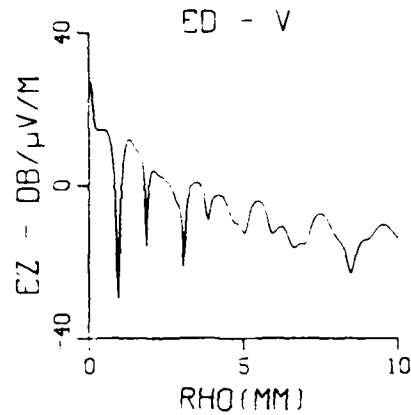
FREQ=20.000 KHZ TXHT=500.0 KM RXHT=10.0 KM

AZIM=58.5 DEGREES CODIP= 39.0 DEGREES

MAGFLD= 4.31×10^{-5} W/M² SIGMA= 4.64×10^9 S/M EPSR= 31.0

IL= 1.69×10^4 A-M

IA= 4.03×10^7 A-M²



REFERENCES

1. Pappert, RA and LR Hitney, A program to compute ELF/VLF earth-ionosphere modal height gains via WKB methods up to satellite altitudes. Interim Report No. 724 prepared by the Naval Ocean Systems Center for the Defense Nuclear Agency, September 1981.
2. Budden, KG, Radio waves in the ionosphere, Cambridge University Press, Cambridge 1961.
3. Pappert, RA, and LR Shockey, A program for computing earth ionosphere ELF/VLF excitation factors for satellite-borne antennas. Interim Report No. 741 prepared by the Naval Electronics Laboratory Center (now NOSC) for the Defense Atomic Support Agency (now DNA), April 1974.
4. Smith, RR, A program to compute ionospheric height gain functions and field strengths, Interim Report No. 711 prepared by the Naval Electronics Laboratory Center (now NOSC) for the Defense Atomic Support Agency (now DNA), December 1970.
5. Sheddy, CH, RA Pappert, Y Gough and WF Moler, A FORTRAN program for mode constants in an earth-ionosphere waveguide of arbitrary electron density distribution. Interim Report No. 683 prepared by the Naval Electronics Laboratory Center (now NOSC) for the Defense Atomic Support Agency (now DNA), May 1968.
6. Clemmow, PC, and J Heading, Coupled forms of the differential equations governing radio propagation in the ionosphere, Proc. Cambridge Phil. Soc., 50, 1954, pp 319-333.
7. Pappert, RA, Excitation of the earth-ionosphere waveguide by a vertical dipole at satellite heights, Interim Report No. 723 prepared by the Naval Electronics Laboratory Center (now NOSC) for the Defense Atomic Support Agency (now DNA), June 1972.

8. Pappert, RA, Excitation of the earth-ionosphere waveguide by point dipoles at satellite heights. Radio Science 8(6), 1973, pp 535-545.
9. Sheddy, CH, A general analytic solution for reflection from a sharply bounded anisotropic ionosphere, Radio Science, Vol 3, 1968, pp 792-795.
10. Staff of the Computation Laboratory, Tables of the modified Hankel functions of order one third and of their derivatives, Harvard University Press, Cambridge, MA, 1945.

APPENDIX A
SATELLITE EXCITATION FACTOR PROGRAM LISTING

```

1  C      PROGRAM DRIVER
2  C      THE DRIVER PROGRAM ALTERNATELY CALLS
3  C      FOR THE INPUT OF DATA ON THE STANDARD
4  C      INPUT UNIT AND CALLS FOR THE COMPUTATION
5  C      OF HEIGHT GAIN FUNCTIONS BY WAVFLD.
6  C
7  C      IMPLICIT REAL*8 (A-H,O-Z)
8  C      COMPLEX*16 EX(129,6),EY(129,6),EZ(129,6) ,
9  C      $      HX(129,6),HY(129,6),HZ(129,6)
10 C
11 C
12 C      ISTART = 1
13 C      PRINT 905
14 C      100 CALL XINPUT ( ISTART, ISTOP)
15 C      150 ISTART=0
16 C      DO 200 J=1,129
17 C      DO 200 K=1,6
18 C      EX(J,K) = 0.0
19 C      EY(J,K) = 0.0
20 C      EZ(J,K) = 0.0
21 C      HX(J,K) = 0.0
22 C      HY(J,K) = 0.0
23 C      HZ(J,K) = 0.0
24 C      200 CONTINUE
25 C      CALL WAVFLD(EX,EY,EZ,HX,HY,HZ)
26 C
27 C      600 IF (ISTOP.EQ.0) GO TO 100
28 C      905 FORMAT('1',/)
29 C
30 C
31 C      END

```

```

1  SUBROUTINE XINPUT (ISTART, ISTOP)
2
3  C XINPUT READS IN IONOSPHERIC INPUT
4  DATA (VIA NAMELIST), AS WELL AS
5  ELECTRON OR ION DENSITY AND
6  COLLISION FREQUENCY PROFILES. THIS
7  ROUTINE SHOULD BE CALLED PRIOR TO
8  CALLING WAVFLD. ISTART = 1 INDICATES
9  THAT A NEW SET OF INPUT DATA IS TO BE
10 READ. ISTART = 0 INDICATES AN UPDATE
11 OF EXISTING DATA. ISTOP = 1 INDICATES
12 THE END OF INPUT DATA FOR THIS JOB.
13 ISTOP = 0 INDICATES MORE INPUT DATA
14 APPEARS IN THE DATA DECK.
15
16 IMPLICIT REAL *8 (A-H,G-Z)
17 DIMENSION ED(5),COLL(5),TEM(100,5),SAVE(100),RMAG(4),RANG(4)
18 COMMON/EXTRA/XTRA,R
19 COMMON/STOR/ STOR
20 COMMON/WFINPT/THETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
21 TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
22 $ COMMON/WF FLAG/PRECSN,ISO,IOBG
23 COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
24 LHT,WHT,CHARGE(5),RAT10M(5),NRSPEC
25 $ COMMON/EXC IN/TXHT,RXHT
26 COMMON/DELTA/NUMDIV,STPFLG
27 CHARACTER*8 BCD(10)
28 INTEGER STPFLG
29 REAL*8 MAGFLD, LWSTHT
30 COMPLEX*16 R(4),XTRA,I/(0.0D0,1.0D0)/,THETA
31
32 C
33 NAMELIST/DATUM/THETA,FREQ,IOBG,TOPTH,LWSTHT,WKBHT,DELHT,PRECSN,
34 $ AZIM,CODIP,MAGFLD,COEFNU,EXPNU,ALPHA,SIGMA,EPSLON,EPSLNO,
35 $ TXHT,RXHT, H,RMAG,RANG,XTRMAG,XTRANG,NUMDIV,STPFLG,
36 $ NRSPEC,CHARGE,RAT10M
37
38 C DATA DEGRAD/1.74532925D-2/
39
40
41 IDAT = 0
42 ISTOP = 1
43 ICOLL = 1
44 IF (ISTART.NE.0) ICOLL = 0
45 READ 900, BCD
46 PRINT 901, BCD
47 IF (BCD(1) .EQ. 'DATUMFOL') GO TO 200
48 IF (BCD(1) .EQ. 'COLLREQ') GO TO 400
49 IF (BCD(1) .EQ. 'PREFILE') GO TO 500
50 IF (BCD(1) .EQ. 'STOP') GO TO 120
51 IF (BCD(1) .NE. 'QUIT') GO TO 800
52 ISTOP = 0
53 IF (IDAT.EQ.0.AND.ISTART.NE.0) GO TO 800
54 IF (NRSPEC.EQ.0) NRSPEC = 1
55 IF (ICOLL.NE.0) RETURN

```

```

55 COLLHT(1) = STORE
56 COLLHT(2) = 0.0
57 DO 150 J = 1,NRSPEC
58 COLLFR(2,J) = DLOG(COEFNU(J)*DEXP(STORE*1000.*EXPNU(J)))
59 COLLFR(1,J) = COLLFR(2,J)-1000.0*STORE*EXPNU(J)
60 CONTINUE
61 RETURN
62
63
64
65
66
67
68
69
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71
72
73
74
75
76
77
78
79
80
81
82
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100
101
102
103
104
105
106
107
108
109
110
111
150 CONTINUE
    RETURN
C
200
    IDAT = 1
    PREVNU = COEFNU(1)
    COEFNU(1) = 0.0
    READ (5, DATUM)
    IF (COEFNU(1).NE.0.0) ICOLL = 0
    IF (COEFNU(1).EQ.0.0) COEFNU(1) = PREVNU
    IF (NUMDIV.NE.0 .OR. STPLG.EQ.1) GO TO 249
    NUM=DLOG( 75. * DSQRT(DELHT * DSQRT(FREQ) ) )
    NUMDIV=2 *NUM
    WRITE (6, DATUM)
    DO 20 JK=1,4
    RANG(JK) = RANG(JK)*DEGRAD
    R(JK) = RMAG(JK)*(DCOS(RANG(JK))+I*DSIN(RANG(JK)))
    XTRA = XTRMAG*(DCOS(XTRANG)+I*DSIN(XTRANG))
    PUNCH 920
    PUNCH 921, THETA
    PUNCH 922, FREQ
    PUNCH 923, TXHT, RXHT
    EPSR = EPSLON/EPSLNO
    PUNCH 925, AZIM, CODIP, MAGFLD, SIGMA, EPSR
    PUNCH 924
    GO TO 100
C
C
400 ICOLL = 1
    L = 1
410 READ 902, HT, COLL
    IF (DABS(HT-999.99).LT.0.001) GO TO 430
    IF (L.GT.25) GO TO 800
    IF (L.NE.1 .AND. HT .GE. COLLHT(L-1)) GO TO 800
    DO 411 M=1,NRSPEC
    IF (COLL(M) .LE. 0.0) COLL(M)=1.0D-40
    CONTINUE
    PRINT 903, HT, (COLL(M), M=1,NRSPEC)
    COLLHT(L) = HT
    DO 415 M=1,NRSPEC
    COLLFR(L,M)=DLOG(COLL(M))
    L = L + 1
    GO TO 410
430 PRINT 903, HT
    LL = L-1
    DO 420 J=1,LL
    JJ= LL+1-J
    TEM(JJ,M) = COLLFR(J,M)
    DO 425 J=1,LL
    CC 425 M=1,NRSPEC
    COLLFR(J,M) = TEM(J,M)
    LL = L-1
420 TEM(JJ,M) = COLLFR(J,M)
425 COLLFR(J,M) = TEM(J,M)

```

```

112 DO 440 J=1,LL
113 COLLHT(J) = -COLLHT(J)+STORE
114 JJ = LL+1-J
115 SAVE(JJ) = COLLHT(J)
116 DO 450 J=1,LL
117 COLLHT(J) = SAVE(JJ)
118 PRINT 903, COLLHT(J), (COLLFR(J,M), M=1, NRSPEC)
119 GO TO 100
120 C
121 READ 900,BCD
122 PRINT 901,BCD
123 PUNCH 900,BCD
124 L=1
125 READ 902,HT,ED
126 IF (DABS(HT-999.99) .LT. 0.001) GO TO 530
127 IF (L.GT.100) GO TO 800
128 IF (L .NE. 1 .AND. HT .GE. ENHT(L-1)) GO TO 800
129 ENHT(L) = HT
130 IF (NRSPEC .EQ. 3) ED(3) = ED(2)-ED(1)
131 DO 511 M=1,NRSPEC
132 IF (ED(M) .LE. 0.0) ED(M)=1.0D-40
133 CONTINUE
134 PRINT 903,HT,(ED(M),M=1,NRSPEC)
135 DO 515 M=1,NRSPEC
136 ENLOG(L,M) = DLOG(ED(M))
137 L = L+1
138 GO TO 510
139 PRINT 903,HT
140 LL = L-1
141 DO 520 J=1,LL
142 DO 520 M=1,NRSPEC
143 JJ = LL+1-J
144 TEM(JJ,M) = ENLOG(J,M)
145 DO 525 J=1,LL
146 DO 525 M=1,NRSPEC
147 ENLOG(J,M) = TEM(J,M)
148 TXHT = -TXHT+ENHT(1)
149 RXHT = -RXHT+ENHT(1)
150 TOPHT = -TOPHT+ENHT(1)
151 LWSTHT = -LWSTHT+ENHT(1)
152 WKRHT = -WKRHT+ENHT(1)
153 TEMP = LWSTHT
154 LWSTHT = TOPHT
155 TOPHT = TEMP
156 H = -H +ENHT(1)
157 LL = L-1
158 STORE = ENHT(1)
159 DO 540 J=1,LL
160 ENHT(J) = -ENHT(J)+STORE
161 JJ = LL+1-J
162 SAVE(JJ) = ENHT(J)
163 DO 550 J=1,LL
164 ENHT(J) = SAVE(JJ)
165 PRINT 903, ENHT(J), (ENLOG(J,M), M=1, NRSPEC)
166 GO TO 100
167 C
168 ERROR EXIT

```

```

169      PRINT 910
170      STOP
171      FORMAT (10A8)
172      FORMAT (1X,10A8)
173      FORMAT(F7.2,4X,5(1X,E9.2))
174      FORMAT(1X,F7.2,5X,5(1PE9.2,6X))
175      FORMAT ('!ERROR IN DATA DECK DETECTED',/,
176      $ ' IN SUBROUTINE XINPUT')
177      FORMAT(' &DATUM')
178      FORMAT(' THETA=(',F6.3,',',F7.3,',',')')
179      FORMAT(' FREQ=(',F7.3,',',')')
180      FORMAT(' TXHT=(',F8.3,',',RXHT=(',F8.3,',',')')
181      FORMAT(' &END')
182      FORMAT(' AZIM=(',F7.3,',',CODIP=(',F7.3,',',MAGFLD=(',D11.4,',',',
183      $ 'SIGMA=(',D10.3,',',EPSR=(',F4.1,',',')')
184      END

```

```

1  SUBROUTINE WAVFLD(EX,EY,LZ,HX,HY,HZ)
2
3  C
4  C
5  C
6  C
7  C
8  C
9  C
10 C
11 C
12 C
13 C
14 C
15 C
16 C
17 C
18 C
19 C
20 C
21 C
22 C
23 C
24 C
25 C
26 C
27 C
28 C
29 C
30 C
31 C
32 C
33 C
34 C
35 C
36 C
37 C
38 C
39 C
40 C
41 C
42 C
43 C
44 C
45 C
46 C
47 C
48 C
49 C
50 C
51 C
52 C
53 C
54 C

    WAVFLD CALLS FOR THE DOWNWARD
    INTEGRATION, AND THEN PERFORMS THE
    BACK SUBSTITUTION OF NORMALIZING
    VALUES (SAVED AS DATA BY WFSTOR).
    FIELD STRENGTHS ARE COMPUTED AT
    HEIGHTS FROM TOPHT TO LWSTHT AT
    DELHT INCREMENTS, AND ARE RETURNED
    IN THE LISTS EX, EY, EZ, HX, HY, HZ.

    IMPLICIT REAL *8 (A-H,O-Z)
    COMMON/EXTRA/XTRA,R(4)
    COMMON/STOR/ STORE
    COMMON/WF FLAG/PREC/N,ISO,IDBG
    COMMON/WF SAVE/PI(4),M31,M32,M33,ORTHO,ANORM,BNORM,HT,LEVL
    COMMON/CS/C,S,CI,SI
    COMMON/WFINPT/THETA,FREQ,AZMUTH,CODIP,MAGFLD,CEFFNU(5),EXPNU(5),
    $ TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
    COMMON/EXC IN/TXHT,RXHT
    COMMON/D RX TX/EY D,EZ D,EX TXHT,EY TXHT,EZ TXHT,
    $ EX RXHT,EY RXHT,EZ RXHT,
    $ HX RXHT,HY RXHT,HZ RXHT
    REAL*3 MAGFLD, LWSTHT
    COMPLEX*16 I/(0.000,1.000)/
    COMPLEX*16 EX(129,6),EY(129,6),EZ(129,6),
    $ HX(129,6),HY(129,6),HZ(129,6),
    $ XTRA,R,P,M31,M32,M33,ORTHO,C,S,CI,SI,THETA,EYD,EZD,
    $ EXTXHT,EYTXHT,EZTXHT,EXRXHT,EYRXHT,EZRXHT,HXRXHT,
    $ HYRXHT,HZRXHT,B(12),W(4,12),OSUM,RBAR11,RBAR22,EXT,EYT,
    $ EZT,HXT,HYT,HZT,HYD,HYENT,HYREC,EXC,EFIELD(3,3),
    $ HFIELD(3,3),EYDEE,EYENTH,EXENTH,EYREC,EXREC
    DIMENSION EMAG(3,3),EANG(3,3),HANG(3,3),HANG(3,3)
    DIMENSION EXMAG(6),EYMAG(6),EZMAG(6),HXMAG(6),HYMAG(6),HZMAG(6),
    $ EXANG(6),EYANG(6),EZANG(6),HXANG(6),HYANG(6),HZANG(6)
    EQUIVALENCE(TOPHT,D)
    DATA PI/3.14159265359/

    JHT = TOPHT/DELHT+1.01
    TEST = (JHT-1)*DELHT-TOPHT
    IF(DABS(TEST) .GT. 0.0001) GO TO 800
    JHT = LWSTHT/DELHT+1.01
    TEST = (JHT-1)*DELHT-LWSTHT
    IF(DABS(TEST) .GT. 0.0001) GO TO 800

    CALL WFINTG(TOPHT,LWSTHT,DELHT,0)
    CALL DECOMP(LWSTHT)
    CALL WRB

    COYSINE SOLUTIONS AT GROUND SO THAT
    THEY SATISFY BOUNDARY CONDITION.
    CALL WF BNDY(E)

```

```

55 C PERFORM BACK SUBSTITUTION OF
56 C NORMALIZING VALUES.
57   U SUM = 0.0
58   PRODA = 1.0
59   PRODB = 1.0
60   IHT=MHT
61   CALL WFLD
62   GO TO 25
63
64 C
65   21 U SUM = 0 SUM*ANORM/BNORM+ORTHO
66   PRODA = PRODA + ANORM
67   IF (PRODA .LT. 1.0D-30) PRODA = 0.0
68   PRODB = PRODB + BNORM
69   CALL WF LOAD
70   DO 23 J=1,4
71   P(J,2) = (P(J,2)-O SUM*P(J,1))*PRODB
72   23 P(J,1) = P(J,1) * PRODA
73
74 C
75 C COMPUTE FIELD STRENGTHS
76 C AT PROFILE HEIGHTS.
77   25 DO 26 N=1,11,2
78   DO 26 J=1,4
79   W(J,N) = P(J,1)*B(N)+P(J,2)*B(N+1)
80   DO 27 N=1,11,2
81   NN = (N+1)/2
82   EX(IHT,NN) = W(1,N)
83   EY(IHT,NN) = -W(2,N)
84   EZ(IHT,NN) = -(S*W(4,N)+M31*W(1,N)-M32*W(2,N))/(1.+M33)
85   HX(IHT,NN) = W(3,N)
86   HY(IHT,NN) = W(4,N)
87   HZ(IHT,NN) = -S*W(2,N)
88   EXMAG(NN) = CDABS(EX(IHT,NN))
89   EYMAG(NN) = CDABS(EY(IHT,NN))
90   EZMAG(NN) = CDABS(EZ(IHT,NN))
91   HXMAG(NN) = CDABS(HX(IHT,NN))
92   HYMAG(NN) = CDABS(HY(IHT,NN))
93   HZMAG(NN) = CDABS(HZ(IHT,NN))
94   EXANG(NN) = CDANG(EX(IHT,NN))
95   EYANG(NN) = CDANG(EY(IHT,NN))
96   EZANG(NN) = CDANG(EZ(IHT,NN))
97   HXANG(NN) = CDANG(HX(IHT,NN))
98   HYANG(NN) = CDANG(HY(IHT,NN))
99   HZANG(NN) = CDANG(HZ(IHT,NN))
100  27 CONTINUE
101
102 C
103   IHT = IHT + 1
104   IF (IHT.LE.JHT) GO TO 2;
105   IF (LEVL .NE. 0) PRINT 903,LEVL
106   CALL RBARS(C,S,RBAR11,RBAR22)
107   CALL HTGAIN(D,EXT,EYT,EZT,HXT,HYT,HZT)
108   HYD = HYT
109   EYDEE = EYT
110   CALL HTGAIN(STORE,EXT,EYT,EZT,HXT,HYT,HZT)
111   HYENHT = HYT/HYD
112   EYENHT = EYT/EYDEE
113   EXENHT = EXT/HYD
114   IF (RXHT .EQ. STORE) GO TO 50

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112 CALL HTGAIN(RXHT,EXT,EYT,EZT,HXT,HYT,HZT)
113 HYREC = HYT/HYD
114 EYREC = EYT/EYDEE
115 EXREC = EXT/HYD
116 GO TO 60
117 HYREC = HYENHT
118 EYREC = EYENHT
119 EXREC = EXENHT
120
121 EXC = RBAR11*XTA/(CDSQRT(S)*S*2* (1.+RBAR11))*2*(1.-R(2)*
122 $ RBAR22)*HYENHT*2)
123 EFIELD(1,1) = C*CDQRT(S)*EXC*COEXP(-.25*PI*I)*HYREC*((1.-R(2)*
124 $ RBAR22)*HY(IHT-1,1)+R(3)*RBAR22*EY(IHT-1,1))*2.0*(1.+RBAR11)
125 EFIELD(1,2) = C*EXC*COEXP(.75*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,1)
126 $ +(1.-R(1)*RBAR11)*EY(IHT-1,1))*2.0*(1.+RBAR22)
127 $ /CDSQRT(S)
128 EFIELD(1,3) = C*EXC*COEXP(1.75*PI*I)*EXREC*((1.-R(2)*RBAR22)*
129 $ HY(IHT-1,1)+R(3)*RBAR22*EY(IHT-1,1))*2.0*(1.+RBAR11)
130 $ /CDSQRT(S)
131 EFIELD(2,1) = C*CDQRT(S)*EXC*COEXP(-.25*PI*I)*HYREC*((1.-R(2)*
132 $ RBAR22)*HY(IHT-1,2)+R(3)*RBAR22*EY(IHT-1,2))*2.0*(1.+RBAR11)
133 EFIELD(2,2) = C*EXC*COEXP(.75*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,2)
134 $ +(1.-R(1)*RBAR11)*EY(IHT-1,2))*2.0*(1.+RBAR22)
135 $ /CDSQRT(S)
136 EFIELD(2,3) = C*EXC*COEXP(1.75*PI*I)*EXREC*((1.-R(2)*RBAR22)*
137 $ HY(IHT-1,2)+R(3)*RBAR22*EY(IHT-1,2))*2.0*(1.+RBAR11)
138 $ /CDSQRT(S)
139 EFIELD(3,1) = C*CDQRT(S)*EXC*COEXP(-.25*PI*I)*HYREC*((1.-R(2)*
140 $ RBAR22)*HY(IHT-1,3)+R(3)*RBAR22*EY(IHT-1,3))*2.0*(1.+RBAR11)
141 EFIELD(3,2) = C*EXC*COEXP(.75*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,3)
142 $ +(1.-R(1)*RBAR11)*EY(IHT-1,3))*2.0*(1.+RBAR22)
143 $ /CDSQRT(S)
144 EFIELD(3,3) = C*EXC*COEXP(1.75*PI*I)*EXREC*((1.-R(2)*RBAR22)*
145 $ HY(IHT-1,3)+R(3)*RBAR22*EY(IHT-1,3))*2.0*(1.+RBAR11)
146 $ /CDSQRT(S)
147 EFIELD(1,1) = C*CDQRT(S)*EXC*COEXP(-.75*PI*I)*HYREC*((1.-R(2)*
148 $ RBAR22)*HY(IHT-1,4)+R(3)*RBAR22*EY(IHT-1,4))*2.0*(1.+RBAR11)
149 EFIELD(1,2) = C*EXC*COEXP(.25*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,4)
150 $ +(1.-R(1)*RBAR11)*EY(IHT-1,4))*2.0*(1.+RBAR22)
151 $ /CDSQRT(S)
152 EFIELD(1,3) = C*EXC*COEXP(1.25*PI*I)*EXREC*((1.-R(2)*RBAR22)*
153 $ HY(IHT-1,4)+R(3)*RBAR22*EY(IHT-1,4))*2.0*(1.+RBAR11)
154 $ /CDSQRT(S)
155 EFIELD(2,1) = C*CDQRT(S)*EXC*COEXP(-.75*PI*I)*HYREC*((1.-R(2)*
156 $ RBAR22)*HY(IHT-1,5)+R(3)*RBAR22*EY(IHT-1,5))*2.0*(1.+RBAR11)
157 EFIELD(2,2) = C*EXC*COEXP(.25*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,5)
158 $ +(1.-R(1)*RBAR11)*EY(IHT-1,5))*2.0*(1.+RBAR22)
159 $ /CDSQRT(S)
160 EFIELD(2,3) = C*EXC*COEXP(1.25*PI*I)*EXREC*((1.-R(2)*RBAR22)*
161 $ HY(IHT-1,5)+R(3)*RBAR22*EY(IHT-1,5))*2.0*(1.+RBAR11)
162 $ /CDSQRT(S)
163 EFIELD(3,1) = C*CDQRT(S)*EXC*COEXP(-.75*PI*I)*HYREC*((1.-R(2)*
164 $ RBAR22)*HY(IHT-1,6)+R(3)*RBAR22*EY(IHT-1,6))*2.0*(1.+RBAR11)
165 EFIELD(3,2) = C*EXC*COEXP(.25*PI*I)*EYREC*(R(4)*RBAR11*HY(IHT-1,6)
166 $ +(1.-R(1)*RBAR11)*EY(IHT-1,6))*2.0*(1.+RBAR22)
167 $ /CDSQRT(S)
168 EFIELD(3,3) = C*EXC*COEXP(1.25*PI*I)*EXREC*((1.-R(2)*RBAR22)*
169 $ HY(IHT-1,6)+R(3)*RBAR22*EY(IHT-1,6))*2.0*(1.+RBAR11)

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169      $ , COSRT(S)
170      DO 100 J=1,3
171      DO 100 K=1,3
172      EMAG(J,K) = CDABS(EFIELD(J,K))
173      EANG(J,K) = CDANG(EFIELD(J,K))
174      HMAG(J,K) = CDABS(HFIELD(J,K))
175      HANG(J,K) = CDANG(HFIELD(J,K))
176      CONTINUE
177      PRINT 920
178      PRINT 921
179      PRINT 922
180      PRINT 923, (EMAG(1,K), EANG(1,K), K=1,3)
181      PRINT 924, (EMAG(2,K), EANG(2,K), K=1,3)
182      PRINT 925, (EMAG(3,K), EANG(3,K), K=1,3)
183      PUNCH 927, (EMAG(1,K), EANG(1,K), K=1,3)
184      PUNCH 928, (EMAG(2,K), EANG(2,K), K=1,3)
185      PUNCH 929, (EMAG(3,K), EANG(3,K), K=1,3)
186      PRINT 930
187      PRINT 921
188      PRINT 922
189      PRINT 923, (HMAG(1,K), HANG(1,K), K=1,3)
190      PRINT 924, (HMAG(2,K), HANG(2,K), K=1,3)
191      PRINT 925, (HMAG(3,K), HANG(3,K), K=1,3)
192      PUNCH 927, (HMAG(1,K), HANG(1,K), K=1,3)
193      PUNCH 928, (HMAG(2,K), HANG(2,K), K=1,3)
194      PUNCH 929, (HMAG(3,K), HANG(3,K), K=1,3)
195      PRINT 926
196      RETURN
197
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C
C      800 PRINT 902
C      STOP
C
902  FORMAT (' ERROR IN WAVELD',/,
903  FORMAT(' ', 'LEVL NOT ZERO. LEVL = ', I3)
904  FORMAT(' ', 'ELECTRIC DIPOLE TRANSMITTER'///)
905  FORMAT(' ', '31X', 'Z', '25X', 'Y', '25X', 'X'//)
906  FORMAT(' ', '24X', '3', 'MAG', '9X', 'ANG', '11X')
907  FORMAT(' ', '14X', 'V', '4X', '3(E13.6, 2X, F6.3, 5X)')
908  FORMAT(' ', '13X', 'HB', '4X', '3(E13.6, 2X, F6.3, 5X)')
909  FORMAT(' ', '13X', 'HE', '4X', '3(E13.6, 2X, F6.3, 5X)')
910  FORMAT(' ', 'V', '2X', '3(E13.6, 2X, F6.3, 4X)')
911  FORMAT(' ', 'HB', '2X', '3(E13.6, 2X, F6.3, 4X)')
912  FORMAT(' ', 'HE', '2X', '3(E13.6, 2X, F6.3, 4X)')
913  FORMAT(' ', '0', '14X', 'MAGNETIC DIPOLE TRANSMITTER'///)
914  END

```

```

1  SUBROUTINE WF INTG(TOPHT,LWSTHT,DELHT,IFLAG)
2
3  C WF INTG PERFORMS THE INTEGRATION OF THE P MATRIX THROUGH THE
4  C IONOSPHERE, USING THE TECHNIQUES GIVEN BY PITTEWAY. ACCURACY IS
5  C MAINTAINED BY ADJUSTING THE STEP SIZE SO THAT THE P MATRIX IS
6  C COMPUTED WITH SUFFICIENT ACCURACY.
7
8  C IFLAG=0 INTEG FOR THETA ONLY
9  C IFLAG=1 INTEG FOR THETA AND THETA-DTHETA
10
11  C IMPLICIT REAL *8 (A-H,O-Z)
12  C COMMON/WF FLAG/PRECSN,ISO,IDBG
13  C COMMON/P MIX/P(8),PI(8)
14  C COMMON/WF SAVE/P SAVE(8),M31 SAV,M32 SAV,M33 SAV,
15  C $ ORTHO,ANORM,BNORM,HT,LEVL
16  C COMMON/M MTX/M(3,3)
17  C COMMON/WF PROF/ENHT(100),ENLOG(100.5),COLLHT(25),COLLFR(25.5),
18  C $ LHT,MHT,CHARGE(5),RAT10M(5),NRSPEC
19
20  C INTEGER SVFLAG
21  C REAL*8 LWSTHT
22  C COMPLEX*16 M31 SAV,M32 SAV,M33 SAV,ORTHOM
23  C COMPLEX*16 P,PI,P SAVE,PREV P,TEMP P,DPDH,PV DPDH,DPIDH
24  C DIMENSION PREVP(8),TEMPP(8),DPDH(8),PV DPDH(8),DPIDH(8)
25  C DIMENSION PR(16),TPR(16)
26  C EQUIVALENCE (P,PR),(TEMPP,TPR)
27  C DATA EPSHT /5.0D-4/
28  C DATA DHMIN /1.0D-3/
29
30  C MINIMUM STEP-SIZE ALLOWED
31
32  C CALL INIT T
33  C CALL T MTRX(TOP HT)
34  C CALL WF INIT(P)
35  C CALL P DERIV(P,DPDH)
36  C IF(IFLAG.EQ. 0) GO TO 11
37  C CALL TI MTRX
38  C CALL WF INIT(PI)
39  C CALL P DERIV(PI,DPIDH)
40
41  C 11 CONTINUE
42
43  C ISTEPS = 0
44  C KMAX = 0
45  C LEVL = 0
46  C HT = TOPHT
47  C CALL XFER(P,P SAVE,8)
48  C M31 SAV = M(3,1)
49  C M32 SAV = M(3,2)
50  C M33 SAV = M(3,3)
51  C CALL WF STOR
52  C WFHT = TOPHT - DELHT
53  C DELH2 = 0.125D0*DELHT
54  C SVFLAG=0
55
56  C DETERMINE NEXT STEP SIZE TO USE.

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55 10 IF (SVFLAG.EQ.1) DELH2=SAVDH2
56 SVFLAG=0
57 NODBL = 0
58 HTO=HT
59 CALL XFER(P,PREVP,8)
60 CALL XFER(DPDH,PV,DPDH,8)
61 HTLIM = XHT
62 IF (ENHT(LHT+1).GT.HTLIM+EPSHT)
63 $ HTLIM = ENHT(LHT+1)
64 IF (COLLHT(MHT+1).GT.HTLIM+EPSHT)
65 $ HTLIM = COLLHT(MHT+1)
66 IF (HTO-DELH2.GE.HTLIM+EPSHT) GO TO 50
67 SAVDH2 = DELH2
68 SVFLAG = 1
69 DELH2 = HTO - HTLIM
70
71 C
72 C PERFORM NEXT INTEGRATION STEP.
73 50 CALL WF STEP(P,DPDH,HT,DELH2,0)
74 CALL XFER(P,TEMP,8)
75 M31 SAV = M(3,1)
76 M32 SAV = M(3,2)
77 M33 SAV = M(3,3)
78 HT=HTO
79 CALL XFER(PREVP,P,8)
80 CALL XFER(PV,DPDH,DPDH,8)
81 DELH=0.5*DELH2
82 CALL WF STEP(P,DPDH,HT,DELH,1)
83 CALL P DERIV(P,DPDH)
84 CALL WF STEP(P,DPDH,HT,DELH,2)
85 CHECK ACCURACY OF RESULT.
86 FMAX = 0.0
87 UO 85 J=1,16
88 PABS = DABS(PR(J)-TPR(J))
89 IF(PMAX.LT. PABS) PMAX = PABS
90
91 85 CONTINUE
92 ADJUST STEP SIZE IF NECESSARY.
93 IF (PMAX.LT.PRECSN) GO TO 100
94
95 C
96 IF (DELH.GT.DHMIN) GO TO 95
97 IF (KMAX.EQ.0) PRINT 900, HT
98 KMAX = 1
99 GO TO 100
100
101 95 CONTINUE
102 DELH2 = 0.5 * DELH2
103 NODBL = 1
104 IF (PMAX.LT.10.0*PRECSN) GO TO 99
105 DELH2 = 0.25 * DELH2
106 NODBL = 0
107 99 CONTINUE
108 HT=HTO
109 CALL XFER(PREVP,P,8)
110 CALL XFER(PV,DPDH,DPDH,8)
111 SVFLAG=0
112 GO TO 50
113
114 C
115 100 CALL WF SCAL(P,0)
116 CALL XFER(P,P,SAVE,3)

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112 IF (HT .LT. WFHT+EPSHT) CALL WF STOR
113 CALL P DERIV(P,DPDH)
114 IF (IFLAG .EQ. 0) GO TO 72
115 HT = H10
116 CALL WF STEP(PI,DPIDH,HT,DELH,3)
117 CALL P DERIV(PI,DPIDH)
118 CALL WF STEP(PI,DPIDH,HT,DELH,4)
119 CALL WF SCAL(PI,1)
120 CALL P DERIV(PI,DPIDH)
121
122 72 CONTINUE
123 C
124 ISTEPS = ISTEPS+1
125 IF (IDBG .EQ. 0) GO TO 73
126 IDIV = ISTEPS/50
127 IF (ISTEPS .EQ. 50*IDIV) PRINT 902,ISTEPS,HT
128 73 CONTINUE
129 IF (NO DBL .EQ. 0 .AND. PMAX .LT. 0.1*PRECSN) DELH2 = 2.0*DELH2
130 C
131 C CHECK INTEGRATION AND PROFILE HEIGHTS.
132 IF (HT.LT.LWSTHT+EPSHT) GO TO 80
133 IF (HT.LT.WFHT+EPSHT) WFHT = WFHT - DELHT
134 IF (HT.LT.ENHT(LHT+1)+EPSHT) LHT = LHT + 1
135 IF (HT.LT.COLLHT(MHT+1)+EPSHT) MHT = MHT + 1
136 GO TO 10
137 C
138 80 PRINT 901,ISTEPS
139 RETURN
140 C
141 900 FORMAT (' MINIMUM STEPSIZE USED AT HT =',D14.5)
142 901 FORMAT (1X,13,' INTEGRATION STEPS USED IN WAVFLD',/)
143 902 FORMAT (1X,14,' INTEGRATION STEPS, HT =',F9.4)
144 END

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SUBROUTINE T MTRX(HT)

C T MTRX COMPUTES THE MATRICES
C M- THE SUSCEPTIBILITY TENSOR
C T- THE COEFFICIENT MATRIX OF
C THE LINEAR SYSTEM OF O.D.E.
C DP/DZ = -IK*T*P.
C NOTE THAT ON CALL TO ENTRY INIT T, VARIOUS IONOSPHERIC CONSTANTS
C ARE COMPUTED.

C
C IMPLICIT REAL *8 (A-H,O-Z)
COMMON/WF FLAG/PRECSN,ISO,IOBG
COMMON/M MTRX/M11,M21,M31,M12,M22,M32,M13,M23,M33
COMMON/T MTRX/T11,T31,T41,T12,T32,T42,T14,T34,T44
COMMON/TW MTRX/TM11,TM31,TM41,TM12,TM32,TM42,TM14,TM34,TM44
COMMON/CS/C,S,CI,SI
COMMON/WFINPT/THETA,FREQ,AZMUTH,CODIP,MAGFLD,CEFFNU(5),EXPNU(5),
$ TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
COMMON/WF CON/OMEGA,WAVE NR
COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
$ LHT,MHT,CHARGE(5),RAT10M(5),NRSPEC

C REAL*B MAGFLD, LWSTHT,
$ LSQYSQ, MSQYSQ, NSQYSQ,
$ LMYSQ, LNYSQ, MNYSQ, NU,
$ LY,MY,NY
C COMPLEX*16 M(3,3),
$ M11,M21,M31,M12,M22,M32,M13,M23,M33,
$ T11,T31,T41,T12,T32,T42,T14,T34,T44,
$ TM11,TM31,TM41,TM12,TM32,TM42,TM14,TM34,TM44,
$ C,S,CI,SI,CSQ,SSQ,CSQI,SSQI,
$ THETA,DTHETA,
$ D,M13D,M23D,
$ U,USQ,DD,I,IUD,TA,TB
C DIMENSION Y(5),YSQ(5),LY(5),MY(5),
$ NY(5),LMYSQ(5),LNYSQ(5),MNYSQ(5),EN(5),NU(5),
$ LSQYSQ(5),MSQYSQ(5),NSQYSQ(5),
$ COEF EN(5)

C EQUIVALENCE(M11,M)
DATA PI/3.141592653D0/
DATA D1R/1.745329252D-2/
DATA COEFFX/3.182357D03/,COEFFY/1.758796D11/
DATA I/(0.0D0,1.0D0)/
DATA VELLT/2.997928D05/
DATA DTHETA/(5.0D-2,1.0D-2)/

C
C CALCULATE THE MATRIX M.
C M(1,1) = 0.0
C M(1,2) = 0.0
C M(1,3) = 0.0
C M(2,1) = 0.0
C M(2,2) = 0.0
C M(2,3) = 0.0

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55 M(3,1) = 0.0
56 M(3,2) = 0.0
57 M(3,3) = 0.0
58
59 C CALL WF DENS (HT, EN, NU)
60 NFLAG = 0
61 DO 20 K=1,NRSPEC
62 ADD IN THE CONTRIBUTIONS TO THE
63 SUSCEPTIBILITY TENSOR M FOR EACH
64 SPECIE IN THE IONOSPHERE.
65 IF (EN(K) .LT. 1.0E-3) GO TO 20
66 NFLAG = 1
67 X = COEF EN(K)*EN(K)
68 Z = NU(K)*OV OMGA
69 U=1.0-1+Z
70 USQ=U*U
71 DD = -X / (U * (USQ - YSQ(K)))
72 IUD = (Z+1)*DD
73 TA = USQ * DD
74 M(1,1) = M(1,1) + TA
75 M(2,2) = M(2,2) + TA
76 M(3,3) = M(3,3) + TA
77 M(2,2) = M(2,2) - MSQSQ(K) * DD
78 TA = MY(K)*IUD
79 TB = LNYSQ(K) * DD
80 M(1,3) = M(1,3) + TA - TB
81 M(3,1) = M(3,1) - TA - TB
82 IF (ISO.NE.0) GO TO 20
83 M(1,1) = M(1,1) - LSQSQ(K) * DD
84 M(3,3) = M(3,3) - NSQSQ(K) * DD
85 TA = NY(K)*IUD
86 TB = LMYSQ(K) * DD
87 M(2,1) = M(2,1) + TA - TB
88 M(1,2) = M(1,2) - TA - TB
89 TA = LY(K)*IUD
90 TB = MNYSQ(K) * DD
91 M(3,2) = M(3,2) + TA - TB
92 M(2,3) = M(2,3) - TA - TB
93
94 20 CONTINUE
95
96 C CRVTRM=ALPHA*(H-HT)
97 M(1,1) = M(1,1) + CRVTRM
98 M(2,2) = M(2,2) + CRVTRM
99 M(3,3) = M(3,3) + CRVTRM
100
101 C CALCULATE THE MATRIX T.
102 D = 1.0/(1.0+M33)
103 TM41 = 1.0+M11
104 TM32 = M22
105 TM14 = D
106 IF(NFLAG .EQ. 0) GO TO 40
107 M13D = M13*D
108 M23D = M23*D
109 TM41 = TM41-M31*M13D
110 TM11 = M31*D
111 TM44 = M13D
112 IF(ISO .NE. 0) GO TO 40

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112 TM32 = TM32-W32-W23D
113 TM31 = W31-W23D-W21
114 TM12 = W32-D
115 TM42 = W32-W13D-W12
116 TM34 = W23D
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C
40 T41 = TM41
T32 = CSQ+TM32
T14 = 1.0-SSQ+TM14
IF(FLAG.EQ. 0) GO TO 70
T11 = -S+TM11
T44 = -S+TM44
IF(ISO.NE. 0) RETURN
T31 = TM31
T12 = S+TM12
T42 = TM42
T34 = S+TM34
RETURN

C
C
ENTRY TI MTRX
T41 = TM41
T32 = CSQ+TM32
T14 = 1.0-SSQ+TM14
T11 = -S+TM11
T44 = -S+TM44
IF(ISO.NE. 0) RETURN
T31 = TM31
T12 = S+TM12
T42 = TM42
T34 = S+TM34
RETURN

C
C
ENTRY INIT T
C COMPUTE VARIOUS QUANTITIES
C WHICH DO NOT VARY WITH HEIGHT.
LHT = 0
ISO=0
IF(MAGFLD.EQ. 0.0) GO TO 250
IF (DABS(CODIP-90.0).GE.0.15) GO TO 300
IF (DABS(AZMUTH-90.0).LT.0.15) GO TO 250
IF (DABS(AZMUTH-270.0).GE.0.15) GO TO 300
250 ISO = 1
300 OMEGA = 2000.0*PI*FREQ
C OMEGA = 1.0/OMEGA
WAVENR = OMEGA/VELLT
SINDIP = DSIN (CODIP+DTR)
DRCOSL = SINDIP * DCOS (AZMUTH * DTR)
DRCOSM = -SINDIP * DSIN (AZMUTH * DTR)
DRCOSN = DCOS (CODIP * DTR)
D360 K=1,NRSPEC
COEFF EN(K) = COEFFX+1.0E6*CHARGE(K)**2/(OMEGA**2*RATION(K))
Y(K) = COEFFY * CHARGE(K) * MAGFLD
$ OMEGA * RATION(K))
YSQ(K)=Y(K)**2
LY(K) = DRCOSL*Y(K)

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169 MY(K) = DRCOSM*Y(K)
170 NY(K) = DRCOSN*Y(K)
171 LSQYSQ(K)=DRCOSL**2*YSQ(K)
172 MSQYSQ(K)=DRCOSM**2*YSQ(K)
173 NSQYSQ(K)=DRCOSN**2*YSQ(K)
174 LMYSQ(K)=DRCOSL*DRCOSM*YSQ(K)
175 LNYSQ(K)=DRCOSL*DRCOSN*YSQ(K)
176 MNYSQ(K)=DRCOSM*DRCOSN*YSQ(K)
177
60 CONTINUE
178 C = CDCOS(THETA*DTR)
179 S = CDSIN(THETA*DTR)
180 CSQ = C**2
181 SSQ = S**2
182 C1 = CDCOS((THETA-DTHETA)*DTR)
183 S1 = CDSIN((THETA-DTHETA)*DTR)
184 CSQ1 = C1**2
185 SSQ1 = S1**2
186
C
187 T11 = 0.0
188 T31 = 0.0
189 T12 = 0.0
190 T42 = 0.0
191 T34 = 0.0
192 T44 = 0.0
193 RETURN
194 END

```

```

1  SUBROUTINE WF DENS (HT, EN, COLL)
2
3  C
4  C WF DENS COMPUTES THE ION DENSITY
5  C AND COLLISION FREQUENCY FOR EACH
6  C SPECIE BY LOGARITHMIC INTERPOLATION
7  C OF THE CORRESPONDING PROFILES.
8  C PROFILE VALUES ARE INTERPOLATED BETWEEN
9  C ENTRIES MHT AND MHT+1 (LHT AND LHT+1).
10
11 C
12 C IMPLICIT REAL *8 (A-H,O-Z)
13 C COMMON/WFPROF/ENHT(100),ENLOG(100,5),COLLHT(25),COLLFR(25,5),
14 C $ LHT,MHT,CHARGE(5),RAT10M(5),NRSPEC
15 C DIMENSION EN(5),COLL(5),DELE(5),DELC(5)
16 C COMMON/PRIMES/DELE,DELC
17 C DATA EPSHT/5.D-4/
18
19 C
20 C LUCKY=0
21 C MUCKY=0
22 C IF (LHT.EQ.0) LHT=1
23 C IF (MHT.EQ.0) MHT=1
24
25 10 IF (HT.GE.ENHT(LHT+1)-EPSHT .AND. HT.LT.ENHT(LHT)+EPSHT) GO TO 20
26 IF (LUCKY.EQ.1) GO TO 30
27 LHT=LHT-1
28 IF (LHT.EQ.0) LHT=1
29 IF (LHT.EQ.1) LUCKY=1
30 GO TO 10
31
32 30 LHT=LHT+1
33 IF (LHT.GT.101) GO TO 899
34 GO TO 10
35
36 20 IF (HT.GE.COLLHT(MHT+1)-EPSHT .AND. HT.LT.COLLHT(MHT)+EPSHT) GOTO 100
37 IF (MUCKY.EQ.1) GO TO 40
38 MHT=MHT-1
39 IF (MHT.EQ.0) MHT=1
40 IF (MHT.EQ.1) MUCKY=1
41 GO TO 20
42
43 40 MHT=MHT+1
44 IF (MHT.GT. 26) GO TO 899
45 GO TO 20
46
47 C
48 100 IF (LHT.EQ.LSAVE) GO TO 200
49 DO 150 K = 1,NRSPEC
50 DELE(K) = (ENLOG(LHT+1,K) - ENLOG(LHT,K))
51 $ / (ENHT(LHT+1) - ENHT(LHT))
52
53 150 CONTINUE
54 LSAVE = LHT
55
56 C
57 200 IF (MHT.EQ.MSAVE) GO TO 300
58 DO 250 K = 1,NRSPEC
59 DELC(K) = (COLLFR(MHT+1,K) - COLLFR(MHT,K))
60 $ / (COLLHT(MHT+1) - COLLHT(MHT))
61
62 250 CONTINUE
63 MSAVE = MHT

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300 DH = HT - ENHT(LHT)
    DC = HT - COLLHT(MHT)
    DO 500 K = 1, NRSPEC
        EN(K) = DEXP (ENLOG(LHT,K) + DH * DELE(K))
        COLL(K) = DEXP (COLLFR(MHT,K) + DC * DELC(K))
500 CONTINUE
    RETURN
899 PRINT 900
900 FORMAT (' ERROR IN PROFILE INTERPOLATION')
    STOP
    END

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      SUBROUTINE P DERIV(P,DPDH)
      C
      C P DERIV COMPUTES THE HEIGHT DERIVATIVES
      C OF THE FIELD VECTORS P ACCORDING TO
      C CLENNOW AND HEADING (1954).
      C EQUATION IS  $DP/DZ = -IK \cdot T \cdot P$ .
      C MULTIPLICATION BY -I IS PERFORMED BY
      C OPERATING ON REAL AND IMAG PARTS.
      C MULTIPLICATION BY K IS PERFORMED
      C IN SUBROUTINE WF STEP.
      C
      COMMON/T MTX/ T11,T31,T41,T12,T32,T42,T14,T34,T44
      COMPLEX*16 P(4,2),DPDH(4,2),DERIV,
      $      T11,T31,T41,T12,T32,T42,T14,T34,T44
      C
      C
      DO 11 J=1,2
      DERIV = T11*P(1,J)+T12*P(2,J)+T14*P(4,J)
      DPH(1,J) = (0.00,-1.00)*DERIV
      DERIV = P(3,J)
      DPH(2,J) = (0.00,-1.00)*DERIV
      DERIV = T31*P(1,J)+T32*P(2,J)+T34*P(4,J)
      DPH(3,J) = (0.00,-1.00)*DERIV
      DERIV = T41*P(1,J)+T42*P(2,J)+T44*P(4,J)
      DPH(4,J) = (0.00,-1.00)*DERIV
      11 CONTINUE
      RETURN
      C
      END

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1  SUBROUTINE XFER(A,B,N)
2
3  C  TRANSFER ARRAY A INTO ARRAY B.
4  C
5  C  COMPLEX*16 A,B
6  C  DIMENSION A(1),B(1)
7  C
8  C  DO 11 J=1,N
9  C  11 B(J) = A(J)
10 C  RETURN
11 C
12 C  END
13

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```

1      SUBROUTINE WF SCAL (PP, IFLAG)
2
3      C
4      C WFSAL SCALES AND ORTHOGONALIZES THE SOLUTION
5      C VECTORS P. THIS SCALING MUST BE
6      C REMOVED TO YIELD CORRECT (UNSCALED) SOLUTIONS.
7      C
8
9      IMPLICIT REAL*8 (A-H,O-Z)
10     COMMON/ WF SAVE/ P SAVE(8), M31 SAV, M32 SAV, M33 SAV,
11     $      O SUM, APROD, BPROD, HT, LEVL
12     COMMON/ SAVE/ P ETC(27, 129)
13     COMPLEX*16 P(4,2), PP, PSAVE,
14     $      M31 SAV, M32 SAV, M33 SAV, O SUM, ORTHO
15     DIMENSION PR(8,2), PP(8), PSTORE(27)
16     EQUIVALENCE (PSAVE, PSTORE)
17     EQUIVALENCE (P, PR)
18
19     CALL XFER (PP, P, 8)
20     ANORM = 0.0
21     DO 11 J=1, 8
22     11 ANORM = ANORM+PR(J,1)**2
23     ORTHO = 0.0
24     DO 12 J=1, 4
25     12 ORTHO = ORTHO+DCONJG(P(J,1))*P(J,2)
26     ORTHO = ORTHO/ANORM
27
28     DO 13 J=1, 4
29     13 P(J,2) = P(J,2)-ORTHO*P(J,1)
30     BNORM = 0.0
31     DO 14 J=1, 8
32     14 B'ORM = BNORM+PR(J,2)**2
33
34     ANORM = 1.0/DSQRT(ANORM)
35     BNORM = 1.0/DSQRT(BNORM)
36     DO 15 J=1, 8
37     15 PR(J,1) = PR(J,1)*ANORM
38     PR(J,2) = PR(J,2)*BNORM
39     CALL XFER (P, PP, 8)
40     IF (IFLAG.NE. 0) RETURN
41
42     O SUM = O SUM+ORTHO*APROD/BPROD
43     APROD = APROD*ANORM
44     BPROD = BPROD*BNORM
45     RETURN
46
47     C
48     C
49     ENTRY WF STOR
50     LEVL = LEVL+1
51     DO 25 J=1, 27
52     25 F ETC(J, LEVL)=PSTORE(J)
53     O SUM = 0.0
54     A PROD = 1.0
55     B PROD = 1.0
56     RETURN

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55 C
56 C
57
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59 35
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ENTRY WF LOAD
 GO 35 J=1,27
 PSTORE(J)=P ETC(J,LEVL)
 LEVL = LEVL-1
 RETURN
 END

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      SUBROUTINE WF STEP(P,DPDH,HT,DELH,IFLAG)
      C
      C WF STEP INCREMENTS THE SOLUTION OF P
      C FROM HT TO HT+DELH, USING
      C RUNGE-KUTTA INTEGRATION
      C
      C
      C IFLAG=0 ONE LARGE STEP, THETA
      C IFLAG=1 FIRST SMALL STEP, THETA
      C IFLAG=2 SECOND SMALL STEP, THETA
      C IFLAG=3 FIRST SMALL STEP, THETA-OTHEA
      C IFLAG=4 SECOND SMALL STEP, THETA-OTHEA
      C
      C
      C IMPLICIT REAL*8 (A-H,O-Z)
      C COMMON/WF CON/OMEGA,WAVE NR
      C COMMON/WF FLAG/PRECSN,ISO,IDBG
      C COMMON/T MTX/T(9)
      C COMMON/TM MTX/TM(9)
      C COMPLEX*16 P(8),DPDH(8),PO(8),HDELP0(8),DELP1(8),DELP2(8),DELP4
      C COMPLEX*16 T,TSAVE1(9),TSAVE2(9),
      C $ TM,TMSAV1(9),TMSAV2(9),TMSAV3(9),TMSAV4(9)
      C
      C
      C HT0 = HT
      C DELH K = DELH*WAVE NR
      C HDELH K = DELH K*0.5
      C DO 11 J=1,8
      C PO(J) = P(J)
      C HDELP0(J) = -DPDH(J)*HDELH K
      C 11 P(J) = PO(J)+HDELP0(J)
      C
      C
      C HT = HT0-0.5*DELH
      C IF(IFLAG.LE. 2) CALL T MTRX(HT)
      C IF(IFLAG.EQ. 0) CALL XFER(T, TSAVE1,9)
      C IF(IFLAG.EQ. 0) CALL XFER(TM,TM SAV2,9)
      C IF(IFLAG.EQ. 1) CALL XFER(TM,TM SAV1,9)
      C IF(IFLAG.EQ. 2) CALL XFER(TM,TM SAV3,9)
      C IF(IFLAG.EQ. 3) CALL XFER(TM SAV1,TM,9)
      C IF(IFLAG.EQ. 4) CALL XFER(TM SAV3,TM,9)
      C IF(IFLAG.GE. 3) CALL T1 MTRX
      C
      C CALL P DERIV(P,DPDH)
      C DO 12 J=1,8
      C DELP1(J) = -DPDH(J)*DELH K
      C 12 P(J) = PO(J)+0.5*DELP1(J)
      C
      C CALL P DERIV(P,DPDH)
      C DO 13 J=1,8
      C DELP2(J) = -DPDH(J)*DELH K
      C 13 P(J) = PO(J)+DELP2(J)
      C
      C HT = HT0-DELH

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55 IF (FLAG.EQ. 0) CALL TTRXINH1
56 IF (FLAG.EQ. 1) CALL XFER(TT,SAVE2,9)
57 IF (FLAG.EQ. 1) CALL XFER(TT,SAVE1,5,9)
58 IF (FLAG.EQ. 2) CALL XFER(TT,SAVE2,T,9)
59 IF (FLAG.EQ. 0) CALL XFER(TT,IM,SAVE4,9)
60 IF (FLAG.EQ. 3) CALL XFER(TT,SAVE2,IM,9)
61 IF (FLAG.EQ. 4) CALL XFER(TT,SAVE4,IM,9)
62 IF (FLAG.EQ. 3) CALL TT MTRX
63
64 C
65 CALL PDERIV(P,DPDH)
66 THIRD = 1.000/3.000
67 DO 14 J=1,8
68   DELP4 = (HDELP0(J)+DELP1(J)+DELP2(J)-DPDH(J)*HDELH K)*THIRD
69   P(J) = PC(J)+DELP4
70 RETURN
71 C
72 END

```

```

1  SUBROUTINE WKB
2  IMPLICIT REAL*8(A-H,O-Z)
3  INTEGER STPFLG
4  REAL*8 MAGFLD,LWSTHT
5  COMPLEX*16 I,THETA,Q,GAMMA,INTGRQ,INTGAM,SUMQ,SUMGAM,EXPO,
6  PI(4,2),PARTS
7  COMMON/WFINPT/T,ETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
8  TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
9  COMMON/WFCON/OMEGA,WAVENR
10 COMMON/DELTA/NUMDIV,STPFLG
11 COMMON/ANSWER/PART S(4,2)
12 COMMON/P MTX/P,IGORR(32)
13 DATA I/(0.0D0,1.0D0)/
14
15 IF (WKBHT.GE.LWSTHT) RETURN
16 CALL INIT DT
17
18 C STPFLG=0 FIXED INTEGRATION STEP SIZE OF DELHT/NUMDIV
19 C STPFLG=1 VARIABLE INTEGRATION STEP SIZE
20 IF (STPFLG.EQ.1) CALL WKBVAR
21 IF (STPFLG.EQ.1) RETURN
22
23 EPSHT=DELHT/NUMDIV
24 INT=(LWSTHT-WKBHT)/EPSHT + 1.01D0
25 SUMQ=(0.0D0,0.0D0)
26 SUMGAM=(0.0D0,0.0D0)
27
28 DO 90 N=1,INT-2,2
29 DO 30 M=1,3
30 HT = LWSTHT - EPSHT*(N+M-2)
31 CALL QGAMMA(HT,DELHT,LWSTHT,Q,GAMMA)
32 IF (M.EQ.2) GO TO 110
33 INTGRQ=EPSHT*Q/3.0D0
34 INTGAM=EPSHT*GAMMA/3.0D0
35 GO TO 120
36
37 110 INTGRQ=4.0D0*EPSHT*Q/3.0D0
38 INTGAM=4.0D0*EPSHT*GAMMA/3.0D0
39
40 120 SUMQ=SUMQ+INTGRQ
41 30 SUMGAM=SUMGAM+INTGAM
42
43 NNN=(N+1)/NUMDIV
44 IF ((N+1)/NUMDIV - NNN.NE. 0.0) GO TO 90
45 EXPO=CDEXP(WAVENR*(SUMQ*I - SUMGAM))
46 DO 150 K=1,4
47 DO 150 L=1,2
48 F(K,L) = EXPO*PART S(K,L)
49
50 C OUTPUT OF INTERMEDIATE P VALUES COULD BE ACCOMPLISHED HERE
51 90 CONTINUE
52 RETURN
53 END

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1  CUMULATIVE WAVE VAR
2  IMPLICIT REAL*8(A-H,O-Z)
3  INTEGER STEPS,SVFLAG
4  REAL*8 DELH2,LWSTHT
5  COMMON /PAR/ T,THETA,Q,GAMMA,INTGRQ,INTGAM,SUMQ,SUMGAM,EXPO,QSAV,
6  $          Q,DELH2,PARTS
7  $
8  COMMON /FIRPT/ THETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
9  $          TQHT,LWSTHT,WKHT,DELHT,H,ALPHA,SIGMA,EPSLON
10 $
11 COMMON /WELON/ ONE,GAMMAENR
12 COMMON /ELTA/ NWDIV,STPELG
13 COMMON /WFLAG/ PRECSN,ISO,IDBUG
14 COMMON /ANSWER/ PART S(4,2)
15 COMMON /FIX P/IGNORR(32)
16 DATA EPSHT 5,D-4/
17 DATA DMTIN,1,D-3/
18 DATA I,(0.000,1.000)/
19
20 SVFLAG = 0
21 SUMQ=0.000,0.000)
22 SUMGAM=(0.000,0.000)
23 NQINT=0
24 HT=LWSTHT
25 XFHT=LWSTHT-DELHT
26 DELH2=DELHT/8.
27 DELHSV = DELH2
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55 DELH2=DELH2/2.
56 GO TO 60
57
58 70 DELH2=DELH2*2.
59 QABS=CDABS(IQSAV-INTGRQ)
60 IF (CDABS(INTGRQ).NE.0.) QABS=QABS/CDABS(INTGRQ)
61 IF (QABS.LT.PRECSN) GO TO 100
62 IF (DELH2.GT.DHMIN) GO TO 95
63 IF (KMAX.EQ.0) PRINT 900,HT
64
65 900 FORMAT (' MINIMUM STEP SIZE USED FIRST AT HT =',D14.5)
66 KMAX=1
67 GO TO 100
68
69 95 HT=HT+DELH2
70 DELH2=DELH2/2.
71 NODBL=1
72 IF (QABS.LT.10.*PRECSN) GO TO 99
73 DELH2=DELH2/4.
74 NODBL=0
75 SVFLAG=0
76 GO TO 50
77
78 100 IF (NODBL.EQ.0 .AND. QABS.LT.PRECSN/3.) DELH2=2.*DELH2
79 SUMQ=SUMQ+INTGRQ
80 SUNGAM=SUNGAM+INTGAM
81 NUMINT=NUMINT+1
82 IF (HT.GT.WFHT+EPSHT) GO TO 10
83 WFHT=WFHT-DELH2
84 EXPO=CDEXP(WAVENR*(SUMQ*1 - SUNGAM))
85 DO 150 K=1,4
86 DO 150 L=1,2
87
88 150 P(K,L) = EXPO*PART S(K,L)
89 C
90 OUTPUT OF INTERMEDIATE P VALUES COULD BE ACCOMPLISHED HERE
91 IF (HT.GT.WKBHT+EPSHT) GO TO 10
92 DELHAV = (LWSTHT-WKBHT)/(4*NUMINT)
93 PRINT 909,LWSTHT,WKBHT,DELHAV
94 RETURN
95
96 909 FORMAT(' SMALLEST INTEGRATION INTERVAL BETWEEN LWSTHT' = ',F7.1,
97 $ ' KM AND WKBHT' = ',F7.1, ' KM IS ',F9.4, ' KM')
98
99 910 FORMAT(' AVERAGE INTEGRATION INTERVAL BETWEEN LWSTHT' = ',F7.1,
100 $ ' KM AND WKBHT' = ',F7.1, ' KM IS ',F9.4, ' KM')
101 END

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1  C=PRIME(1,1)=0.0
2  C=PRIME(1,2)=0.0
3  C=PRIME(1,3)=0.0
4  C=PRIME(2,1)=0.0
5  C=PRIME(2,2)=0.0
6  C=PRIME(2,3)=0.0
7  C=PRIME(3,1)=0.0
8  C=PRIME(3,2)=0.0
9  C=PRIME(3,3)=0.0
10  C=PRIME(4,1)=0.0
11  C=PRIME(4,2)=0.0
12  C=PRIME(4,3)=0.0
13  C=PRIME(5,1)=0.0
14  C=PRIME(5,2)=0.0
15  C=PRIME(5,3)=0.0
16  C=PRIME(6,1)=0.0
17  C=PRIME(6,2)=0.0
18  C=PRIME(6,3)=0.0
19  C=PRIME(7,1)=0.0
20  C=PRIME(7,2)=0.0
21  C=PRIME(7,3)=0.0
22  C=PRIME(8,1)=0.0
23  C=PRIME(8,2)=0.0
24  C=PRIME(8,3)=0.0
25  C=PRIME(9,1)=0.0
26  C=PRIME(9,2)=0.0
27  C=PRIME(9,3)=0.0
28  C=PRIME(10,1)=0.0
29  C=PRIME(10,2)=0.0
30  C=PRIME(10,3)=0.0
31  C=PRIME(11,1)=0.0
32  C=PRIME(11,2)=0.0
33  C=PRIME(11,3)=0.0
34  C=PRIME(12,1)=0.0
35  C=PRIME(12,2)=0.0
36  C=PRIME(12,3)=0.0
37  C=PRIME(13,1)=0.0
38  C=PRIME(13,2)=0.0
39  C=PRIME(13,3)=0.0
40  C=PRIME(14,1)=0.0
41  C=PRIME(14,2)=0.0
42  C=PRIME(14,3)=0.0
43  C=PRIME(15,1)=0.0
44  C=PRIME(15,2)=0.0
45  C=PRIME(15,3)=0.0
46  C=PRIME(16,1)=0.0
47  C=PRIME(16,2)=0.0
48  C=PRIME(16,3)=0.0
49  C=PRIME(17,1)=0.0
50  C=PRIME(17,2)=0.0
51  C=PRIME(17,3)=0.0
52  C=PRIME(18,1)=0.0
53  C=PRIME(18,2)=0.0
54  C=PRIME(18,3)=0.0

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```

55 C
56 CALL WF DENS (HT, EH, NU)
57 DO 10 K=1,NRSPEC
58 ENPRIM(K)=EN(K)*DELE(K)
59 NUPRIM(K)=NU(K)*DELC(K)
60
61 10 CONTINUE
62
63 C
64 NFLAG = 0
65 DO 20 K=1,NRSPEC
66 ADD IN THE CONTRIBUTIONS TO THE
67 SUSCEPTIBILITY TENSOR M FOR EACH
68 SPECIE IN THE IONOSPHERE.
69 IF (EN(K) .LT. 1.0E-3) GO TO 20
70 NFLAG = 1
71 X = COEF EN(K)*EN(K)
72 XPRIME=CUFEN(K)*ENPRIM(K)/WAVENR
73 Z = NU(K)*OV OMGA
74 U=1.0-I*Z
75 UPRIME=-I*NUPRIM(K)*OV OMGA/WAVENR
76 USQ=U*U
77 CD = -X / (U * (USQ - YSQ(K)))
78 DDPRIM=(X*(3.00*USQ*UPRIME-YSQ(K)*UPRIME) -
79 XPRIME*(U*(USQ-YSQ(K))))/(U*(USQ-YSQ(K)))*2
80
81 IUD = (Z+I)*DD
82 IUDPRI=NUPRIM(K)*OV OMGA/WAVENR*DD + (Z+I)*DDPRIM
83
84 TA = USQ * DD
85 M(1,1) = M(1,1) + TA
86 M(2,2) = M(2,2) + TA
87 M(3,3) = M(3,3) + TA
88 M(2,2) = M(2,2) - MSQYSQ(K) * DD
89 TAPRIM=2.00*U*UPRIME*DD + USQ*DDPRIM
90 MPRIME(1,1)=MPRIME(1,1) + TAPRIM
91 MPRIME(2,2)=MPRIME(2,2) + TAPRIM
92 MPRIME(3,3)=MPRIME(3,3) + TAPRIM
93 MPRIME(2,2)=MPRIME(2,2) - MSQYSQ(K) * DDPRIM
94
95 TA = MY(K)*IUD
96 TB = LNYSQ(K) * DD
97 M(1,3) = M(1,3) + TA - TB
98 M(3,1) = M(3,1) - TA - TB
99 TAPRIM=MY(K)*IUDPRI
100 TBPRIM=LNYSQ(K)*DDPRIM
101 MPRIME(1,3)=MPRIME(1,3) + TAPRIM - TBPRIM
102 MPRIME(3,1)=MPRIME(3,1) - TAPRIM - TBPRIM
103
104 IF (ISO.NE.C) GO TO 20
105 M(1,1) = M(1,1) - LSQYSQ(K) * DD
106 M(3,3) = M(3,3) - NSQYSQ(K) * DD
107 MPRIME(1,1)=MPRIME(1,1) - LSQYSQ(K)*DDPRIM
108 MPRIME(3,3)=MPRIME(3,3) - NSQYSQ(K)*DDPRIM
109 TA = NY(K)*IUD
110 TB = LMYSQ(K) * DD
111 M(2,1) = M(2,1) + TA - TB
112 M(1,2) = M(1,2) - TA - TB
113 TAPRIM=NY(K)*IUDPRI
114 TBPRIM=LMSQ(K)*DDPRIM

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112 MPRIME(2,1)=MPRIME(2,1) + TAPRIM - TBPRIM
113 MPRIME(1,2)=MPRIME(1,2) - TAPRIM - TBPRIM
114 TA = LY(1)*1.0
115 TB = WAVELENGTH* DD
116 M(3,2) = M(3,2) + TA - TB
117 M(2,3) = M(2,3) - TA - TB
118 TAPRIM LY(1)*100PRI
119 TBPRIM WAVELENGTH*100PRIM
120 MPRIME(3,2)=MPRIME(3,2) + TAPRIM -TBPRIM
121 MPRIME(2,3)=MPRIME(2,3) - TAPRIM -TBPRIM
122
123 20 CONTINUE
124
125 C CURVIM-ALPHA*(H-HT)
126 M(1,1) = M(1,1) + CRVTRM
127 M(2,2) = M(2,2) + CRVTRM
128 M(3,3) = M(3,3) + CRVTRM
129 CRVPR=ALPHA/WAVENR
130 MPRIME(1,1)=MPRIME(1,1) + CURVPR
131 MPRIME(2,2)=MPRIME(2,2) + CURVPR
132 MPRIME(3,3)=MPRIME(3,3) + CURVPR
133
134 C CALCULATE THE MATRIX T.
135
136 T(1,1)=-S*M(3,1)/(1.0D0+M(3,3))
137 T(4,4)=-S*M(1,3)/(1.0D0+M(3,3))
138 T(1,2)= S*M(3,2)/(1.0D0+M(3,3))
139 T(3,4)= S*M(2,3)/(1.0D0+M(3,3))
140 T(1,3)=0.0D0
141 T(2,4)=0.0D0
142 T(1,4)=(C+C*M(3,3))/(1.0D0+M(3,3))
143 T(2,1)=0.0D0
144 T(4,3)=0.0D0
145 T(2,2)=0.0D0
146 T(3,3)=0.0D0
147 T(2,3)=1.0D0
148 T(3,1)=M(2,3)*M(3,1)/(1.0D0+M(3,3)) - M(2,1)
149 T(4,2)=M(3,2)*M(1,3)/(1.0D0+M(3,3)) - M(1,2)
150 T(3,2)= C*C + M(2,2) - M(2,3)*M(3,2)/(1.0D0+M(3,3))
151 T(4,1)=1.0D0 + M(1,1) - M(1,3)*M(3,1)/(1.0D0+M(3,3))
152
153 M331=1.0D0+M(3,3)
154 TPRIME(1,1)=(-S*MPRIME(3,1)+M331+S*M(3,1)*MPRIME(3,3))/M331**2
155 TPRIME(4,4)=(-S*MPRIME(1,3)+M331+S*M(1,3)*MPRIME(3,3))/M331**2
156 TPRIME(1,2)=(-S*MPRIME(2,3)+M331-S*M(3,2)*MPRIME(3,3))/M331**2
157 TPRIME(3,4)=(-S*MPRIME(2,3)+M331-S*M(2,3)*MPRIME(3,3))/M331**2
158 TPRIME(1,3)=0.0D0
159 TPRIME(2,4)=0.0D0
160 TPRIME(1,4)=( MPRIME(3,3)*M331 - MPRIME(3,3)*(C+C*M(3,3)))/M331**2
161 TPRIME(4,3)=0.0D0
162 TPRIME(2,2)=0.0D0
163 TPRIME(3,3)=0.0D0
164 TPRIME(2,3)=0.0D0
165 TPRIME(3,1)=( M(2,3)*MPRIME(3,1)+M331+MPRIME(2,3)*M(3,1)*M331 -
166 MPRIME(3,3)*M(2,3)*M(3,1))/M331**2 - MPRIME(2,1)
167 TPRIME(4,2)=( M(3,2)*MPRIME(1,3)+M331+MPRIME(3,2)*M(1,3)*M331 -
168 MPRIME(3,3)*M(3,2)*M(1,3))/M331**2 - MPRIME(1,2)

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169 TPRIME(3,2)=MPRIME(2,2) - (MPRIME(2,3)*M(3,2)+M331+
170 M(2,3)*MPRIME(3,2)+M331-MPRIME(3,3)*M(2,3)+M(3,2) )/
171 M331**2
172 TPRIME(4,1)=MPRIME(1,1) - (MPRIME(1,3)*M(3,1)+M331+
173 M(1,3)*MPRIME(3,1)+M331-MPRIME(3,3)*M(1,3)+M(3,1) )/
174 M331**2
175 RETURN
176
177 C
178
179 C
180 ENTRY INIT DT
181 ISO=0
182 IF(MAGFLD.EQ. 0.0) GO TO 250
183 IF (DABS(CODIP-90.0).GE.0.15) GO TO 300
184 IF (DABS(AZMUTH-90.0).LT.0.15) GO TO 250
185 IF (DABS(AZMUTH-270.0).GE.0.15) GO TO 300
186
187 250 ISO = 1
188 300 OMEGA = 2000.0*PI*FREQ
189 OV OMGA = 1.0/OMEGA
190 WAVENR = OMEGA/VELLT
191 SINDIP = DSIN (CODIP*DTR)
192 DRCOSL = SINDIP * DCOS (AZMUTH * DTR)
193 DRCOSM = -SINDIP * DSIN (AZMUTH * DTR)
194 DRCOSN = DCOS (CODIP * DTR)
195 DO 60 K=1,NRSPEC
196 COEF EN(K) = CCOEFF*1.0EG*CHARGE(K)**2/(OMEGA**2*RAT10M(K))
197 Y(K) = COEFFY * CHARGE(K) * MAGFLD
198 $ / (OMEGA * RAT10M(K))
199 YSQ(K)=Y(K)**2
200 LY(K) = DRCOSL*Y(K)
201 MY(K) = DRCOSM*Y(K)
202 NY(K) = DRCOSN*Y(K)
203 LSQYSQ(K)=DRCOSL**2*YSQ(K)
204 MSQYSQ(K)=DRCOSM**2*YSQ(K)
205 NSQYSQ(K)=DRCOSN**2*YSQ(K)
206 LMYSQ(K)=DRCOSL*DRCOSM*YSQ(K)
207 LNYSQ(K)=DRCOSL*DRCOSN*YSQ(K)
208 MNYSQ(K)=DRCOSM*DRCOSN*YSQ(K)
209 60 CONTINUE
210 C = CCO5(THETA*DTR)
211 S = CDSIN(THETA*DTR)
212 CSQ = C**2
213 SSQ = S**2
214 CI = CCO5((THETA-DTHETA)*DTR)
215 SI = CDSIN((THETA-DTHETA)*DTR)
216 CSQ1 = CI**2
217 SSQ1 = SI**2
218
219 C
220 RETURN
221 END

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1 SUBROUTINE QUADMM (HT,DELHT,LWSTHT,Q,GAMMA)
2 IMPLICIT REAL*8(A-H,O-Z)
3 REAL*8 LWSTHT
4 COMPLEX*16 C,S,CI,SI,I,Q2(4),O,GAMMA,AU,FU,F,DERIVE,
5 $ AU(3,4),T(4,4),MPPRIME(3,3),TPRIME(4,4),
6 $ COEFFB,COEFFC,COEFFD,COEFFE,COEFFFC,COEFFFD,COEFFG,COEFFH,COEFFI,COEFFJ,
7 $ AU(2,4),AU(1,4),AU(0,4),AU(3,3),AU(2,3),AU(1,3),AU(0,3),
8 $ AU(2,2),AU(1,2),AU(0,2),AU(2,1),AU(1,1),AU(0,1),
9 $ AU(2,0),AU(1,0),AU(0,0),
10 $ BPPRIM,BPPRIM,BPPRIM,BPPRIM,BPPRIM,BPPRIM,
11 $ SPVEC,S,NORM(4,2), PART S
12 COMMON/CS/C,S,CI,SI
13 COMMON/ANSWER/PART S(4,2)
14 COMMON/S MTX/SPVEC(4,4)
15 DATA I/(C.000,1.000)/
16
17 CALL DDKXMT(HT,M,T,MPPRIME,TPRIME)
18 COEFFA = 1.000
19 COEFFB = -(T(1,1)+T(4,4))
20 COEFFC = T(1,1)*T(4,4) - T(1,4)*T(4,1) - T(3,2)
21 COEFFD = T(3,2)*(T(1,1)+T(4,4)) - T(1,2)*T(3,1) - T(3,4)*T(4,2)
22 COEFFE = T(1,1)*(T(3,4)+T(4,2)) - T(3,2)*T(4,4) +
23 $ T(1,2)*(T(3,1)+T(4,1)) - T(3,1)*T(4,2)
24
25 JJ=7
26 IF (HT.LT.LWSTHT) GO TO 400
27
28 10 CALL QUARTC (COEFFB,COEFFC,COEFFD,COEFFE,QQ)
29 GR MAX=QQ(1)
30 J2=1
31 DO 23 J=2,4
32 $ GREAL=QQ(J)
33 IF (GREAL.LT.QR MAX) GO TO 23
34 QR MAX=GREAL
35 J2=J
36
37 23 CONTINUE
38 Q=QQ(J2)
39
40 K=1
41 500 CONTINUE
42 IF (K.GT.21) GO TO 510
43 F = Q**4*COEFFA + Q**3*COEFFB + Q**2*COEFFC + Q*COEFFD + COEFFE
44 DERIVE=4.00*Q**3*COEFFA + 3.00*Q**2*COEFFB + 2.00*Q*COEFFC + COEFFD
45 REAL=F/DERIVE
46 GINARY=-1.0/F/DERIVE
47 IF ((REAL**2.LE.1.0-20).AND.(GINARY**2.LE.1.0-30)) GO TO 530
48 Q=Q-F,DERIVE
49 K=K+1
50 GO TO 500
51
52 510 IF (JJ.EQ.7) GO TO 570
53 PRINT 520,HT
54 520 FORMAT (10X,'DOES NOT CONVERGE AFTER 20 ITERATIONS AT HEIGHT=',
55 $ F10.5/)
56 530 CONTINUE
57 REAL=Q

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55 GINARY=-1*Q
56 IF (REAL**2 .GT. GINARY**2 .AND. REAL.GT.0.) GO TO 540
57 IF (JJ.EQ.13) GO TO 550
58 JJ=13
59 GO TO 10
60 PRINT 500, HT
61 560 FORMAT (10X, 'DOES NOT CONVERGE TO THE PROPER Q AT HEIGHT=',F10.5/)
62 540 CONTINUE
63
64 A1=-(T(1,1)+T(4,4))
65 A2=T(1,1)*T(4,4) - T(1,4)*T(4,1)
66 A3=T(1,2)
67 A4=T(1,4)*T(4,2) - T(1,2)*T(4,4)
68 A5=T(4,2)
69 A6=T(4,1)*T(1,2) - T(1,1)*T(4,2)
70 B3=T(3,4)
71 B4=T(1,4)*T(3,1) - T(3,4)*T(1,1)
72 B5=T(3,1)
73 B6=T(4,1)*T(3,4) - T(4,4)*T(3,1)
74 A3PRIM=TPRIME(1,2)
75 A4PRIM=TPRIME(1,4)*T(4,2)+T(1,4)*TPRIME(4,2) -
76 1 TPRIME(1,2)*T(4,4)-T(1,2)*TPRIME(4,4)
77 A5PRIM=TPRIME(4,2)
78 A6PRIM=TPRIME(4,1)*T(1,2)+T(4,1)*TPRIME(1,2) -
79 1 TPRIME(1,1)*T(4,2)-T(1,1)*TPRIME(4,2)
80 B3PRIM=TPRIME(3,4)
81 B4PRIM=TPRIME(1,4)*T(3,1)+T(1,4)*TPRIME(3,1) -
82 1 TPRIME(3,4)*T(1,1)-T(3,4)*TPRIME(1,1)
83 B5PRIM=TPRIME(3,1)
84 B6PRIM=TPRIME(4,1)*T(3,4)+T(4,1)*TPRIME(3,4) -
85 1 TPRIME(4,4)*T(3,1)-T(4,4)*TPRIME(3,1)
86 AU=Q*Q+A1*Q+A2
87 FU=2.000*Q*AJ + (Q*Q-T(3,2))*(2.000*Q+A1) - (A3*B5+B3*A5)
88 COEFF0=A4*B6PRIM-A4PRIM*B6+A6*B4PRIM-A6PRIM*B4
89 COLFF1=A3*B6PRIM-A3PRIM*B6+A4*B5PRIM-A4PRIM*B5+A5*B4PRIM-
90 1 A5PRIM*B4+A6*B3PRIM-A6PRIM*B3
91 COEFF2=A3*B5PRIM-A3PRIM*B5+A5*B3PRIM-A5PRIM*B3
92 GAMMA=(Q*Q*COEFF2 + Q*COEFF1 + COEFF0)/(2.00*AJ*FU)
93
94 NICE=(LWSTH -HT)/DELHT
95 IF ((LWSTH-HT)/DELHT - NICE .NE. 0.0) RETURN
96 IF (HT.NE.LWSTH) GO TO 605
97 DO 600 N=1,2
98 S NORM(1,N) = (Q*A3+A4)/CDSQRT(AJ*FU) /SPVEC(1,N)
99 S NORM(2,N) = (-AJ) /CDSQRT(AJ*FU) /SPVEC(2,N)
100 S NORM(3,N) = (Q*AJ) /CDSQRT(AJ*FU) /SPVEC(3,N)
101 S NORM(4,N) = (Q*A5+A6)/CDSQRT(AJ*FU) /SPVEC(4,N)
102 DO 610 N=1,2
103 PART S(1,N) = (Q*A3+A4)/CDSQRT(AJ*FU) /S NORM(1,N)
104 PART S(2,N) = (-AJ) /CDSQRT(AJ*FU) /S NORM(2,N)
105 PART S(3,N) = (Q*AJ) /CDSQRT(AJ*FU) /S NORM(3,N)
106 PART S(4,N) = (Q*A5+A6)/CDSQRT(AJ*FU) /S NORM(4,N)
107 RETURN
108 END

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1  SUBROUTINE QUARTIC (FOURB3, SIXB2, FOURB1, B0, Q)
2
3  C QUARTIC FINDS THE ROOTS OF A QUARTIC
4  C POLYNOMIAL, FROM THE CLOSED FORM.
5
6  C
7
8  I=1
9  $ COMPLEX*16
10  $
11  $ C3,B2,B1,B0,Q,FOURB3,SIXB2,FOURB1,B3SQ,H,I,G,HPRIME,GPRIME
12  $ 1,SQROOT,PPLUS,P,LOGP,CBERT0,CBERT1,CBERT2,OMEGA1,OMEGA2,ROOTP,ROOT
13  $ 0,ROOTR
14  REAL*8 MGPLUS,MGMNUS
15  DIMENSION Q(4),PRI(2)
16  EQUIVALENCE (P,PRI)
17  DATA OMEGA1/(-5.0D-1, 8.660254038D-1)/
18  DATA OMEGA2/(-5.0D-1,-8.660254038D-1)/
19  DATA PRECSN /1.0D-10/
20
21  C
22  C
23  B3=FOURB3*0.25
24  B2=SIXB2/6.0
25  B1=FOURB1*0.25
26  B3SQ=B3**2
27  H=B2-B3SQ
28  I=B0-4.0*B3*B1+3.0*B2**2
29  G=B1+B3*(-3.0*B2+2.0*B3SQ)
30  HPRIME=-I/12.0
31  GPRIME=-G**2/4.0-H*(H**2+3.0*HPRIME)
32  SQROOT = CDSQRT (GPRIME**2 + 4.0 * HPRIME**3)
33  P=(-GPRIME+SQROOT)*0.5
34  MGPLUS=DABS(PRI(1))+DABS(PRI(2))
35  PPLUS=P
36  P=(-GPRIME-SQROOT)*0.5
37  MGMNUS=DABS(PRI(1))-DABS(PRI(2))
38  IF (MGPLUS.GT.MGMNUS) P=PPLUS
39  LOGP = CDLOG (P)
40  CBERT0 = CDEXP (LOGP / 3.0)
41  CBERT1=OMEGA1*CBERT0
42  CBERT2=OMEGA2*CBERT0
43  ROOTP = CDSQRT (CBERT0 - HPRIME / CBERT0 - H)
44  ROOTQ = CDSQRT (CBERT1 - HPRIME / CBERT1 - H)
45  ROOTR = CDSQRT (CBERT2 - HPRIME / CBERT2 - H)
46  IF (CDABS(G).LE. 1.0D-50) GO TO 5
47  SIGN=-ROOTP*ROOTQ*ROOTR*2.0/G
48  IF (SIGN.LT.0.0) ROOTR=-ROOTR
49  Q(1)=+ROOTP+ROOTQ+ROOTR-B3
50  Q(2)=+ROOTP-ROOTQ-ROOTR-B3
51  Q(3)=-ROOTP+ROOTQ-ROOTR-B3
52  Q(4)=-ROOTP-ROOTQ+ROOTR-B3
53  DO 20 N=1,4
54  ITER = 0
55  200 CONTINUE
56  ROOTP = Q(N)**4 + FOURB3 * Q(N)**3 + SIXB2 * Q(N)**2
57  $ + FOURB1 * Q(N) + BC
58  ROOTQ = 4.0 * Q(N)**3 + 3.0 * FOURB3 * Q(N)**2

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55      S = 2.0 * SIXB2 * Q(N) + FOURB1
56      ROOTR = ROOTP / ROOTQ
57      Q(N) = Q(N) - ROOTR
58      IF (CDABS (ROOTR).LT.PRECSN) GO TO 20
59      ITER = ITER + 1
60      IF (ITER.LT.10) GO TO 200
61      PRINT 900, ITER, Q(N)
62      20 CONTINUE
63      RETURN
64      900 FORMAT (I3,' ITERATIONS, Q ≈ ',
65      $E15.5,E13.5,' FAILS TO CONVERGE')
66      END

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SUBROUTINE WF BNDY(B)
C
C WF BNDY COMPUTES THE VECTOR B,
C WHICH DETERMINES HOW TO COMBINE
C THE SOLUTION VECTORS IN ORDER TO
C SATISFY THE BOUNDARY CONDITIONS.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/1 MTX/ T11,T31,T41,T12,T32,T42,T14,T34,T44
      COMMON/2 MTX/ M
      COMMON/3 CS COSINE, SINE,IGNOR2(8)
      COMMON/4 WF CON/IGNOR3(2),WAVENR
      COMMON/5 P MTX/P,IGNOR4(32)
      COMMON/6 EXC IN/XMTRHT,PAHI
      COMMON/7 WF FLAG/ ISKIP(3),IDBG
      COMMON/8 EXTRA/XTRA,R(4)
      COMMON/9 WFIMPT,THETA,FREQ,AZIM,CODIP,MAGFLD,COEFNU(5),EXPNU(5),
      $ TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
      COMMON/10 S MTX/PP(4,4)
      COMPLEX*16 T(4,4),T11,T31,T41,T12,T32,T42,T14,T34,T44,
      $ Q(4),SPVEC(4,4),ASPEC(4,4),BETA(2,2),P(4,2),
      $ BB(4,4,2),TEMP,I/(0.00,1.00)/,M(3,3),SOURCE(9,2),SINE,
      $ BP(4,2),AAA(4),BBB(4),B(12)
      COMPLEX*16 TN(4,4,4),SUM(4,4,4),PROD(4,4),SPVECN(4,4)
      COMPLEX*16 R,RBAR11,RBAR22,XTRA,COSINE,THETA,SMALL F,PP,QQ
      REAL*8 MAGFLD,LWSTHT
      REAL*4 ERR
      DATA QMAX/200.00/

      CALL TMTRX(0.00)
      T(1,1) = T11
      T(2,1) = 0.0
      T(3,1) = T31
      T(4,1) = T41
      T(1,2) = T12
      T(2,2) = 0.0
      T(3,2) = T32
      T(4,2) = T42
      T(1,3) = 0.0
      T(2,3) = 1.0
      T(3,3) = 0.0
      T(4,3) = 0.0
      T(1,4) = T14
      T(2,4) = 0.0
      T(3,4) = T34
      T(4,4) = T44
      CALL EIGVAL(T,Q)
      DO 10 N=1,4
      QT = CDABS(Q(N))
      IF(QT.GT. QMAX) IFAIL=1
      CONTINUE
      CALL EIGVEC(T,Q,SPVEC)
      CALL WFSORT(Q,SPVEC,IFAIL)
10
C

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55 DO 30 N=1,2
56 BB(1,1,N) = Q(N)*2*(T(4,4)-Q(N))-T(2,3)*(T(3,2)*(T(4,4)-Q(N))
57 $ -T(4,2)*T(3,4))
58 BB(1,2,N) = T(1,2)*Q(N)*(T(4,4)-Q(N))-Q(N)*T(1,4)*T(4,2)
59 BB(1,3,N) = T(1,2)*T(2,3)*(T(4,4)-Q(N))-T(1,4)*T(4,2)*T(2,3)
60 BB(1,4,N) = -T(1,2)*T(2,3)*T(3,4)-T(1,4)*Q(N)*2-T(3,2)*T(2,3))
61 BB(2,1,N) = T(2,3)*T(3,1)*(T(4,4)-Q(N))-T(4,1)*T(3,4)
62 BB(2,2,N) = -Q(N)*T(1,1)-Q(N)*(T(4,4)-Q(N))+T(1,4)*Q(N)
63 BB(2,3,N) = -T(2,3)*(T(1,1)-Q(N))*(T(4,4)-Q(N))+T(1,4)*T(4,1)
64 $ *T(2,3)
65 BB(2,4,N) = T(2,3)*T(3,4)*(T(1,1)-Q(N))-T(1,4)*T(3,1)*T(2,3)
66 BB(3,1,N) = Q(N)*T(3,1)*(T(4,4)-Q(N))-Q(N)*T(4,1)*T(3,4)
67 BB(3,2,N) = -T(1,1)-Q(N)*(T(3,2)*(T(4,4)-Q(N))-T(4,2)*T(3,4))
68 $ +T(1,2)*(T(3,1)*(T(4,4)-Q(N))-T(4,1)*T(3,4))
69 $ -T(1,4)*(T(3,1)*T(4,2)-T(4,1)*T(3,2))
70 BB(3,3,N) = -Q(N)*(T(1,1)-Q(N))*(T(4,4)-Q(N))+Q(N)*T(1,4)*T(4,1)
71 BB(3,4,N) = Q(N)*T(3,4)*(T(1,1)-Q(N))-Q(N)*T(1,4)*T(3,1)
72 BB(4,1,N) = -Q(N)*2*T(4,1)-T(2,3)*(T(3,1)*T(4,2)-T(4,1)*T(3,2))
73 BB(4,2,N) = Q(N)*(T(1,1)-Q(N))*T(4,2)-T(1,2)*Q(N)*T(4,1)
74 BB(4,3,N) = T(4,2)*T(2,3)*(T(1,1)-Q(N))-T(1,2)*T(4,1)*T(2,3)
75 BB(4,4,N) = (T(1,1)-Q(N))*(Q(N)*2-T(3,2)*T(2,3))+T(1,2)*T(3,1)
76 $ *T(2,3)
77 DO 16 N=1,4
78 TN(1,1,N) = T(1,1)-Q(N)
79 TN(2,2,N) = T(2,2)-Q(N)
80 TN(3,3,N) = T(3,3)-Q(N)
81 TN(4,4,N) = T(4,4)-Q(N)
82 TN(1,2,N) = T(1,2)
83 TN(1,3,N) = T(1,3)
84 TN(1,4,N) = T(1,4)
85 TN(2,1,N) = T(2,1)
86 TN(2,3,N) = T(2,3)
87 TN(2,4,N) = T(2,4)
88 TN(3,1,N) = T(3,1)
89 TN(3,2,N) = T(3,2)
90 TN(3,4,N) = T(3,4)
91 TN(4,1,N) = T(4,1)
92 TN(4,2,N) = T(4,2)
93 TN(4,3,N) = T(4,3)
94 DO 17 J=1,4
95 DO 17 K=1,4
96 DO 17 N=1,2
97 SUM(J,K,N) = TN(J,1,N)*BB(1,K,N)+TN(J,2,N)*BB(2,K,N)
98 $ +TN(J,3,N)*BB(3,K,N)+TN(J,4,N)*BB(4,K,N)
99 CONTINUE
100 DO 40 N=1,2
101 TEMP = CDEXP(I*WAVENR*XMRHT*Q(N))/(1.+M(3,3))
102 SOURCE(1,N) = -TEMP*SINE**2
103 SOURCE(2,N) = 0.0
104 SOURCE(3,N) = TEMP*M(2,3)*SINE
105 SOURCE(4,N) = -TEMP*A(1,3)*SINE
106 TEMP = (1.+M(3,3))*TEMP
107 SOURCE(5,N) = -TEMP*SINE
108 SOURCE(6,N) = -SOURCE(5,N)
109 SOURCE(7,N) = -SOURCE(5,N)*SINE
110 SOURCE(8,N) = SOURCE(5,N)
111 SOURCE(9,N) = SOURCE(5,N)

```

```

112 IF (AAHT,LT,LWSTHT) GO TO 500
113 DO 500 I1=1,4
114 BP(1,1) = (BB(11,1,1)*SOURCE(1,1)+BB(11,2,1)*SOURCE(2,1)
115 +BP(11,3,1)*SOURCE(3,1)+BB(11,4,1)*SOURCE(4,1))/
116 /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
117 IF(11,2) = (BB(11,1,2)*SOURCE(1,2)+BB(11,2,2)*SOURCE(2,2)
118 +BB(11,3,2)*SOURCE(3,2)+BB(11,4,2)*SOURCE(4,2))/
119 /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
120 DO 60 I1=1,4
121 AAA(11) = (BP(11,1)/(SPVEC(11,1)*BETA(2,1))-BP(11,2)/(SPVEC(11,2)*
122 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
123 BBB(11) = (BP(11,1)/SPVEC(11,1)-AAA(11)*BETA(1,1))/
124 BETA(2,1)
125 $ CONTINUE
126 B(1) = AAA(1)
127 B(2) = BBB(1)
128 BP(1,1) = SOURCE(5,1)*BB(1,3,1)
129 $ /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
130 BP(1,2) = SOURCE(5,2)*BB(1,3,2)
131 $ /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
132 B(3) = (BP(1,1)/(SPVEC(1,1)*BETA(2,1))-BP(1,2)/(SPVEC(1,2)*
133 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
134 B(4) = (BP(1,1)/SPVEC(1,1)-B(3)*BETA(1,1))/BETA(2,1)
135 BP(1,1) = SOURCE(6,1)*BB(1,4,1)
136 $ /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
137 BP(1,2) = SOURCE(6,2)*BB(1,4,2)
138 $ /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
139 B(5) = (BP(1,1)/(SPVEC(1,1)*BETA(2,1))-BP(1,2)/(SPVEC(1,2)*
140 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
141 B(6) = (BP(1,1)/SPVEC(1,1)-B(5)*BETA(1,1))/BETA(2,1)
142 BP(1,1) = SOURCE(7,1)*BB(1,3,1)
143 $ /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
144 BP(1,2) = SOURCE(7,2)*BB(1,3,2)
145 $ /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
146 B(7) = (BP(1,1)/(SPVEC(1,1)*BETA(2,1))-BP(1,2)/(SPVEC(1,2)*
147 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
148 B(8) = (BP(1,1)/SPVEC(1,1)-B(7)*BETA(1,1))/BETA(2,1)
149 BP(1,1) = SOURCE(8,1)*BB(1,1,1)
150 $ /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
151 BP(1,2) = SOURCE(8,2)*BB(1,1,2)
152 $ /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
153 B(9) = (BP(1,1)/(SPVEC(1,1)*BETA(2,1))-BP(1,2)/(SPVEC(1,2)*
154 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
155 B(10) = (BP(1,1)/SPVEC(1,1)-B(9)*BETA(1,1))/BETA(2,1)
156 BP(1,1) = SOURCE(9,1)*BB(1,2,1)
157 $ /((Q(1)-Q(2))*(Q(1)-Q(3))*(Q(1)-Q(4)))
158 BP(1,2) = SOURCE(9,2)*BB(1,2,2)
159 $ /((Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4)))
160 B(11) = (BP(1,1)/(SPVEC(1,1)*BETA(2,1))-BP(1,2)/(SPVEC(1,2)*
161 BETA(2,2)))/(BETA(1,1)/BETA(2,1)-BETA(1,2)/BETA(2,2))
162 B(12) = (BP(1,1)/SPVEC(1,1)-B(11)*BETA(1,1))/BETA(2,1)
163 RETURN
164
165 C 500 I1=4
166 QC = (Q(2)-Q(1))*(Q(2)-Q(3))*(Q(2)-Q(4))
167 BP(11,2) = (BB(11,1,2)*SOURCE(1,2)+BB(11,2,2)*SOURCE(2,2)
168 +BB(11,3,2)*SOURCE(3,2)+BB(11,4,2)*SOURCE(4,2))

```

```

169      B(1)=BP(11,2)/(QQ*P(11,2))
170      B(2)=SMALLF*B(1)
171      B(3)=SOURCE(5,2)*BB(11,3,2)/(QQ*P(11,2))
172      B(4)=SMALLF*B(3)
173      B(5)=SOURCE(6,2)*BB(11,4,2)/(QQ*P(11,2))
174      B(6)=SMALLF*B(5)
175      B(7)=SOURCE(7,2)*BB(11,3,2)/(QQ*P(11,2))
176      B(8)=SMALLF*B(7)
177      B(9)=SOURCE(8,2)*BB(11,1,2)/(QQ*P(11,2))
178      B(10)=SMALLF*B(9)
179      B(11)=SOURCE(9,2)*BB(11,2,2)/(QQ*P(11,2))
180      B(12)=SMALLF*B(11)
181      RETURN
182
183      ENTRY DECOMP(HT)
184      CALL TMTRX(HT)
185      T(1,1) = T11
186      T(3,1) = T31
187      T(4,1) = T41
188      T(1,2) = T12
189      T(3,2) = T32
190      T(4,2) = T42
191      T(1,4) = T14
192      T(3,4) = T34
193      T(4,4) = T44
194      T(2,1) = 0.0
195      T(2,2) = 0.0
196      T(1,3) = 0.0
197      T(2,3) = 1.0
198      T(3,3) = 0.0
199      T(4,3) = 0.0
200      T(2,4) = 0.0
201      CALL EIGVAL(T,Q)
202      DO 101N=1,4
203      QT = CDABS(Q(N))
204      IF (QT .GT. QMAX) IFAIL=1
205      10 1 CONTINUE
206      CALL EIGVEC(T,Q,SPVEC)
207      CALL WFSORT(Q,SPVEC,IFAIL)
208      DO 311 J=1,4
209      DO 311 K=1,4
210      SPVECN(J,K) = SPVEC(J,K)
211      CALL CINVER(SPVECN,ASPECN,4,4,ERR)
212      DO 15 J=1,4
213      DO 15 K=1,4
214      PROD(J,K) = ASPECN(J,1)*SPVEC(1,K)+ASPECN(J,2)*SPVEC(2,K)
215      +ASPECN(J,3)*SPVEC(3,K)+ASPECN(J,4)*SPVEC(4,K)
216      $
217      15 CONTINUE
218      DO 20 N=1,2
219      BETA(N,NN) = ASPECN(NN,1)*P(1,N)+ASPECN(NN,2)*P(2,N)
220      +ASPECN(NN,3)*P(3,N)+ASPECN(NN,4)*P(4,N)
221      $
222      20 CONTINUE
223      CALL RBARS(COSINE,SINE,RBAR11,RBAR22)
224      IF (CDABS(1.-R(1)*RBAR11) .LT. CDABS(1.-R(2)*RBAR22)) GO TO 230
225      SMALL F = -(1.-R(1)*RBAR11)/(R(3)*R(2))
226      GO TO 240

```

```

226
227
228
229
230
231
232

230 SMALL F = -R(4)*R(1)/(1.-R(2)*R(2)*R(2))
240 CONTINUE
    DO 507 II=1,4
    10 507 N=1,2
    507 M2(II,N) = (BETA(1,N)+SMALL F*BETA(2,N))*SPVEC(II,N)
    RETURN
    END

```

```

1  SUBROUTINE EIGVAL (A, SIG)
2  IMPLICIT REAL*8 (A-H,O-Z)
3  COMPLEX*16 A, SIG
4  DIMENSION A(4,4), SIG(4)
5
6  C  COMPUTES 4 EIGENVALUES OF MATRIX A,
7  C  AND RETURNS THEM IN SIG.
8  C  THE COEFFICIENTS OF THE CHARACTERISTIC
9  C  POLYNOMIAL OF A ARE CALCULATED, AND
10 C  IT ROOTS COMPUTED BY QUARTC, A QUARTIC
11 C  POLYNOMIAL ROUTINE.
12 C
13 COMMON/CF FLAG/PRECSN,ISO,IDBG
14 COMPLEX*16 B(4), BX(3), BY(3)
15 COMPLEX*16 B0, B1, SQROOT, SIGN
16 DIMENSION INDEX(4,4)
17 DATA INDEX /0, 4, 4, 3,
18 $ 3, 0, 4, 3, 2, 1, 0, 2, 2, 1, 1, 0/
19
20 C
21 IF (ISO .NE. 0) GO TO 600
22 DO 100 I = 1,4
23   100 B(I) = 0.0
24   DO 500 J = 1,3
25     IP = I + 1
26     DO 500 J = IP,4
27       II = INDEX(I,J)
28       JJ = INDEX(J,I)
29       BX(1) = A(I,1) * A(J,2) - A(I,2) * A(J,1)
30       BX(2) = 0.0
31       BX(3) = 0.0
32       IF (J.NE.2) GO TO 200
33       BX(2) = - A(1,1) - A(2,2)
34       BX(3) = 1.0
35       GO TO 250
36   200 IF (I.EQ.1) BX(2) = - A(J,2)
37       IF (I.EQ.2) BX(2) = A(J,1)
38 C
39   250 BY(1) = A(II,3) * A(JJ,4) - A(II,4) * A(JJ,3)
40       BY(2) = 0.0
41       BY(3) = 0.0
42       IF (II.NE.3) GO TO 300
43       BY(2) = - A(3,3) - A(4,4)
44       BY(3) = 1.0
45       GO TO 350
46   300 IF (JJ.EQ.4) BY(2) = - A(II,3)
47       IF (JJ.EQ.3) BY(2) = A(II,4)
48 C
49   350 SIGN = (-1)**(I+J-1)
50       B(1) = B(1) + SIGN * BX(1) * BY(1)
51       B(2) = B(2) + SIGN *
52 $ (BX(2) * BY(1) + BX(1) * BY(2))
53       B(3) = B(3) + SIGN *
54 $ (BX(3) * BY(1) + BX(2) * BY(2) + BX(1) * BY(3))

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```

65      B(3) = B(4) + SIGN *
66      $ (BX(2) * BY(3) + BX(3) * BY(2))
67      500 CONTINUE
68      C
69      CALL QUARTC (B(4), B(3), B(2), B(1), SIG)
70      RETURN
71      C
72      C COMPUTES THE EIGENVALUES      X 0 0 X
73      C OF A AS THE ROOTS OF TWO      0 X X 0
74      C QUADRATICS IF A HAS THE      0 X X 0
75      C SPECIAL FORM ON THE RIGHT.  X 0 0 X
76      600 CONTINUE
77      B1 = 0.5 * (A(1,1) + A(4,4))
78      B0 = A(1,1) * A(4,4) - A(1,4) * A(4,1)
79      SQROOT = CDSQRT (B1**2 - B0)
80      SIG(1) = B1 + SQROOT
81      SIG(4) = B1 - SQROOT
82      B1 = 0.5 * (A(2,2) + A(3,3))
83      B0 = A(2,2) * A(3,3) - A(2,3) * A(3,2)
84      SQROOT = CDSQRT (B1**2 - B0)
85      SIG(2) = B1 + SQROOT
86      SIG(3) = B1 - SQROOT
87      RETURN
88      END

```

```

1  SUBROUTINE EIGVEC (A, SIG, VEC)
2  IMPLICIT REAL*8 (A-H,O-Z)
3  DIMENSION A(4,4), SIG(4), VEC(4,4)
4  COMPLEX*16 A, SIG, VEC
5
6  C COMPUTES FOUR EIGENVECTORS OF A,
7  C AND RETURNS THEM IN VEC.
8  C VECTORS ARE COMPUTED AS SOLUTION OF
9  C REDUCED SYSTEM OF LINEAR EQNS.
10 C
11 COMMON/WF FLAG/PRECSN,ISO,IDBG
12 DIMENSION B(3,3), Y(3), X(3)
13 COMPLEX*16 B, Y, X
14 REAL*4 ERR
15
16 C
17 C
18 IF(ISO .NE. 0) GO TO 600
19 C COMPUTE VECTORS WITH VEC(1,J) = A(1,4).
20 C (THIS IS DONE AGREE WITH SPECIAL
21 C ISOTROPIC CASE COMPUTED BELOW.)
22 DO 100 J = 1,4,3
23   B(1,1) = A(2,2) - SIG(J)
24   B(1,2) = A(2,3)
25   B(1,3) = A(2,4)
26   Y(1) = - A(2,1) * A(1,4)
27   B(2,1) = A(3,2)
28   B(2,2) = A(3,3) - SIG(J)
29   B(2,3) = A(3,4)
30   Y(2) = - A(3,1) * A(1,4)
31   B(3,1) = A(4,2)
32   B(3,2) = A(4,3)
33   B(3,3) = A(4,4) - SIG(J)
34   Y(3) = - A(4,1) * A(1,4)
35   CALL CLINEQ (B, Y, X, 3, 0, ERR)
36   VEC(1,J) = A(1,4)
37   VEC(2,J) = X(1)
38   VEC(3,J) = X(2)
39   VEC(4,J) = X(3)
40   100 CONTINUE
41 C
42 C COMPUTE VECTORS WITH VEC(2,J) = A(2,3)
43 DO 200 J = 2,3
44   B(1,1) = A(1,1) - SIG(J)
45   B(1,2) = A(1,3)
46   B(1,3) = A(1,4)
47   Y(1) = - A(1,2) * A(2,3)
48   B(2,1) = A(3,1)
49   B(2,2) = A(3,3) - SIG(J)
50   B(2,3) = A(3,4)
51   Y(2) = - A(3,2) * A(2,3)
52   B(3,1) = A(4,1)
53   B(3,2) = A(4,3)
54   B(3,3) = A(4,4) - SIG(J)
55   Y(3) = - A(4,2) * A(2,3)

```

AD-A169 006

A WKB PROGRAM FOR ELF/VLF EARTH-IONOSPHERE EXCITATION
BY SOURCES AT SATELLITE HEIGHTS(U) NAVAL OCEAN SYSTEMS
CENTER SAN DIEGO CA R A PAPPERT ET AL. SEP 82

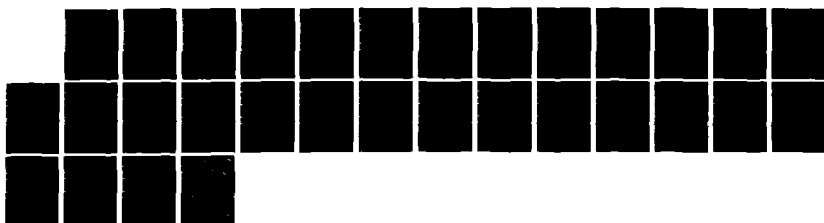
272

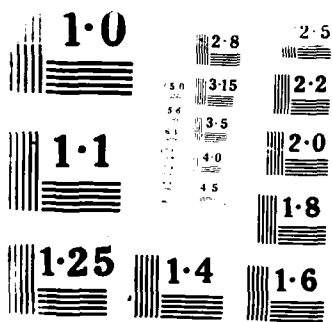
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NL





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55 CALL CLINEO (9, Y, X, 3, 3, 0, ERR)
56 VEC(1,J) = X(1)
57 VEC(2,J) = A(2,3)
58 VEC(3,J) = X(2)
59 VEC(4,J) = X(3)
60
61 200 CONTINUE
62 RETURN
63
64 C
65 C COMPUTE EIGENVECTORS IN X 0 0 X
66 C SIMPLIFIED FORM IF A HAS 0 X X 0
67 C THE SPECIAL FORM ON 0 X X 0
68 C THE RIGHT. X 0 0 X
69
70 C 600 CONTINUE
71 C COMPUTE VECTORS WITH VEC(1,J) = A(1,4).
72 DO 300 J = 1,4,3
73 VEC(1,J) = A(1,4)
74 VEC(2,J) = 0.0
75 VEC(3,J) = 0.0
76 VEC(4,J) = SIG(J) - A(1,1)
77 300 CONTINUE
78
79 C
80 C COMPUTE VECTORS WITH VEC(2,J) = A(2,3)
81 DO 400 J = 2,3
82 VEC(1,J) = 0.0
83 VEC(2,J) = A(2,3)
84 VEC(3,J) = SIG(J) - A(2,2)
85 VEC(4,J) = 0.0
86 400 CONTINUE
87 RETURN
88 END

```

```

1  SUBROUTINE WF SORT (Q, A, IFAIL)
2  IMPLICIT REAL*8 (A-H,O-Z)
3  COMPLEX*16 Q(4), A(4,4)
4
5  C
6  C WF SORT INITIALLY ARRANGES THE
7  C Q VALUES SO THAT THEY OCCUR IN THE
8  C ORDER UPGOING FAST (EVANESCENT),
9  C UPGOING SLOW (TRAVELLING), DOWNGOING
10 C SLOW, AND DOWNGOING FAST.
11 C
12 C
13 C COMPLEX*16 QT(4), B(4,4), I, CT
14 C DIMENSION QI(4)
15 C DATA I /(0.0D0,1.0D0)/
16 C
17 C
18 C DO 510 J = 1,4
19 C QT(J) = Q(J)
20 C QI(J) = - I * Q(J)
21 C DO 510 K = 1,4
22 C B(J,K) = A(J,K)
23 C DO 530 J = 1,4
24 C T = QI(1)
25 C JJ = 1
26 C DO 520 K = 2,4
27 C IF(QI(K).GE.T) GO TO 520
28 C T = QI(K)
29 C JJ = K
30 C 520 CONTINUE
31 C Q(J) = QT(JJ)
32 C DO 525 K = 1,4
33 C A(K,J) = B(K,JJ)
34 C QI(JJ) = 1.0D50
35 C 530 CONTINUE
36 C QI(1) = - I * Q(2)
37 C QI(2) = Q(2)
38 C IF (DABS(QI(1)/QI(2)).LT.0.2) GO TO 550
39 C IF(QI(1).GT.0.0) GO TO 850
40 C QI(1) = - I * Q(3)
41 C IF( QI(1).LT.0.0) GO TO 850
42 C RETURN
43 C 550 QI(1) = Q(3)
44 C IF (QI(2).GT.QI(1)) GO TO 560
45 C CT = Q(2)
46 C Q(2) = Q(3)
47 C Q(3) = CT
48 C QI(3) = QI(2)
49 C QI(2) = QI(1)
50 C QI(1) = QI(3)
51 C DO 555 K = 1,4
52 C CT = A(K,2)
53 C A(K,2) = A(K,3)
54 C 555 A(K,3) = CT
55 C 560 IF (QI(2).LT.0.0) GO TO 850
56 C IF(QI(1).GT.0.0) GO TO 850

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```

55      QI(1) = - 1 * Q(4)
56      QI(2) = Q(4)
57      IF (QI(1).LT.0.2*DBABS(QI(2))) GO TO 850
58      RETURN
59
60      C
61      850 IFAIL = 1
62      PRINT 901
63      PRINT 902
64      PRINT 903, Q, QT
65      RETURN
66      900 FORMAT (5X, ' Q = ', 4(E15.5,E13.5), '/',
67      $      ' PREV Q = ', 4(E15.5,E13.5))
68      901 FORMAT (' ERROR IN INITIAL Q VALUES')
69      902 FORMAT (' Q ELEMENTS CANNOT BE ORDERED')
70      END

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C
SUBROUTINE RBARS(C,S,RBAR11,RBAR22)
IMPLICIT REAL *8 (A-H,O-Z)
COMMON/WFINPT/THETA,FREQ,AZMUTH,CODIP,MAGFLD,CEFFNU(5),EXPNU(5),
$ TOPHT,LWSTHT,WKBHT,DELHT,H,ALPHA,SIGMA,EPSLON
COMMON/STOR/ STORE
COMMON/WF CON/OMEGA,K
COMPLEX *16 THETA,I,NGSQ,C,S,SSQ,SQROOT,RTIORT,IKC,
$ PO,H10,H20,H1PRM0,H2PRM0,CAPH10,CAPH20,
$ PD,H1D,H2D,H1PRMD,H2PRMD,CAPH1D,CAPH2D,
$ PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,
$ A1ST,A2ND,A3RD,A4TH,A1,A2,A3,A4,
$ EXD,EXDSQ,EXZ,EXZSQ,
$ RBAR11,RBAR22,Z1,Z2,
$ DEN12,DEN34,
$ EX,EY,EZ,HX,HY,HZ
REAL *8 K,KVRAOT,KVRATT,NOSQ,NDSQ,NZSQ,MAGFLD,LWSTHT
EQUIVALENCE(PZ,PD),(H1Z,H1D),(H2Z,H2D),(H1PRMZ,H1PRMD),
$ DATA I/(0.000,1.000)/
DATA TSTTHM/1.001/
DATA EPSLN0/B.85434D-12/

C
D = TOPHT
SSQ=S*5
NGSQ = (EPSLN0-I*SIGMA/OMEGA)/EPSLN0
SQROOT=CDSQRT(NGSQ-SSQ)
THTIM=I*THETA
IF(THTIM.GT. TSTTHM) GO TO 10

C
KVRAOT=DEXP(DLOG(K/ALPHA))/3.0)
KVRATT=KVRAOT**2
AVRKOT=1.0/KVRAOT
AVRKT=AVRKOT**2*0.5
NOSQ=1.0-ALPHA*(H-STORE)
RTIORT=NOSQ/NGSQ*SQROOT
PO=KVRATT*(NOSQ-SSQ)
CALL MDHNL (PO,H10,H20,H1PRM0,H2PRM0)
CAPH10=H1PRM0+AVRKT*H10
CAPH20=H2PRM0+AVRKT*H20
A1ST=CAPH20-I*RTIORT*KVRAOT*H20
A2ND=CAPH10-I*RTIORT*KVRAOT*H10
A3RD=H2PRM0-I*KVRAOT*SQROOT*H20
A4TH=H1PRM0-I*KVRAOT*SQROOT*H10
DEN12 = H20*A2ND-H10*A1ST
DEN34 = H20*A4TH-H10*A3RD
IF(D.EQ. 0.0) GO TO 10

C
NDSQ=1.0-ALPHA*(H-D)
PD=KVRATT*(NDSQ-SSQ)
CALL MDHNL (PD,H1D,H2D,H1PRMD,H2PRMD)
CAPH1D=H1PRMD+AVRKT*H1D
CAPH2D=H2PRMD+AVRKT*H2D

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1  SUBROUTINE MOHKL (Z,H1,H2,H1PRME,H2PRME)
2  IMPLICIT REAL *8 (A-H,O-Z)
3  COMPLEX*16 Z,I,H1,H2,H1PRME,H2PRME,ZPOWER,TERM1,TERM2,
4  $ ZTERM,TERM,SUM1,SUM2,SUM3,SUM4,SORTZB,
5  $ EXP1,EXP2,EXP3,EXP4,EXP5,GM2F,GMFP,MPower,BETA,RTZ,
6  $ CONST1,CONST2,CONST3,CONST4
7  DIMENSION A(23), B(23), C(23), D(23), CAP(14)
8  DATA A,
9  $ 9.30436716930000D-01,3.10145572309700D 01,2.08703714373160D 02,
10 $ 5.74343652425450D 02,8.70217655190000D 02,8.28778719228640D 02,
11 $ 5.41685437404340D 02,2.57945446383020D 02,9.34584950663100D 01,
12 $ 2.66283518707400D 01,6.1210043005600D 00,1.15928038448000D 00,
13 $ 1.84012759441000D-01,2.48330309640000D-02,2.88420801000000D-03,
14 $ 2.91334142000000D-04,2.58274150000000D-05,2.02568600000000D-06,
15 $ 1.41557000000000D-07,8.87000000000000D-09,5.01000000000000D-10,
16 $ 2.60000000000000D-11,1.00000000000000D-12/
17 DATA B,
18 $ 6.78298725140000D-01,1.13049787524000D 01,5.38332321543100D 01,
19 $ 1.19629404787350D 02,1.53371031778650D 02,1.27809193148800D 02,
20 $ 7.47422182157200D 01,3.23559386215200D 01,1.07853128738400D 01,
21 $ 2.85325737403000D 00,6.13603736351000D-01,1.03767800980000D-01,
22 $ 1.64229399550000D-02,2.10550512200000D-03,2.33167788000000D-04,
23 $ 2.25282890000000D-05,1.91567100000000D-06,1.44470000000000D-07,
24 $ 9.72900000000000D-09,5.89000000000000D-10,3.20000000000000D-11,
25 $ 2.00000000000000D-12,0.00000000000000D 00/
26 DATA C,
27 $ 4.65218358460000D-01,6.20291144619000D 00,2.58454643591500D 01,
28 $ 5.22130593114000D 01,6.21584039421500D 01,4.87516893663900D 01,
29 $ 2.70842718702200D 01,1.12150194079600D 01,3.59455750255000D 00,
30 $ 9.18150064510000D-01,1.91281263439000D-01,3.31222966990000D-02,
31 $ 4.84244103800000D-03,6.05683682000000D-04,6.55501820000000D-05,
32 $ 6.19859900000000D-06,5.16550000000000D-07,3.82200000000000D-08,
33 $ 2.52800000000000D-09,1.50000000000000D-10,8.00000000000000D-12,
34 $ 0.00000000000000D 00,0.00000000000000D 00/
35 DATA D,
36 $ 6.78298725140000D-01,4.52193150096200D 01,3.768332025080150D 02,
37 $ 1.19629404787350D 03,1.56382341312250D 03,2.04494709038206D 03,
38 $ 1.42010214609865D 03,7.1180649673510D 02,2.69632821846030D 02,
39 $ 7.98912064729000D 01,1.90217158268800D 01,3.71881052333900D 00,
40 $ 6.07648779323000D-01,8.42202049000000D-02,1.00262148690000D-02,
41 $ 1.03630127400000D-03,9.38678690000000D-05,7.51243500000000D-06,
42 $ 5.35074000000000D-07,3.41350000000000D-08,1.96200000000000D-09,
43 $ 1.02000000000000D-10,5.00000000000000D-12/
44 DATA CAP,
45 $ 1.04165666666667D-01,8.35503472222222D-02,1.28226571556327D-01,
46 $ 2.91849026464140D-01,8.81627267443758D-01,3.32140828186277D 00,
47 $ 1.41957629908627D 01,7.89230130115870D 01,4.74451538868000D 02,
48 $ 3.20749009100000D 03,2.40865496000000D 04,1.98923120000000D 05,
49 $ 1.79190200000000D 06,1.74843770000000D 07/
50
51 DATA I/(0.000,1.000)/
52 DATA ROOT3/1.73205080756888D 00/
53 DATA ALPHA/R.53667218835931D-01/
54 DATA CONST1/( 2.58819045102522D-01,-9.65935826289067D-01)/

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C

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55 DATA C0A5T2/(-2.58819045102522D-01, 9.65925826289067D-01)/
56 DATA C0A5T3/(-9.65925826289067D-01, 2.58819045102522D-01)/
57 DATA C0A5T4/(-9.65925826289067D-01, -2.58819045102522D-01)/
58
59 C
60 ZPOWER=1.0
61 SUM3=0.0
62 SUM2=0.0
63 ZMAG=CDABS(Z)
64 IF(ZMAG .GT. 4.2) GO TO 70
65 IF(ZMAG .GE. 3.2) GO TO 10
66 N=12
67 GO TO 30
68 IF(ZMAG .GE. 4.1) GO TO 20
69 N=15
70 GO TO 30
71 N=23
72 SUM1=0.
73 SUM2=0.
74 ZTERM=-Z**3/200.0
75 DO 50 M=1,N
76 SUM1=SUM1+A(M)*ZPOWER
77 SUM2=SUM2+B(M)*ZPOWER
78 SUM3=SUM3+C(M)*ZPOWER
79 SUM4=SUM4+D(M)*ZPOWER
80 ZPOWER=ZPOWER*ZTERM
81 IF(CDABS(ZPOWER) .LE. 1.0D-30) GO TO 60
82 CONTINUE
83 GM2F=1*(Z*SUM2-2.*SUM1)/ROOT3
84 GPMFP=1*(SUM4+2.*Z*SUM3)/ROOT3
85 H1=Z*SUM2+GM2F
86 H2=H1-2.0*GM2F
87 H1PRVE=SUM4+GPMFP
88 H2PRVE=H1PRVE-2.0*GPMFP
89 RETURN
90
91 C
92 SUM1=1.0
93 SUM2=1.0
94 R1Z=CDSORT(Z)
95 SQRIZB=RTZ*Z
96 ZTERM=1/SQRIZB
97 MPOWER=1.0
98 TERM=-1.5/Z
99 DO 80 M=1,14
100 ZPOWER=ZPOWER*ZTERM
101 MPOWER=MPOWER*(-ZTERM)
102 TERM1=CAP(M)*ZPOWER
103 TERM2=CAP(M)*MPOWER
104 SUM1=SUM1+TERM1
105 SUM2=SUM2+TERM2
106 SUM3=SUM3+M*TERM1
107 SUM4=SUM4+M*TERM2
108 CONTINUE
109 SUM3=SUM3*TERM
110 SUM4=SUM4*TERM
111 EXP1=CDEXP(2.*I*SQRIZB/3.)
112 EXP2=EXP1-CONST1
113 EXP3=CONST2/EXP1

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112 EXP4=CONST3*EXP1
113 EXP5=CONST4/EXP1
114 BETA=ALF:HA/CDSQRT(RTZ)
115 ZREAL=Z
116 ZIMAG=-I*Z
117 IF (ZREAL.GE.0.0.OR.ZIMAG.GE.0.0)GO TO 90
118 H1=BETA*(EXP2-SUM2+EXP5*SUM1)
119 H1PRME=BETA*(EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)+EXP5*(SUM1*(-0.25/Z
120 -I*RTZ)+SUM3))
121 GO TO 110
122 H1=BETA*EXP2*SUM2
123 H1PRME=BETA*EXP2*(SUM2*(-0.25/Z+I*RTZ)+SUM4)
124 IF (ZREAL.GE.0.0.OR.ZIMAG.LT.0.0)GO TO 120
125 H2=BETA*(EXP3*SUM1+EXP4*SUM2)
126 H2PRME=BETA*(EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)+EXP4*(SUM2*(-0.25/Z
127 +I*RTZ)+SUM4))
128 RETURN
129 H2=BETA*EXP3*SUM1
130 H2PRME=BETA*EXP3*(SUM1*(-0.25/Z-I*RTZ)+SUM3)
131 RETURN
132 END

```

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1  SUBROUTINE CLIN EQ (A, B, X, N,
2  $ N DIM, IFLAG, ERR)
3
4  C
5  C CLIN EQ USES L-U DECOMPOSITION TO
6  C FIND THE TRIANGULAR MATRICES L, U
7  C SUCH THAT  $L \cdot U = A$ . L AND U ARE
8  C STORED IN A. THIS FORM IS USED WITH
9  C BACK-SUBSTITUTION TO FIND THE SOLN
10 C X OF  $A \cdot X = L \cdot U \cdot X = B$ .
11 C N IS THE NUMBER OF EQUATIONS AND
12 C N DIM IS THE DIMENSION OF ALL ARRAYS
13 C IN THE PARAMETER LIST.
14
15 C IF IFLAG = 0, L, U, AND X ARE COMPUTED
16 C IF IFLAG IS NON-ZERO, IT IS ASSUMED
17 C THAT L AND U HAVE BEEN COMPUTED IN
18 C A PREVIOUS CALL AND ARE STILL STORED
19 C IN A. THUS ONLY X IS COMPUTED.
20 C ERR IS THE ESTIMATED RELATIVE
21 C ERROR OF THE SOLUTION VECTOR.
22
23 C
24 C COMPLEX*16 A, B, X, T
25 C INTEGER*4 IROW
26 C DIMENSION A(N DIM, N DIM),
27 C $ B(N DIM), X(N DIM)
28 C DIMENSION IROW(50), Q(50)
29 C DATA EPS /1.0E-15/
30
31 C
32 IF (N.GT.50) GO TO 900
33 IF (IFLAG.NE.0) GO TO 600
34 DO 050 I = 1, N
35 Q(I) = 0.0
36 DO 040 J = 1, N
37 QJ = CDABS (A(I,J))
38 Q(I) = Q(I) + QJ
39
40 040 IF (Q(I).LT.QQ) Q(I) = QQ
41 IF (Q(I).EQ.0.0) GO TO 901
42
43 050 CONTINUE
44 ERR = EPS
45 PPIV = 0.0
46 DO 100 I = 1, N
47 IROW(I) = I
48
49 C
50 DO 500 L = 1, N
51 PIVOT = 0.0
52 K = L - 1
53 DO 240 I = L, N
54 IF (K.LT.1) GO TO 230
55 DO 220 J = 1, K
56 A(I,L) = A(I,L) - A(J,L) * A(I,J)
57 F = CDABS (A(I,L)) / Q(I)
58 IF (PIVOT.GT.F) GO TO 240
59 PIVOT = F
60 NPIVOT = I
61
62 240 CONTINUE

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55 IF (PIVOT.EQ.0.0) GO TO 901
56 IF (PIV.LE.PIVOT) GO TO 250
57 ERR = ERR * PPIV / PIVOT
58 IF (ERR.GE.1.0) GO TO 901
59
250 PPIV = PIVOT
60 IF (NPIVOT.EQ.L) GO TO 280
61 Q(NPIVOT) = Q(L)
62 J = IROW(L)
63 IROW(L) = IROW(NPIVOT)
64 IROW(NPIVOT) = J
65 DO 260 I = 1,N
66 T = A(L,I)
67 A(L,I) = A(NPIVOT,I)
68 A(NPIVOT,I) = T
69
260 CONTINUE
280 IF (L.EQ.N) GO TO 500
70 T = (1.0D0,0.0D0) / A(L,L)
71 K = L + 1
72 M = L - 1
73
74 DO 450 I = K,N
75 IF (M.LT.1) GO TO 400
76 DO 350 J = 1,M
77
350 A(L,I) = A(L,I) - A(L,J) * A(J,I)
78
400 A(L,I) = T * A(L,I)
79
450 CONTINUE
500 CONTINUE
510 IF (ERR.GT.1.0E-5) PRINT 998, ERR
C
600 DO 620 I = 2,N
620 X(I) = (0.0D0,0.0D0)
J = IROW(I)
X(I) = B(J) / A(1,1)
DO 700 I = 2,N
J = IROW(I)
K = I - 1
DO 650 L = 1,K
650 X(I) = X(I) + A(I,L) * X(L)
X(I) = (B(J) - X(I)) / A(I,I)
700 CONTINUE
K = N - 1
DO 800 I = 1,K
J = N - I
M = J + 1
DO 800 L = M,N
X(J) = X(J) - X(L) * A(J,L)
800 CONTINUE
RETURN
C
900 PRINT 999
ERR = 1.0
RETURN
901 PRINT 997
ERR = 1.0
RETURN
997 FORMAT ('ERROR IN CLIN EQ. MATRIX IS SINGULAR')
998 FORMAT ('CAUTION-')
999 $ CLIN EQ HAS DECOMPOSED AN ILL-CONDITIONED MATRIX. '//,

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112 \$ ' RESULTS WILL HAVE RELATIVE ERROR = ',E11.2)
113 999 FORMAT ('ERROR IN CLIN EQ, MATRIX SIZE GREATER THAN 50')
114 END

```

1      SUBROUTINE CINVER (A, A INV, N, N DIM, ERR)
2
3      C
4      C CINVER SUCCESSIVELY COMPUTES EACH COLUMN
5      C OF THE INVERSE MATRIX OF A, USING THE
6      C SUBROUTINE CLIN EQ TO SOLVE  $A * X = E$ 
7      C FOR EACH UNIT VECTOR E.
8      C N IS THE ORDER OF THE MATRIX A AND
9      C N DIM IS THE DIMENSION OF ALL ARRAYS
10     C IN THE PARAMETER LIST.
11     C ERR IS THE ESTIMATED RELATIVE ERROR
12     C OF THE INVERTED MATRIX.
13     C THE INVERSE MATRIX IS
14     C RETURNED IN A INV.
15
16     C
17     C COMPLEX*16 A, A INV, B, X
18     C DIMENSION A(N DIM, N DIM),
19     C $ A INV(N DIM, N DIM)
20     C DIMENSION B(50), X(50)
21
22     C
23     C IF (N.GT.50) GO TO 900
24     C II = 0
25     C DO 100 I = 1,N
26     C   B(I) = (0.0D0,0.0D0)
27     C   DO 300 J = 1,N
28     C     B(I) = (1.0D0,0.0D0)
29     C     CALL CLIN EQ (A, B, X, N, N DIM, II, ERR)
30     C     IF (ERR.GE.1.0) GO TO 901
31     C     DO 200 J = 1,N
32     C       A INV(J,I) = X(J)
33     C     B(I) = (0.0D0,0.0D0)
34     C     II = 1
35     C   300 CONTINUE
36     C   IF (ERR.GT.1.0E-5) GO TO 901
37     C   RETURN
38
39     C
40     C 900 PRINT 998
41     C   ERR = 1.0
42     C   RETURN
43     C 901 PRINT 999
44     C   RETURN
45     C 998 FORMAT ('!ERROR IN CINVER, MATRIX SIZE GREATER THAN 50')
46     C 999 FORMAT (' CLIN EQ WAS CALLED BY CINVER')
47     C   END

```

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SUBROUTINE MA3(Z1,Z2,Z3,OUT)
  COMPLEX*16 Z1,Z2,Z3
  REAL*8 CDANG
  DIMENSION OUT(6)
  OUT(1)=CDABS(Z1)
  OUT(3)=CDABS(Z2)
  OUT(5)=CDABS(Z3)
  OUT(2)=CDANG(Z1)
  OUT(4)=CDANG(Z2)
  OUT(6)=CDANG(Z3)
  RETURN
END

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1		FUNCTION CDANG(ARG)
2	C	
3		IMPLICIT REAL*8 (A-H,O-Z)
4		COMPLEX*16 ARG,ARG PRT
5		DIMENSION PARTS(2)
6		EQUIVALENCE(ARG PRT,PARTS)
7	C	
8	C	
9		ARG PRT = ARG
10		ARG RL = PARTS(1)
11		ARG IM = PARTS(2)
12		CDANG = DATAN2(ARG IM,ARG RL)
13		RETURN
14	C	
15		END

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BLOCK DATA
C
C INITIALIZE THE COMMON BLOCK VALUES.
C
    IMPLICIT REAL *8 (A-H,O-Z)
    COMMON /FINPT, THETA, FREQ, AZMUTH, CODIP, MAGFLD, CEFFNU(5), EXPNU(5),
    $ TOPHT, LUSTHT, WKBHT, DELHT, H, ALPHA, SIGMA, EPSLON
    COMMON /WT FLAG, PRECSN, ISQ, IDBG
    COMMON /EPROF, ENHT(100), ENLUG(100,5), COLLHT(25), COLLFR(25,5),
    $ LHT, WHT, CHARGE(5), RATIOH(5), NRSPEC
    COMMON /EXC IN/ TXHT, RXHT
    REAL *8 MAGFLD, LNSTHT
    COMPLEX *16 THETA
C
C
    DATA MAGFLD /0.000/
    DATA CEFFNU /1.816D11, 4*0.000/
    DATA EXPNU /-1.5D-4, 4*0.000/
    DATA TOPHT /100.000/, LNSTHT /0.000/, WKBHT /000.000/
    DATA H /0.000/
    DATA ALPHA /3.14D-4/
    DATA SIGMA /4.64D0/
    DATA EPSLON /7.172D15D-10/
    DATA PRECSN /3.0D-5/
    DATA IDBG /1/
    DATA CHARGE /-1.000, 1.000, -1.000, 1.000, -1.000/
    DATA RATIOH /1.000, 4*5.8D4/
    DATA NRSPEC /1/
    END

```

APPENDIX B
MODE SUM AND PLOTTING PROGRAM LISTING

1	C	
2	C	
3	C	
4	C	THIS PROGRAM WAS DEVELOPED FOR USE ON THE UNIVAC 1100/82 AT THE
5	C	NAVAL OCEAN SYSTEMS CENTER. IT WAS WRITTEN IN ASCII FORTRAN USING
6	C	THE LEVEL 1001 COMPILER WHICH CONFORMS TO AMERICAN NATIONAL
7	C	STANDARDS INSTITUTE FORTRAN-77 STANDARDS.
8	C	THE DISPLA PACKAGE WAS USED TO GENERATE THE PLOTS.
9	C	
10	C	THE PROGRAM USES EXCITATION FACTORS GENERATED BY THE
11	C	WKB SATELLITE PROGRAM TO CALCULATE MODE SUMS FOR THREE
12	C	ORTHOGONAL FIELD COMPONENTS - EX, EY, AND EZ. SIX CURVES ARE
13	C	GENERATED FOR EACH FIELD COMPONENT DESIRED:
14	C	ELECTRIC DIPOLE - VERTICAL
15	C	ELECTRIC DIPOLE - HORIZONTAL-BROADSIDE
16	C	ELECTRIC DIPOLE - HORIZONTAL-ENDON
17	C	MAGNETIC DIPOLE - VERTICAL
18	C	MAGNETIC DIPOLE - HORIZONTAL-BROADSIDE
19	C	MAGNETIC DIPOLE - HORIZONTAL-ENDON
20	C	
21	C	NOTE THAT THE EXCITATION FACTORS HAVE THE HEIGHT OF THE RECEIVER
22	C	BUILT INTO THEM SO IF THE USER WISHES MODE SUMS FOR DIFFERENT
23	C	TRANSMITTER AND/OR RECEIVER HEIGHTS NEW EXCITATION FACTORS MUST
24	C	BE GENERATED.
25	C	
26	C	CALL INPUT
27	C	
28	C	CALL FIELDS
29	C	
30	C	CALL OUTPUT
31	C	
32		STOP
33		END

```

1  SUBROUTINE INPUT
2
3  C
4  C THIS SUBROUTINE READS IN AN IDENTIFICATION CARD FOR PLOT LABELS,
5  C THE NAMELIST VARIABLES, AND THE COMPLEX EIGEN ANGLE AND
6  C EXCITATION FACTORS FOR EACH MODE.
7  C
8  IMPLICIT REAL*8(A-H,O-Z)
9  REAL*8 IL,IA
10 REAL*4 AZIM,CODIP,MAGFLD,SIGMA,EPSPR,DIST,AMP
11 COMPLEX*16 IM/(0.0D0,1.0D0)/
12 COMPLEX*16 THETA,EXCIT
13 CHARACTER*14 LABEL
14 DIMENSION XTRMAG(3),XTRANG(3)
15 COMMON/ONE/RHOMIN,RHOMAX,DELPHO,MODES,IPLOT
16 COMMON/TWO/AZIM,CODIP,MAGFLD,SIGMA,EPSPR
17 COMMON/THREE/THETA(10),EXCIT(3,6,10)
18 COMMON/FOUR/FREQ,IL,IA,IXHT,RXHT,DIST(500),AMP(6,500),NPTS,
19 $ IDPLOT(20),LABEL
20 NAMELIST/DATUM/FREQ,RHOMIN,RHOMAX,IL,IA,MODES,DELPHO,IXHT,RXHT,
21 $ IPLOT,AZIM,CODIP,MAGFLD,SIGMA,EPSPR
22
23 C
24 C DESCRIPTION OF NAMELIST VARIABLES
25 C
26 C FREQ - FREQUENCY IN KHZ
27 C RHOMIN - MINIMUM DISTANCE (IN KM) AT WHICH FIELDS ARE PRINTED
28 C AND PLOTTED
29 C RHOMAX - MAXIMUM DISTANCE (IN KM) AT WHICH FIELDS ARE PRINTED
30 C AND PLOTTED
31 C IL - ELECTRIC DIPOLE CURRENT MOMENT IN AMP METERS
32 C IA - MAGNETIC DIPOLE MOMENT IN AMP METERS SQUARED
33 C MODES - NUMBER OF MODES USED IN MODE SUMS
34 C DELPHO - DISTANCE INCREMENT (IN KM) AT WHICH FIELDS ARE PRINTED
35 C AND PLOTTED
36 C IXHT - TRANSMITTER HEIGHT IN KM
37 C RXHT - RECEIVER HEIGHT IN KM
38 C IPLOT - PLOTTING FLAG
39 C IPLOT=0 NO PLOTS
40 C IPLOT=1 EZ PLOT
41 C IPLOT=2 EY AND EZ PLOTS
42 C IPLOT=3 EX, EY, AND EZ PLOTS
43 C THE FOLLOWING FIVE VARIABLES ARE USED SOLELY FOR IDENTIFICATION
44 C PURPOSES ON THE PLOTS
45 C AZIM - AZIMUTH IN DEGREES
46 C CODIP - CODIP IN DEGREES
47 C MAGFLD - MAGNETIC FIELD IN WEBERS PER SQUARE METER
48 C SIGMA - CONDUCTIVITY IN SIEMENS PER METER
49 C EPSPR - DIELECTRIC CONSTANT
50 C
51 C
52 C PRINT 902
53 C READ 900,IDPLOT
54 C PRINT 910,IDPLOT
55 C READ(5,DATUM,END=999)

```

```

55 WRITE(6,DATUM)
56 DO 50 M=1,MODES
57 READ 915,THETA(M)
58 PRINT 917,M,THETA(M)
59 DO 50 L=1,6
60 READ 920,(XTRMAG(J),XTRANG(J),J=1,3)
61 DO 50 J=1,3
62 EXCIT(J,L,M) = XTRMAG(J)*(DCOS(XTRANG(J))+IM*DSIN(XTRANG(J)))
63 CONTINUE
64
65 50
66 C
67 900 FORMAT(20A4)
68 902 FORMAT('1')
69 910 FORMAT('0',20A4)
70 915 FORMAT(8X,F6.3,1X,F7.3)
71 917 FORMAT(' MODE ',12,' THETA = ',2F7.3)
72 920 FORMAT(1X,3(4X,D13.6,1X,F7.3))
73 C
74 999 RETURN
75 END

```


C

55
56
57

RETURN
END


```

55      PRINT 960,DIST(N), (FID(I,I,N),I=1,6)
56      CONTINUE
57
58      C
59      910  FORMAT('OX COMPONENT')
60      920  FORMAT('OY COMPONENT')
61      930  FORMAT('OZ COMPONENT')
62      940  FORMAT('O',12X,3('ELECTRIC DIPOLE',5X),3('MAGNETIC DIPOLE',5X))
63      950  FORMAT( 9X,2(8X,'VERTICAL', 6X,'HORIZONTAL-BROADSIDE',2X,
64      $ 'HORIZONTAL-ENDON'))
65      960  FORMAT(' ',F6.3,6D20.7)
66      RETURN
        END

```



```

55 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
56 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
57 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
58 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
59 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
60 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
61 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
62 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
63 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
64 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
65 CALL HEIGHT(0.07)
66 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
67 CALL RESET('HEIGHT')
68 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
69 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
70 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
71 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
72 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
73 CALL HEIGHT(0.07)
74 CALL MESSAGE('INITIAL', W, 1.0, -1.0, 0.9, 2)
75 CALL RESET('HEIGHT')
76 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
77 CALL REALNO(SIGMA, 1, 1, 0.0, 0.2)
78
79 ENDIF
80 CALL ENDGR(0)
81 CONTINUE
82 CALL ENDPL(-1)
83
84 RETURN
85 END

```

700

C

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