

AD-A107 683

NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 20/14
WKB MODE SUMMING PROGRAM FOR DIPOLE ANTENNAS OF ARBITRARY ORIENT--ETC(U)
OCT 81 J A FERGUSON; D G MORFITT DNA-MIPR-81-504
UNCLASSIFIED NOSC/TR-697 NL

[OF]
ADA
107683

NOSC

END
DATE
FILMED
FEB 82
DTIC

LEVEL II

12

NOSC

NOSC TR 697

NOSC TR 697

Technical Report 697

WKB MODE SUMMING PROGRAM FOR DIPOLE ANTENNAS OF ARBITRARY ORIENTATION AND ELEVATION FOR VLF/LF PROPAGATION

Calculation of vlf/lf field strengths
in the earth-ionosphere waveguide

DTIC
ELECTE
NOV 20 1981

JA Ferguson
DG Morfitt

1 October 1981

D
Interim Report for Period October 1980 - May 1981

Prepared for
Defense Nuclear Agency
Subtask S99QAXH B0425 and NOSC Work Unit 532-MP20

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

81 11 19 065

DTIC FILE



NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

This work, sponsored by the Defense Nuclear Agency under Subtask S99QAXH B0425, and NOSC work unit 532-MP20, was performed during the period 1 October 1980 through 30 May 1981.

Released by
JH Richter, Head
EM Propagation Division

Under authority of
JD Hightower, Head
Environmental Sciences
Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
NOSC Technical Report 697 (TR 697)	AD-A107	683
4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED	
WKB MODE SUMMING PROGRAM FOR DIPOLE ANTENNAS OF ARBITRARY ORIENTATION AND ELEVATION FOR VLF/LF PROPAGATION (Calculation of vlf/lf field strength in the earth-ionosphere waveguide)	Interim October 1980 - May 1981	
7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)	
JA Ferguson DG Morfitt	DNA MIPR 81-504	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
NAVAL OCEAN SYSTEMS CENTER San Diego, CA 92152	62715H, S99QAXHB, 00001 (NOSC 532-MP20)	
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE	
DEFENSE NUCLEAR AGENCY Washington, DC 20350	1 October 1981	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	13. NUMBER OF PAGES	
	60	
	15. SECURITY CLASS. (of this report)	
	UNCLASSIFIED	
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Computer programs Earth ionosphere waveguide Low frequency (lf) Very low frequency (vlf) Ionospheric propagation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
The computer program described in this report is a modified version of that described in NELC Interim Report 713, NTIS, AD728414. Changes consist of an increase in the number of waveguide slabs from 25 to essentially an unlimited number, more convenient formatting of the input data, especially in the reduction from three to two cards per waveguide mode, an increase in the number of allowable modes from 15 to 30, and the addition of two new output options. This program is referred to as WKBFLDS or FLD4.		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

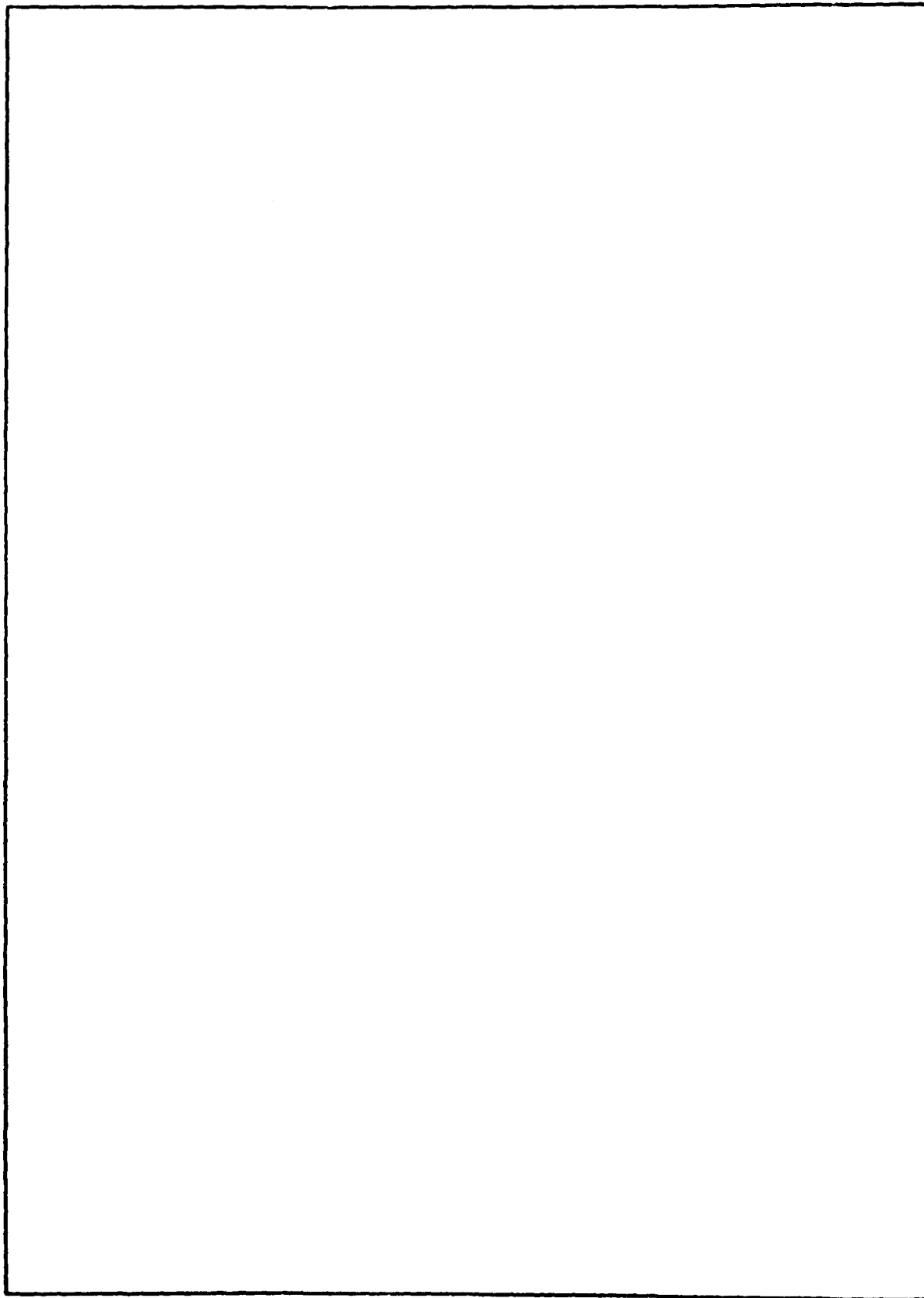
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



S. N. 0102- LF- 014- 6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

OBJECTIVE

Develop a computer program for calculating vlf/lf field strengths in the earth-ionosphere waveguide whose characteristics may vary along the direction of propagation.

RESULTS

The computer program described in this report is a modified version of that described in NELC Interim Report 713, WKB Mode Summing Program for VLF/LF Antennas of Arbitrary Length, Shape, and Elevation. Changes consist of an increase in the number of waveguide slabs from 25 to essentially an unlimited number, more convenient formatting of the input data, especially in the reduction from three to two cards per waveguide mode, an increase in the number of allowable modes from 15 to 30, and the addition of two new output options. This program is referred to as WKBFLDS or FLD4.

RECOMMENDATIONS

Use this program in instances where the characteristics of the earth or ionosphere vary slowly along the propagation path.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

DTIC
ELECTE
NOV 20 1981
S D D

CONTENTS

INTRODUCTION ...page 5

SUMMARY OF THE EQUATIONS ... 6

 Background ... 6

 WKB Implementation ... 11

PROGRAM EXECUTION ... 13

 Options ... 13

 Control Cards ... 14

 Special Considerations ... 18

EXAMPLE DATA ... 20

REFERENCES ... 30

APPENDIX: PROGRAM LISTING ... 31

INTRODUCTION

Electromagnetic radiation in the lower frequency bands emitted in the region between the finitely conducting earth and the weakly ionized plasma of the lower ionosphere is guided by these boundaries and propagated to great distances around the earth. The waveguide model analyzes this propagation using a mode series (ref 1-4). The propagation parameters of interest (phase velocity, attenuation rate, excitation factor) can be evaluated for each mode. The total field at any point along the guide is then the vector sum of the contributions from each mode. The waveguide model has been employed in a series of computer programs (ref 5-7) useful from elf to lf.

In many instances, the earth-ionosphere waveguide can be considered to have constant propagation properties along the transmission path. The mode sum calculations made for these cases are referred to as horizontally homogeneous. However, for propagation to great distances it is unrealistic to assume the waveguide parameters will remain constant along the whole length of the path. For example, the direction and strength of the earth's magnetic field will vary along the path, causing changes in the mode parameters due to the anisotropy of the ionosphere. Discontinuities can occur in the lower wall of the waveguide due to the presence of ground conductivity changes. The ionospheric conductivity varies according to the time of day, season, and the presence of the sunrise or sunset line along the propagation path. Anomalous ionization from a nuclear detonation may also produce important changes in mode parameters along the propagation path. If changes in the waveguide parameters are small within a few radio wavelengths, then the modes can be tracked through the region of change.

The computer program described in this report was developed for calculating vlf/lf field strengths in the earth-ionosphere waveguide. Allowance is made for horizontal inhomogeneity in the direction of propagation. The program is based upon a slab model and assumes the waveguide is homogeneous transverse to the great circle path between a transmitter and a receiver. For purposes of identification it is called FLD4 or WKBFLDS.

In the FLD4/WKBFLDS program, field strength calculations can be generated for all electric field components, at any receiver height within the waveguide, generated by electric dipole exciters of arbitrary orientation located

at any height within the guide. Transmitter and receiver heights must be within the free-space portion of the waveguide.

In describing the WKBFLDS computer program, familiarity is assumed with references 5 and 7 which describe FORTRAN programs for obtaining waveguide mode constants within the earth-ionosphere waveguide. Relevant outputs from these programs are the mode eigenangles and four independent quantities from which the excitation factors may be determined. Principal outputs of the WKBFLDS program are listings of the mode sum parameters and the corresponding plots. The field strengths are given in dB above 1 $\mu\text{V/m}$ and the phase is given relative to free space propagation.

The Summary of the Equations section summarizes the relevant formulae. A description of the program input, output, and operating procedures is given in the Program Execution section. The appendix contains a FORTRAN listing of the computer program.

SUMMARY OF THE EQUATIONS

BACKGROUND

In the propagation of vlf and lf terrestrial radio waves to great distances, the waves are confined within the space between the earth and the ionosphere. This space acts as a waveguide.

The waveguide mode method described in references 6 and 7 obtains the full-wave solution for a waveguide that is characterized by arbitrary electron and ion density distributions and collision frequencies with height and a lower boundary which is a smooth homogeneous earth with an adjustable surface conductivity and dielectric constant. The model allows for earth curvature, ionospheric inhomogeneity, and anisotropy.

The propagation geometry is shown in figure 1. The vertical coordinate is z , the direction of propagation is x , and y is normal to the plane of propagation. Thus, the fields exhibit no y dependence and have a dependence on x of the form $\exp(-ikS_m x)$. All field quantities are assumed to have an $\exp(i\omega t)$ dependence where ω is the angular frequency. The dipole source for the fields is denoted in figure 1 by $\vec{M}$. The dipole is oriented at an inclination angle γ

measured from the vertical, and azimuthal angle θ measured from the x-axis. For a horizontal dipole $\gamma = 90^\circ$, and $\theta = 0^\circ$ represents end-fire launching.

The energy within the waveguide is considered to be partitioned among a series of modes called the eigenangles (or "modes") and designated by the complex angle, θ , obtained by solving the determinantal equation:

$$F(\theta) = |\tilde{R}(\theta) \bar{\tilde{R}}(\theta) - 1| = 0 \quad (1)$$

where

$$\tilde{R}(\theta) = \begin{pmatrix} {}_{\parallel}R_{\parallel}(\theta) & {}_{\perp}R_{\parallel}(\theta) \\ {}_{\parallel}R_{\perp}(\theta) & {}_{\perp}R_{\perp}(\theta) \end{pmatrix} \quad (2)$$

and

$$\bar{\tilde{R}}(\theta) = \begin{pmatrix} \bar{{}_{\parallel}R_{\parallel}}(\theta) & 0 \\ 0 & \bar{{}_{\perp}R_{\perp}}(\theta) \end{pmatrix} \quad (3)$$

are the complex ionospheric reflection coefficient matrices looking up into the ionosphere and down towards the ground, respectively, from a height "d".

Once equation 1 is solved for as many modes, θ_m , as needed, the mode parameters, phase velocity, attenuation rate, and excitation factors can be computed. Let S_m be the sine of the eigenangle θ_m and let the individual components be S_r and S_i so that $S_m = S_r + i S_i$. The phase velocity is given by

$$v = \frac{c}{S_r} \quad (4)$$

where c is the vacuum speed of light.

The attenuation rate is given by

$$\alpha = -8.6859k S_i \quad (\text{in dB/unit distance}) \quad (5)$$

where k is the free-space wave number.

The excitation factor formulae, as given in reference 1, are summarized in table 1. The headings apply to the electric field components (E_z , E_y , E_x) excited by a vertical dipole (z), a horizontal dipole broadside (y), and a horizontal dipole end-on (x).

Field Component	z	y	x
Exciter			
z	$\frac{S^{5/2} (1 + \bar{R}_{\parallel})^2 (1 - \bar{R}_{\perp\perp} R_{\perp})}{F'(\theta_m) \bar{R}_{\parallel} D_{11}}$	$- \frac{S^{3/2} \bar{R}_{\perp} (1 + \bar{R}_{\parallel}) (1 + \bar{R}_{\perp})}{F'(\theta_m) D_{12}}$	$\frac{S^{3/2} (1 + \bar{R}_{\parallel})^2 (1 - \bar{R}_{\perp\perp} R_{\perp})}{F'(\theta_m) \bar{R}_{\parallel} D_{11}}$
y	$- \frac{S^{3/2} \bar{R}_{\perp} (1 + \bar{R}_{\parallel}) (1 + \bar{R}_{\perp})}{F'(\theta_m) D_{12}}$	$\frac{S^{1/2} (1 + \bar{R}_{\perp})^2 (1 - \bar{R}_{\parallel\parallel} R_{\parallel})}{F'(\theta_m) \bar{R}_{\perp} D_{22}}$	$- \frac{S^{1/2} \bar{R}_{\perp} (1 + \bar{R}_{\parallel}) (1 + \bar{R}_{\perp})}{F'(\theta_m) D_{12}}$
x	$- \frac{S^{3/2} (1 + \bar{R}_{\parallel})^2 (1 - \bar{R}_{\perp\perp} R_{\perp})}{F'(\theta_m) \bar{R}_{\parallel} D_{11}}$	$\frac{S^{1/2} \bar{R}_{\perp} (1 + \bar{R}_{\parallel}) (1 + \bar{R}_{\perp})}{F'(\theta_m) D_{12}}$	$- \frac{S^{1/2} (1 + \bar{R}_{\parallel})^2 (1 - \bar{R}_{\perp\perp} R_{\perp})}{F'(\theta_m) \bar{R}_{\parallel} D_{11}}$

Table 1. Excitation factors

In table 1 the following terms are used:

$$F'(\theta_m) = \left. \frac{\partial F}{\partial \theta} \right|_{\theta=\theta_m} \quad (6)$$

$$F_1 = - \left\{ H_2(q_o) - i \frac{n_o^2}{n_g^2} \left(\frac{ak}{2} \right)^{1/3} (n_g^2 - s^2)^{1/2} h_2(q_o) \right\} \quad (7)$$

$$F_2 = H_1(q_o) - i \frac{n_o^2}{n_g^2} \left(\frac{ak}{2} \right)^{1/3} (n_g^2 - s^2)^{1/2} h_1(q_o) \quad (8)$$

$$F_3 = - \left\{ h_2'(q_o) - i \left(\frac{ak}{2} \right)^{1/3} (n_g^2 - s^2)^{1/2} h_2(q_o) \right\} \quad (9)$$

$$F_4 = h_1'(q_0) - i \left(\frac{ak}{2}\right)^{1/3} (n_g^2 - s^2)^{1/2} h_1(q_0) \quad (10)$$

$$q_z = \left(\frac{2}{ak}\right)^{-2/3} \left(1 + \frac{2}{a} z - s\right)^2 \quad (11)$$

$$H_j(q) = h_j'(q) + \frac{1}{2} \left(\frac{2}{ak}\right)^{2/3} h_j(q) ; j = 1, 2 \quad (12)$$

$$n_z^2 = 1 + \frac{2}{a} z \quad (13)$$

$$n_g^2 = \frac{\epsilon}{\epsilon_0} - i \frac{\sigma}{\omega \epsilon_0} \quad (14)$$

$$D_{11} = \{F_1 h_1(q_d) + F_2 h_2(q_d)\}^2 \quad (15)$$

$$D_{12} = \{F_1 h_1(q_d) + F_2 h_2(q_d)\} \{F_3 h_1(q_d) + F_4 h_2(q_d)\} \quad (16)$$

$$D_{22} = \{F_3 h_1(q_d) + F_4 h_2(q_d)\}^2 \quad (17)$$

where ϵ/ϵ_0 = dielectric constant of the ground and σ = the ground conductivity.

The subscripts on q and n represent the value of z at which these quantities are evaluated. The functions h_1 and h_2 are modified Hankel functions of order $1/3$ as defined in reference 8. The primes on these quantities denote derivatives with respect to the argument.

The modal excitation factor and height gain functions are needed in computing electric field strengths. The excitation factors of table 1 must be supplemented with the height gain functions which are given in reference 1 as:

$$f_1(z) = \exp\left(\frac{z}{a}\right) \{F_1 h_1(q) + F_2 h_2(q)\} \quad (18)$$

$$f_2(z) = \{F_3 h_1(q) + F_4 h_2(q)\} / \{F_3 h_1(q_0) + F_4 h_2(q_0)\} \quad (19)$$

$$f_3(z) = \frac{1}{ik} \frac{df_1}{dz} \quad (20)$$

where f_1 is the height gain for the vertical electric field E_z , f_2 is the height gain for the horizontal electric field component E_y , and f_3 is the height gain for the horizontal electric field component E_x .

The basic mode sum equation is given by

$$E = \frac{\eta}{4\pi} \left(\frac{2\pi p}{10k} \right)^{1/2} \frac{k}{2} \frac{\sum E_m}{[a \sin(x/a)]^{1/2}} \quad (21)$$

where E = total electric field in volts/metre

E_m = complex amplitude of each mode

p = power radiated

η = free-space impedance

If the waveguide is homogeneous in the direction of propagation, then E_m is given by

$$E_m = \Lambda_m \exp \{-ik S_m x\} \quad (22)$$

where Λ_m is the complex amplitude of the m th mode to be described later. If the parameters Λ_m and S_m are slowly varying functions of distance, then the so-called WKB form of E_m is given by references 1 and 9 as

$$E_m = \Lambda_m(x) \exp \left\{ -ik \int_0^x S_m(\rho) d\rho \right\} \quad (23)$$

where

$$\begin{aligned}\Lambda_m = & \{[\lambda_{zr}^m(0) \lambda_{zr}^m(x)]^{1/2} g_z(z_t) \cos\gamma \\ & + [\lambda_{yr}^m(0) \lambda_{yr}^m(x)]^{1/2} g_y(z_t) \sin\gamma \sin\theta \\ & + [\lambda_{xr}^m(0) \lambda_{xr}^m(x)]^{1/2} g_x(z_t) \sin\gamma \cos\theta\} g_r(z_r)\end{aligned}\quad (24)$$

and r denotes the orientation of the received electric field component. If equation 24 is used, then equation 26 reduces to

$$\begin{aligned}\Lambda_m = & \{\lambda_{zr}^m g_z(z_t) \cos\gamma \\ & + \lambda_{yr}^m g_y(z_t) \sin\gamma \sin\theta \\ & + \lambda_{xr}^m g_x(z_t) \sin\gamma \cos\theta\} g_r(z_r)\end{aligned}\quad (25)$$

WKB IMPLEMENTATION

The procedure implemented in the WKBFLDS computer program is to segment the earth-ionosphere waveguide into M cascaded uniform waveguides as shown in figure 2. These segments (or slabs) are numbered from left to right. Slab 1 contains the transmitter. The distance from the transmitter to the beginning of each slab is denoted by ρ_k . The waveguide parameters associated with each slab are determined by the user based on consideration of the variations of the path conditions (geomagnetic field, ground conductivity, and the ionospheric profiles of electron density, ion density, and collision frequency).

The mode generating programs (ref 6 or 7) are run to obtain as many modes as desired in each slab. The WKB model requires an equal number of modes in each slab and the modes must be traced from one slab to the next in order to preserve mode numbers. At each slab boundary energy is transferred from a given mode into the corresponding mode in the next slab. The values of Λ_m and S_m at the beginning of each segment are defined to be those obtained from the full-wave programs. The values of each quantity within each segment are obtained by linear interpolation between the values at the segment bound-

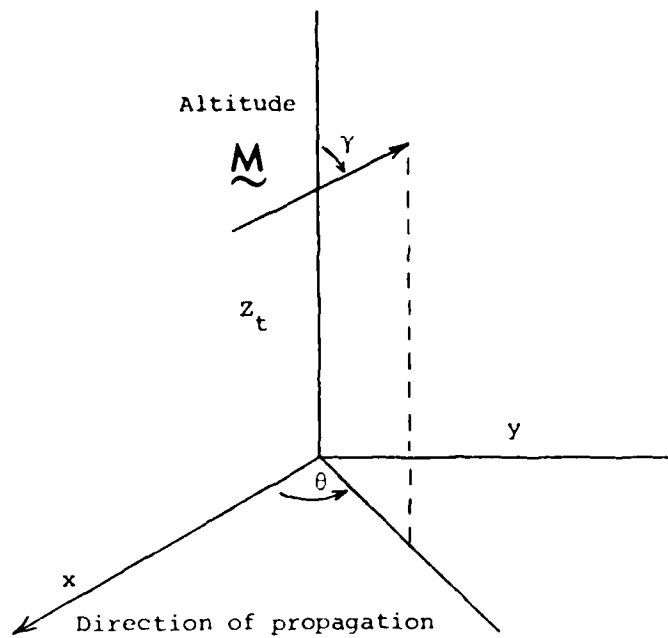


Figure 1. Dipole orientation within the waveguide

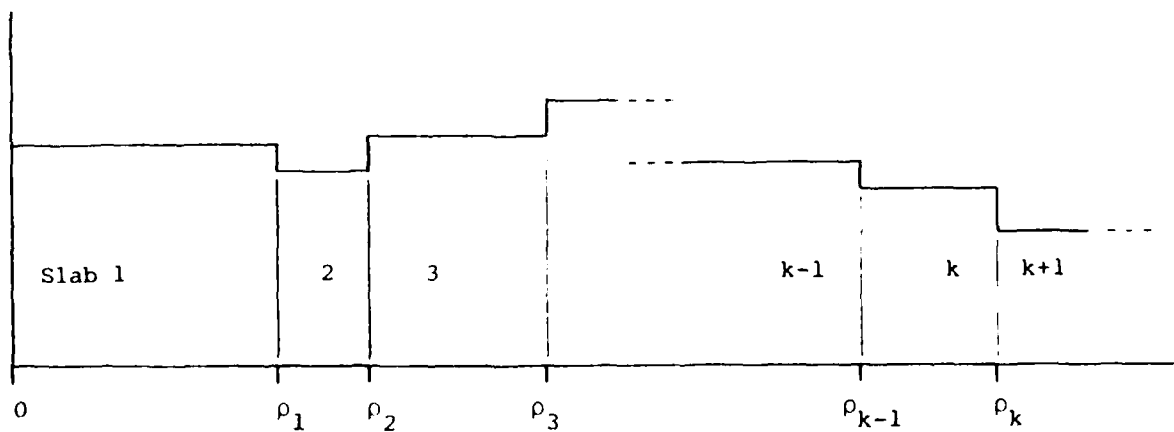


Figure 2. Diagram illustrating propagation path segmentation

aries. Care is taken to insure continuity of the phase of Λ_m and S_m from the transmitter to the receiver.

PROGRAM EXECUTION

OPTIONS

The program has three output options. For compatibility with other programs these options are numbered 1, 2, and 4. Option 1 produces fields as functions of distance parametric in transmitter altitude and orientation for a fixed receiver altitude and orientation. The program generates 501 points between the transmitter (distance = 0) and the end of the path (distance = DMAX, described below). The calculated fields and appropriate constants may be written to logical file 2 for processing by other programs. The calculated amplitude and relative phase may be printed and/or plotted. The vertical and horizontal (distance) dimensions and scales of the plots may be arbitrarily specified. Each set of distance calculations can be made for up to 20 transmitter orientations.

Option 2 produces fields as functions of a transmitter's position in an orbit for a fixed transmitter altitude and antenna inclination and for a fixed receiver altitude and orientation. The program generates 73 points between $\theta = 0^\circ$ and $\theta = 360^\circ$. Up to three different orbit configurations may be obtained: a dipole rotating in a counterclockwise direction, and clockwise and counterclockwise orbiting at a specified radius. Clockwise is determined by looking down the z-axis towards the x-y plane. Each set of orbit calculations is made at as many as 20 different distances from the transmitter. The calculated amplitude and relative phase may be printed. The results are always plotted using a fixed vertical size and scale and a user specified horizontal size.

Option 4 produces fields as functions of distance for fixed values of the transmitter and receiver altitudes and orientations. The data sets are varied so as to produce comparison plots. The printed and plotted outputs are all specified as for option 1. The procedure for storing the calculated fields on an external device is also provided as for option 1.

CONTROL CARDS

The flow of program execution is controlled by a set of cards which define the type of data being input and allow standard defaults to apply. All 80 columns of these control cards are read and printed. However, only the first four columns are examined by the program. Thus the input card and the printout can contain additional comments. For example, "NAMELIST DATA FOR AN ELEVATED TRANSMITTER" can be used in place of the minimum requirement of "NAME". The control cards are described below and a sample set is shown in figure 3.

<u>NAME</u>	Signals that NAMELIST data follow. The NAMELIST name is DATUM. The NAMELIST variables are described below.
IOPT	Option number - DEFAULT = 1
ICOMP	Index of received electric field component = 1 gives the vertical field (z) - DEFAULT = 2 gives the horizontal transverse field (y) = 3 gives the horizontal longitudinal field (x)
TALT	Transmitter altitude in km (ie, z_t) - DEFAULT = 0.0
RALT	Receiver altitude in km (ie, z_r) - DEFAULT = 0.0
INCL	Transmitting antenna inclination in degrees (ie, γ). This is an array of 20 elements - DEFAULT = 0.0
THETA	Transmitting antenna azimuth in degrees (ie, θ). This is an array of 20 elements - DEFAULT = 0.0
NRA	Number of pairs of INCL and THETA to be used. This applies only to option 1 - DEFAULT = 1
DIST	Distance between an orbiting transmitter and a receiver in Mm. This is an array of 20 elements - DEFAULT = 1.0
NRD	Number of values of DIST to be used. This applies only to option 2 - DEFAULT = 1
NRDATA	Number of input data sets to process for option 4 - DEFAULT = 1
RADIUS	Radius of the orbit in Mm used in option 2 - DEFAULT = 0.0
POWER	Total radiated power in kW - DEFAULT = 1.0

NPRINT Printout control flag
 = 0 generates a minimum of print
 = 1 generates full print (described in example data section) -
 DEFAULT

NAPLOT Amplitude plot flag
 = 0 deletes plot
 = 1 generates plot - DEFAULT
 = 0 deletes plot - DEFAULT
 = 1 generates plot

NPDIFF Phase difference plot flag
 = 0 deletes plot - DEFAULT
 = 1 generates plot

NRCURV Number of curves to be plotted per graph for option 1 and 4 -
 DEFAULT = 4

SIZEX Length of the horizontal plot axis for current option in inches
 (for all options) - DEFAULT = 10.0

SIZEY Length of the vertical axis for current option in inches (for
 options 1 and 4 only) - DEFAULT = 9.0

SIZEX1 Length of axis for option 1 and 4 only - DEFAULT = 10.0, 8.0
 SIZEY1

SIZEX2 Lengths of axes for option 2 only - DEFAULT = 1.0, 4.0 (note
 SIZEY2 that SIZEY2 is included for completeness only, the value cannot
 be changed)

AMPMAX Maximum value of amplitude to be plotted in dB above 1 μ V/m for
 options 1 and 4 - DEFAULT = 70.0

AMPMIN Minimum value of amplitude to be plotted - DEFAULT = -10.0

AMPINC Tic mark intervals for amplitude axis in dB - DEFAULT = 10.0

PHSMAX Maximum positive phase excursion to be plotted in degrees for
 options 1 and 4 - DEFAULT = 360.0

PHSMIN Maximum negative phase excursion to be plotted - DEFAULT =
 -360.0

PHSINC Tic mark intervals for phase axis in degrees - DEFAULT = 90.0

DMAX Maximum distance of plot axis in Mm for options 1 and 4 -
 DEFAULT = 10.0

DMIN Minimum distance in Mm - DEFAULT = 0.0

XINC Tic mark intervals for distance axis in Mm - DEFAULT = 1.0

TOTAPE Integer flag for writing calculated fields to logical unit 2
 = 0 deletes output - DEFAULT
 = 1 generates output

TLONG Transmitter longitude (written to logical unit 2 when TOTAPE = 1) - DEFAULT = 0.0

TLAT Transmitter latitude (written to logical unit 2 when TOTAPE = 1) - DEFAULT = 0.0

RBEAR Geographic bearing from transmitter to receiver (written to unit 2 when TOTAPE = 1) - DEFAULT = 0.0

After reading the NAMELIST the program reads the next control card.

DATA Signals that the propagation path data follow. The format of these data is that which is produced by reference 7. The first card contains the data set identification. This card is used to supply a literal path description such as "HAWAII TO WAKE". This is followed by sets of mode constants, one for each path segment. The first card for each segment contains the starting distance (ρ), frequency (f), magnetic azimuth, codip and intensity, ground conductivity (σ), dielectric constant (ϵ/ϵ_0), and the nominal height of the free-space portion of the waveguide (h). Of these parameters, ρ , f , σ , and ϵ/ϵ_0 must appear. The magnetic parameters and h are included for reference. This card is followed by the mode constants, one pair for each mode, containing the following information:

1 θ T_1 T_2
 2 θ T_3 T_4

where 1 and 2 are sequencing indices, θ is the complex eigen-angle at the ground, and T_s are complex constants described below.

$$T_1 = \frac{s^{1/2} (1 + \bar{R}_{\parallel})^2 (1 - R_{\perp} \bar{R}_{\perp})}{F'(0_j) \bar{R}_{\parallel} D_{\parallel}} \quad (26)$$

$$T_2 = \frac{S^{1/2} (1 + \frac{\bar{R}_1}{1 \ 1})^2 (1 - \frac{R_1}{1 \ 1} \frac{\bar{R}_1}{1 \ 1})}{F'(\theta_j) \frac{\bar{R}_1}{1 \ 1} D_{22}} \quad (27)$$

$$T_3 = \frac{S^{1/2} (1 + \frac{\bar{R}_1}{1 \ 1}) (1 + \frac{\bar{R}_1}{1 \ 1}) \frac{R_1}{1 \ 1}}{F'(\theta_j) D_{12}} \quad (28)$$

$$T_4 = \frac{\frac{R_1}{1 \ 1}}{\frac{R_1}{1 \ 1}} \quad (29)$$

In terms of the T s the elements of table 1 are given as:

$$(\lambda_{ij}) = \begin{pmatrix} T_1^2 S & -T_3 S & T_1 S \\ -T_3 T_4 S & T_2 & -T_3 T_4 \\ -T_1 S & T_3 & -T_1 \end{pmatrix} \quad (30)$$

The list of modes for each segment is terminated by a blank card. A maximum of 30 modes will be used although there is no maximum number which the data deck may contain. The list of segments is terminated by a card with $\rho = 40$. Parameters for each segment are stored sequentially on logical file 3. The number of path segments is limited by the space allocated to this file. Each segment requires 1445 words of storage. After reading these data the program returns for another control card if the option is 1 or 2. If the option is 4, then the program generates the required calculations. Upon completion of these calculations, the program returns to read the next data set starting with the data set identification card. This cycle continues until NRDATA sets have been processed.

START Signals that all input is complete and initiates execution for options 1 and 2.

A sample of how the control cards may be used is shown in figure 3.

SPECIAL CONSIDERATIONS

The maximum value of NRCURV is 4 and the maximum number of modes is 30. If either of these values is exceeded, a message is printed and execution continues using the maximum value.

Option 1: Calculations all begin at the transmitter and end at DMAX. DMAX, DMIN, and XINC are used for the horizontal axis scaling.

Option 2: Scaling for amplitude and phase is done automatically. The range on the horizontal axis is 0° to 360° in orbit angle. If RADIUS = 0.0, only the rotating dipole calculations are made for counterclockwise rotation.

Option 4: NAMELIST input (specifying option 4 and NRDATA) must precede the DATA card. Each set of mode constants must be preceded by an identification card and not by a DATA card. Calculations all begin at transmitter and end at DMAX using the first value of INCL and THETA in each list.

TOTAPE = 1: Unit 2 receives the 500 values of the mode sum as single precision complex values, freq, TLONG, TLAT, RBEAR, POWER, INCL, THETA, TALT, RALT, DMIN, and DMAX (in that order). The output is written in unformatted form.

The procedure for using homogeneous sections along a path is to include a single card in the form 'R XX.XXX' after the appropriate segment data. This indicates that the previous set of mode constants are to be used at the distance given by XX.XXX on the card. As a special case, when running the program for the case of a horizontally homogeneous waveguide, mode constant data are input at 'R 0.0'. This is followed by a single card in the format 'R XX.XXX' where XX.XXX is the value of DMAX. Furthermore, the program allows for an instantaneous change in path mode constants. This is accomplished by using the same value of ρ for two consecutive sets of mode constants. This is used for minimizing the discrepancies generated by the program when the WKB assumption is violated, such as for large changes in ground conductivity. An example of the horizontally homogeneous sections is shown in the sample data set of figure 3.

```

1  NAME
2  &DATUM
3  IOPT=1,
4  INCL=0.,90., THETA=0.,90., NRA=2,
5  SIZEX=5., SIZEY=4.,
6  &END
7  DATA
8  TEST DATA
9  R 0.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
10 1 90.0 0.0 1 0.0 -4.70745100-002 0.0 -4.70745100-002
11 2 90.0 0.0 1 0.0 -2.35372600-002 1.0 0.0
12 1 81.93069 0.0 1 1.38439500-002-1.90354300-002 1.38439500-002-1.90354300-002
13 2 81.93069 0.0 1 6.92197500-003-9.51771500-003 1.0 0.0
14
15 R 5.0
16 R 5.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
17 1 90.0 0.0 1 0.0 -4.70745100-003 0.0 -4.70745100-003
18 2 90.0 0.0 1 0.0 -2.35372600-003 1.0 0.0
19 1 81.93069 0.0 1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
20 2 81.93069 0.0 1 6.92197500-004-9.51771500-004 1.0 0.0
21
22 R 10.0
23 R 40.
24 START
25 NAME
26 &DATUM
27 ICOMP=2,
28 NPLOT=1,
29 INCL=0.,90.,90.,THETA=0.,0.,90.,NRA=3,NRCURV=3,
30 &END
31 START
32 NAME
33 &DATUM
34 ICOMP=1,
35 IOPT=2,
36 INCL=45.,
37 DIST=4.9,5.1, NRD=2,
38 &END
39 START
40 NAME
41 &DATUM IOPT=4,NRDATA=2,NPLOT=0,&END
42 DATA
43 TEST DATA
44 R 0.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
45 1 90.0 0.0 1 0.0 -4.70745100-002 0.0 -4.70745100-002
46 2 90.0 0.0 1 0.0 -2.35372600-002 1.0 0.0
47 1 81.93069 0.0 1 1.38439500-002-1.90354300-002 1.38439500-002-1.90354300-002
48 2 81.93069 0.0 1 6.92197500-003-9.51771500-003 1.0 0.0
49
50 R 5.0
51 R 5.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
52 1 90.0 0.0 1 0.0 -4.70745100-003 0.0 -4.70745100-003
53 2 90.0 0.0 1 0.0 -2.35372600-003 1.0 0.0
54 1 81.93069 0.0 1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
55 2 81.93069 0.0 1 6.92197500-004-9.51771500-004 1.0 0.0
56
57 R 10.0
58 R 40.
59 TEST DATA WITH ALL AMPLITUDES REDUCED BY FACTOR OF 10
60 R 0.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
61 1 90.0 0.0 1 0.0 -4.70745100-003 0.0 -4.70745100-003
62 2 90.0 0.0 1 0.0 -2.35372600-003 1.0 0.0
63 1 81.93069 0.0 1 1.38439500-003-1.90354300-003 1.38439500-003-1.90354300-003
64 2 81.93069 0.0 1 6.92197500-004-9.51771500-004 1.0 0.0
65
66 R 5.0
67 R 5.0 F 10.0 A 0.0 C 0.0 M 0.0 S 10.0 E 0.0
68 1 90.0 0.0 1 0.0 -4.70745100-004 0.0 -4.70745100-004
69 2 90.0 0.0 1 0.0 -2.35372600-004 1.0 0.0
70 1 81.93069 0.0 1 1.38439500-004-1.90354300-004 1.38439500-004-1.90354300-004
71 2 81.93069 0.0 1 6.92197500-005-9.51771500-005 1.0 0.0
72
73 R 10.0
74 R 40.

```

↑ Card column 1

Figure 3. Sample data deck

In order to facilitate mode matching across segment boundaries, a missing mode can be indicated by a pair of filler cards inserted in the deck where the mode would have appeared. This pair of cards must contain a non-zero eigen-angle value. Typically the eigenangle is the value from some previous segment which had the mode. The rest of each of the cards is blank.

EXAMPLE DATA

The data listed in figure 3 exercise the program in most of its options. The test data are fictitious. There are only two modes; their attenuation rate, phase velocity relative to the speed of light, and complex excitation factor Λ_{zz} are given in table 2.

Mode	Attenuation Rate dB/Mm	Phase velocity/c	$ \Lambda_{zz} $ dB	ϕ_{zz} in degrees
1	0	1.00	0	0
2	0	1.01	-6	36

Table 2. Test data mode parameters

These modes produce interference minima at 3 Mm intervals. The values of the T_s of equations 28-31 are defined such that $\Lambda_{zz} = \Lambda_{yy} = \Lambda_{xx} = \Lambda_{xz} = \Lambda_{zx}$ and $\Lambda_{yz} = \Lambda_{zy} = \Lambda_{xy} = \Lambda_{yx} = \frac{1}{2} \Lambda_{zz}$ for each mode. Thus, a horizontal broadside antenna produces fields which are the same amplitude as produced by a vertical antenna. In figure 3, lines 1-6 are the NAMELIST input data specifying two transmitting antenna orientations: vertical and horizontal broadside. Lines 7-23 are the propagation path constants. Lines 15 and 22 illustrate the use of horizontally homogeneous segments. The first two pages of output for the calculations specified in lines 1-24 are shown in figures 4 and 5. In figure 4 we see the list of segment parameter cards after the control card DATA. After the control card START we see a listing of the mode parameters for each

```

NAME
SDATUM
IOPT =
TLONG = .00000000 ,TLAT = .00000000 ,RALT = .00000000 ,POWER = .10000000+001,TOAPE = 0,
SIZEY2 = .10000000+001,SIZEY1 = .80000000+001,SIZEY2 = .40000000+001,AMPMAX = .70000000+002,AMPMIN = -.10000000+002,
AMPINC = .10000000+002,PHSMAX = .36000000+003,PHSMIN = -.36000000+003,PHSINC = .90000000+002,DMAX = .10000000+002,
DMIN = .00000000 ,XINC = .10000000+001,NRCURV = 4,NPRINT = 1,NAPLOT = 1,NPLOT = 0,
NPDIFF = 0,RADIUS = .00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
DIST = .10000000+001,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
INCL = .00000000 ,.90000000+002,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
THETA = .00000000 ,.90000000+002,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
SEND
DATA

```

TEST DATA

```

R .000 F 10.000 A .000 C .000 M .000 S 1.000+001 E .0 MODES 2

```

```

R 5.000 F .0000 A .000 C .000 M .000 S .000 E .0

```

USING DATA FROM PREVIOUS RHO

```

R 5.000 F 10.000 A .000 C .000 M .000 S 1.000+001 E .0 MODES 2

```

```

R 10.000 F .0000 A .000 C .000 M .000 S .000 E .0

```

USING DATA FROM PREVIOUS RHO

START

Z COMPONENT OPTION 1

RHO =	.000	MODE	ATTEN	V/C	VERTICAL	BROADSIDE	END FIRE	V	B	E
RHO = .000	1	.000	1.00000	.000	-2.691 .000	-8.712 3.142	-75.238 -2.356	-2.69	-8.71	-75.24
	2	.000	1.01000	.629	-8.885 .629	-14.819 -2.513	-81.345 -1.727	-8.88	-14.82	-81.35
RHO = 5.000	1	.000	1.00000	.000	-2.691 .000	-8.712 3.142	-75.238 -2.356	-2.69	-8.71	-75.24
	2	.000	1.01000	.629	-8.885 .629	-14.819 -2.513	-81.345 -1.727	-8.88	-14.82	-81.35
RHO = 5.000	1	.000	1.00000	.000	-22.691 .000	-28.712 3.142	-95.238 -2.356	-12.69	-18.71	-85.24
	2	.000	1.01000	.629	-28.885 .629	-34.819 -2.513	-101.345 -1.727	-18.88	-24.82	-91.35
RHO = 10.000	1	.000	1.00000	.000	-22.691 .000	-28.712 3.142	-95.238 -2.356	-12.69	-18.71	-85.24
	2	.000	1.01000	.629	-28.885 .629	-34.819 -2.513	-101.345 -1.727	-18.88	-24.82	-91.35

Figure 4. First page of output produced by lines 1-24 of sample deck

Z COMP	INCL	THETA	0.000	TILT	0.000	RALT	0.0	DIST	AMPLITUDE	PHASE	DIST	AMPLITUDE	PHASE
.000	104.7406	.0000	2.520	54.1079	82.0440	5.040	39.3953	64.9618	7.560	33.4001	64.8874	33.4001	64.8874
.020	71.7357	102.4070	2.540	54.1079	82.8111	5.060	39.5119	65.4817	7.580	33.6268	64.0587	33.6268	64.0587
.040	71.6690	103.1432	2.560	54.1047	83.5812	5.080	39.6241	66.0210	7.600	33.8539	63.3351	33.8539	63.3351
.060	69.8481	103.8734	2.580	54.0985	84.3539	5.100	39.7320	66.5785	7.620	34.0802	62.7111	34.0802	62.7111
.080	68.5352	104.5970	2.600	54.0892	85.1289	5.120	39.8356	67.1530	7.640	34.3050	62.1809	34.3050	62.1809
.100	67.4988	105.3135	2.620	54.0768	85.9059	5.140	39.9350	67.7436	7.660	34.5274	61.7391	34.5274	61.7391
.120	66.6361	106.0225	2.640	54.0614	86.6846	5.160	40.0303	68.3492	7.680	34.7470	61.3800	34.7470	61.3800
.140	65.8921	106.7233	2.660	54.0429	87.4645	5.180	40.1216	68.9689	7.700	34.9631	61.0985	34.9631	61.0985
.160	65.2338	107.4155	2.680	54.0214	88.2455	5.200	40.2087	69.6018	7.720	35.1755	60.8894	35.1755	60.8894
.180	64.6401	108.0984	2.700	53.9968	89.0272	5.220	40.2920	70.2472	7.740	35.3837	60.7480	35.3837	60.7480
.200	64.0965	108.7713	2.720	53.9692	89.8092	5.240	40.3713	70.9041	7.760	35.5876	60.6698	35.5876	60.6698
.220	63.5926	109.4337	2.740	53.9385	90.5913	5.260	40.4467	71.5720	7.780	35.7869	60.6504	35.7869	60.6504
.240	63.1209	110.0848	2.760	53.9047	91.3732	5.280	40.5184	72.2501	7.800	35.9816	60.6859	35.9816	60.6859
.260	62.6754	110.7239	2.780	53.8679	92.1546	5.300	40.5863	72.9378	7.820	36.1714	60.7726	36.1714	60.7726
.280	62.2516	111.3501	2.800	53.8281	92.9351	5.320	40.6504	73.6345	7.840	36.3564	60.9071	36.3564	60.9071
.300	61.8459	111.9627	2.820	53.7851	93.7144	5.340	40.7109	74.3395	7.860	36.5364	61.0860	36.5364	61.0860
.320	61.4553	112.5607	2.840	53.7391	94.4922	5.360	40.7678	75.0524	7.880	36.7115	61.3065	36.7115	61.3065
.340	61.0776	113.1432	2.860	53.6899	95.2682	5.380	40.8210	75.7727	7.900	36.8817	61.5658	36.8817	61.5658
.360	60.7106	113.7092	2.880	53.6377	96.0421	5.400	40.8707	76.4997	7.920	37.0470	61.8612	37.0470	61.8612
.380	60.3526	114.2575	2.900	53.5823	96.8135	5.420	40.9169	77.2330	7.940	37.2073	62.1905	37.2073	62.1905
.400	60.0023	114.7870	2.920	53.5237	97.5822	5.440	40.9596	77.9723	7.960	37.3629	62.5513	37.3629	62.5513
.420	59.6583	115.2965	2.940	53.4620	98.3476	5.460	40.9988	78.7170	7.980	37.5136	62.9416	37.5136	62.9416
.440	59.3197	115.7846	2.960	53.3971	99.1095	5.480	41.0347	79.4666	8.000	37.6596	63.3596	37.6596	63.3596
.460	58.9854	116.2498	2.980	53.3289	99.8676	5.500	41.0671	80.2210	8.020	37.8008	63.8034	37.8008	63.8034
.480	58.6547	116.6907	3.000	53.2575	100.6214	5.520	41.0951	80.9795	8.040	37.9375	64.2714	37.9375	64.2714
.500	58.3268	117.1055	3.020	53.1829	101.3705	5.540	41.1218	81.7418	8.060	38.0695	64.7620	38.0695	64.7620
.520	58.0010	117.4925	3.040	53.1049	102.1146	5.560	41.1441	82.5077	8.080	38.1971	65.2739	38.1971	65.2739
.540	57.6768	117.8497	3.060	53.0236	102.8531	5.580	41.1631	83.2766	8.100	38.3202	65.8057	38.3202	65.8057
.560	57.3537	118.1751	3.080	52.9390	103.5858	5.600	41.1788	84.0484	8.120	38.4389	66.3562	38.4389	66.3562
.580	57.0312	118.4665	3.100	52.8509	104.3125	5.620	41.1913	84.8225	8.140	38.5533	66.9241	38.5533	66.9241
.600	56.7090	118.7213	3.120	52.7594	105.0314	5.640	41.2004	85.5988	8.160	38.6634	67.5085	38.6634	67.5085
.620	56.3866	118.9371	3.140	52.6644	105.7434	5.660	41.2063	86.3768	8.180	38.7694	68.1083	38.7694	68.1083
.640	56.0637	119.1110	3.160	52.5659	106.4475	5.680	41.2090	87.1563	8.200	38.8712	68.7225	38.8712	68.7225
.660	55.7402	119.2401	3.180	52.4638	107.1432	5.700	41.2084	87.9369	8.220	38.9689	69.3503	38.9689	69.3503
.680	55.4157	119.3210	3.200	52.3581	107.8298	5.720	41.2046	88.7183	8.240	39.0626	69.9908	39.0626	69.9908
.700	55.0902	119.3503	3.220	52.2488	108.5067	5.740	41.1975	89.5002	8.260	39.1523	70.6432	39.1523	70.6432
.720	54.7635	119.3242	3.240	52.1357	109.1734	5.760	41.1872	90.2824	8.280	39.2381	71.3069	39.2381	71.3069
.740	54.4356	119.2388	3.260	52.0189	109.8290	5.780	41.1737	91.0644	8.300	39.3201	71.9811	39.3201	71.9811
.760	54.1065	119.0897	3.280	51.8982	110.4729	5.800	41.1569	91.8460	8.320	39.3982	72.6650	39.3982	72.6650
.780	53.7762	118.8724	3.300	51.7737	111.1043	5.820	41.1369	92.6269	8.340	39.4726	73.3582	39.4726	73.3582
.800	53.4451	118.5820	3.320	51.6452	111.7224	5.840	41.1137	93.4067	8.360	39.5432	74.0601	39.5432	74.0601
.820	53.1133	118.2136	3.340	51.5128	112.3263	5.860	41.0872	94.1851	8.380	39.6102	74.7699	39.6102	74.7699
.840	52.7812	117.7617	3.360	51.3763	112.9151	5.880	41.0574	94.9619	8.400	39.6735	75.4873	39.6735	75.4873
.860	52.4493	117.2209	3.380	51.2356	113.4877	5.900	41.0244	95.7367	8.420	39.7332	76.2117	39.7332	76.2117
.880	52.1182	116.5855	3.400	51.0908	114.0431	5.920	40.9881	96.5091	8.440	39.7894	76.9426	39.7894	76.9426
.900	51.7888	115.8499	3.420	50.9417	114.5802	5.940	40.9484	97.2789	8.460	39.8420	77.6796	39.8420	77.6796
.920	51.4618	115.0085	3.440	50.7884	115.0978	5.960	40.9055	98.0456	8.480	39.8911	78.4222	39.8911	78.4222
.940	51.1386	114.0559	3.460	50.6306	115.5945	5.980	40.8592	98.8090	8.500	39.9368	79.1699	39.9368	79.1699
.960	50.8204	112.9874	3.480	50.4684	116.0689	6.000	40.8096	99.5686	8.520	39.9790	79.9224	39.9790	79.9224
.980	50.5086	111.7986	3.500	50.3017	116.5196	6.020	40.7566	100.3241	8.540	40.0178	80.6794	40.0178	80.6794
1.000	50.2052	110.4865	3.520	50.1304	116.9449	6.040	40.7002	101.0752	8.560	40.0532	81.4402	40.0532	81.4402
1.020	49.9120	109.0490	3.540	49.9545	117.3431	6.060	40.6403	101.8213	8.580	40.0852	82.2048	40.0852	82.2048
1.040	49.6311	107.4860	3.560	49.7739	117.7123	6.080	40.5770	102.5621	8.600	40.1139	82.9725	40.1139	82.9725
1.060	49.3648	105.7993	3.580	49.5885	118.0506	6.100	40.5102	103.2971	8.620	40.1393	83.7432	40.1393	83.7432
1.080	49.1156	103.9932	3.600	49.3984	118.3556	6.120	40.4399	104.0259	8.640	40.1613	84.5164	40.1613	84.5164

Figure 5. Second page of output produced by lines 1-24 of sample deck

segment. The headings "VERTICAL", "BROADSIDE", and "END FIRE" are for the magnitude in dB and phase in radians of the components of the excitation factors. The headings "V", "B", and "E" are for the relative magnitude of these components at the beginning of each slab. This list appears only when ICOMP, TALT, RALT, or the mode parameters are changed. In figure 5 we see the list of computed amplitude in dB above 1 V/m and phase relative to the speed of light in degrees printed as functions of distance in Mm. This list is preceded by a line of print indicating the received field component, the transmitting antenna orientation, and the altitudes of the transmitter and receiver. The plots for these calculations are shown in figure 6.

Lines 25-31 of figure 3 call for the E_y fields and phase plots. Three transmitting antenna orientations are specified. The resulting plots of the amplitude and relative phase are shown in figures 7a and 7b, respectively. There are apparently only two curves in figure 7a because the amplitude of E_y from a vertical source is the same as that from a horizontal end-fire source.

Lines 32-39 of figure 3 call for a rotating transmitter antenna inclined at 45° . The calculations are to be made for two distances. The first page of printout generated by these lines is shown in figure 8. The mean signal and the standard deviation of the signal for the rotation are printed at each distance. The table of amplitude and relative phase as a function of rotation angle, R , appears as a result of $NPRINT = 1$. The plots resulting from the calculations are shown in figure 9.

Lines 40-74 of figure 3 illustrate the $IOPT = 4$ option. The plots resulting from these calculations are shown in figure 10.

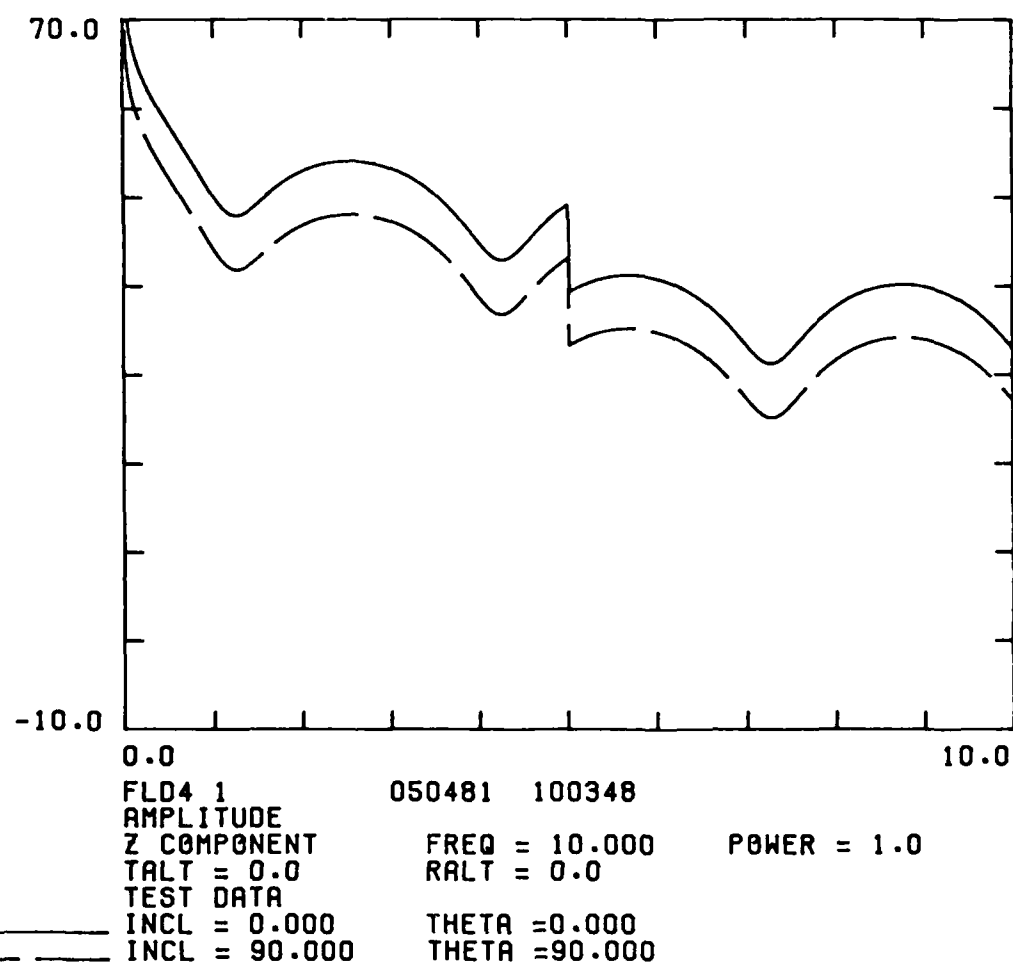


Figure 6. Plotted output generated by lines 1-24 of the sample deck

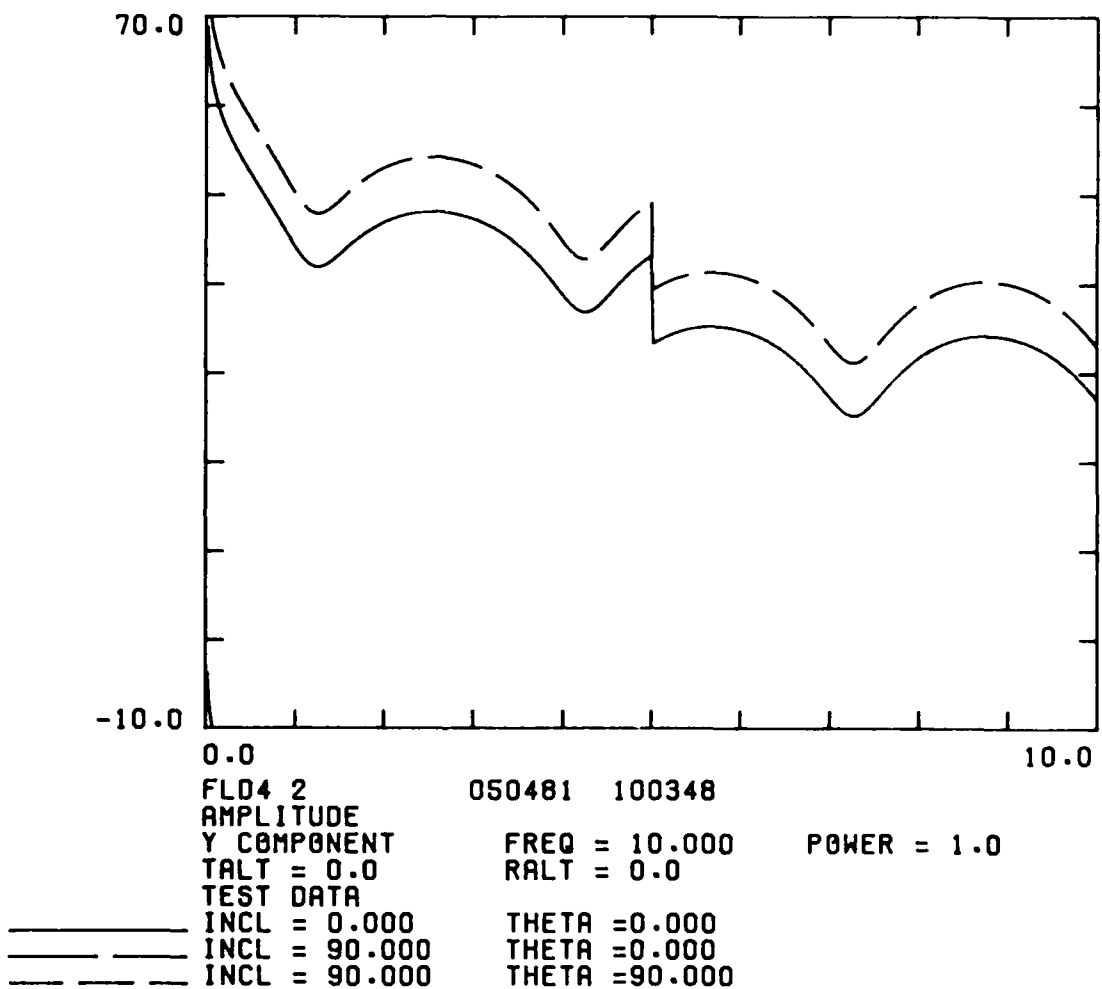


Figure 7a. Plotted amplitude output generated by lines 25-31 of the sample doc:

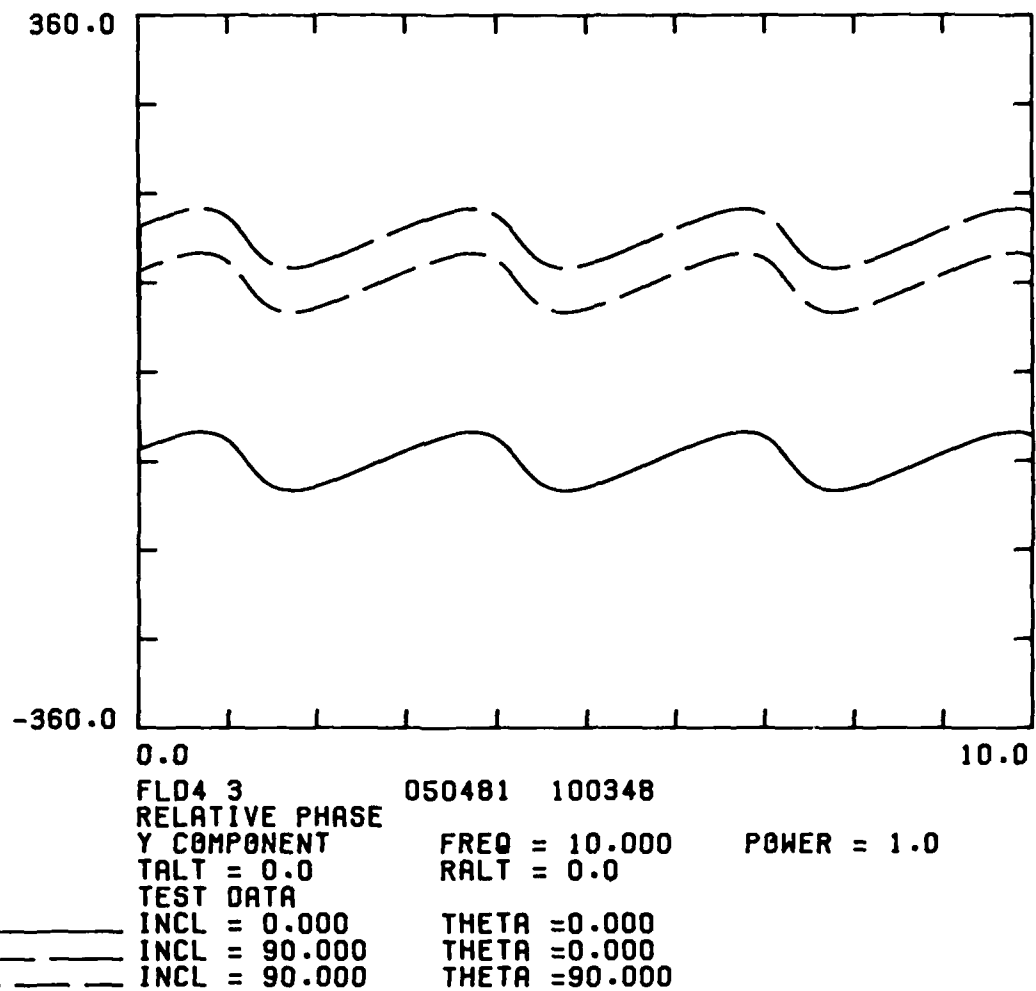


Figure 7b. Plotted relative phase output generated by lines 25-31 of the sample deck

```

NAME
$DATUM
10PT = .00000000 ,TALT = .00000000 ,RALT = .00000000 ,POWER = .10000000+001,TOTAPE = 0,
TLONG = .00000000 ,TLAT = .00000000 ,RBEAR = .00000000 ,SIZEZ = -.10000000+001,SIZEY = -.10000000+001,SIZEX = .50000000+001,
SIZEZ2 = .10000000+001,SIZEY1 = .40000000+001,SIZEY2 = .40000000+001,AMPMAX = .70000000+002,AMPMIN = -.10000000+002,
AMPINC = .10000000+002,PHSMAX = .36000000+003,PHSMIN = -.36000000+003,PHSINC = .90000000+002,DMAX = .10000000+002,
DMIN = .00000000 ,XINC = .10000000+001,NRCURV = 3,NPRINT = 1,NAPLOT = 1,NPPLOT = 1,
NPDIFF = 0,RADIUS = .00000000,
DIST = .49000000+001,.51000000+001,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
INCL = .45000000+002,.90000000+002,.90000000+002,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
THETA = .00000000 ,.00000000 ,.00000000 ,.90000000+002,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,.00000000 ,
$END

```

START

Z COMPONENT OPTION 2

```

Z COMP DIST = 4.900 INCL = 45.000
Z THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE
.000 45.4393 61.9779 95.000 39.4417 62.2505 190.000 46.1663 61.9750 285.000 48.8670 61.9001
5.000 45.0517 61.9895 100.000 39.5402 62.2462 195.000 46.5004 61.9654 290.000 48.7897 61.9012
10.000 44.6492 62.0022 105.000 39.7009 62.2382 200.000 46.8149 61.9567 295.000 48.6903 61.9027
15.000 44.2337 62.0160 110.000 39.9193 62.2269 205.000 47.1091 61.9487 300.000 48.5689 61.9047
20.000 43.8077 62.0309 115.000 40.1894 62.2130 210.000 47.3824 61.9414 305.000 48.4254 61.9072
25.000 43.3741 62.0470 120.000 40.5045 62.1969 215.000 47.6345 61.9349 310.000 48.2600 61.9102
30.000 42.9364 62.0642 125.000 40.8573 62.1793 220.000 47.8652 61.9290 315.000 48.0727 61.9138
35.000 42.4987 62.0823 130.000 41.2404 62.1608 225.000 48.0742 61.9237 320.000 47.8635 61.9179
40.000 42.0659 62.1013 135.000 41.6466 62.1418 230.000 48.2614 61.9190 325.000 47.6327 61.9228
45.000 41.6434 62.1210 140.000 42.0692 62.1228 235.000 48.4266 61.9149 330.000 47.3804 61.9282
50.000 41.2373 62.1409 145.000 42.5021 62.1042 240.000 48.5699 61.9113 335.000 47.1069 61.9344
55.000 40.8544 62.1608 150.000 42.9398 62.0861 245.000 48.6912 61.9082 340.000 46.8126 61.9414
60.000 40.4872 62.1801 155.000 43.3774 62.0689 250.000 48.7904 61.9056 345.000 46.4980 61.9491
65.000 40.1872 62.1983 160.000 43.8110 62.0525 255.000 48.8675 61.9035 350.000 46.1636 61.9578
70.000 39.9174 62.2147 165.000 44.2369 62.0371 260.000 48.9226 61.9018 355.000 45.8104 61.9673
75.000 39.6995 62.2287 170.000 44.6523 62.0227 265.000 48.9557 61.9006 360.000 45.4393 61.9779
80.000 39.5392 62.2397 175.000 45.0548 62.0093 270.000 48.9666 61.8998
85.000 39.4412 62.2472 180.000 45.4423 61.9970 275.000 48.9555 61.8995
90.000 39.4084 62.2508 185.000 45.8132 61.9855 280.000 48.9223 61.8996

```

```

DIST MEAN A STD
4.900 44.845 3.328

```

```

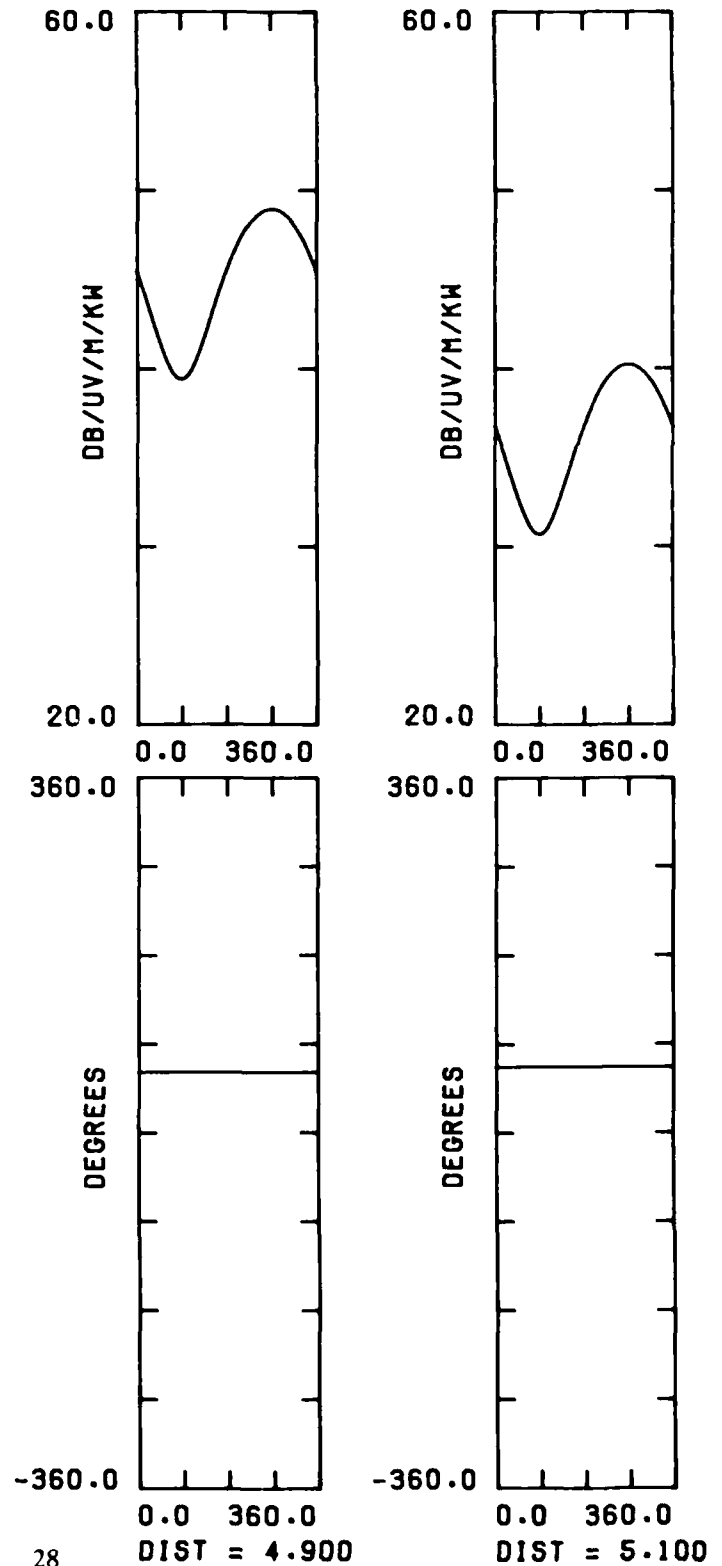
Z COMP DIST = 5.100 INCL = 45.000
Z THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE THETA AMPLITUDE PHASE
.000 36.7202 66.5690 95.000 30.7138 66.7683 190.000 37.4479 66.5721 285.000 40.1508 66.5154
5.000 36.3322 66.5773 100.000 30.8125 66.7657 195.000 37.7823 66.5651 290.000 40.0734 66.5160
10.000 35.9293 66.5863 105.000 30.9736 66.7604 200.000 38.0971 66.5586 295.000 39.9740 66.5169
15.000 35.5133 66.5961 110.000 31.1924 66.7527 205.000 38.3915 66.5528 300.000 39.8524 66.5182
20.000 35.0868 66.6068 115.000 31.4630 66.7430 210.000 38.6650 66.5474 305.000 39.7089 66.5198

```

Figure 8. First page of printout generated by lines 32-39 of the sample deck

FLD4 4 050481 100348
 TEST DATA
 Z COMPONENT
 FREQ = 10.000 POWER = 1.0
 T ALT = 0.0 R ALT = 0.0
 INCL = 45.000
 RADIUS = 0.0000

Figure 9. Plotted output
 generated by lines 32-39 of
 the sample deck



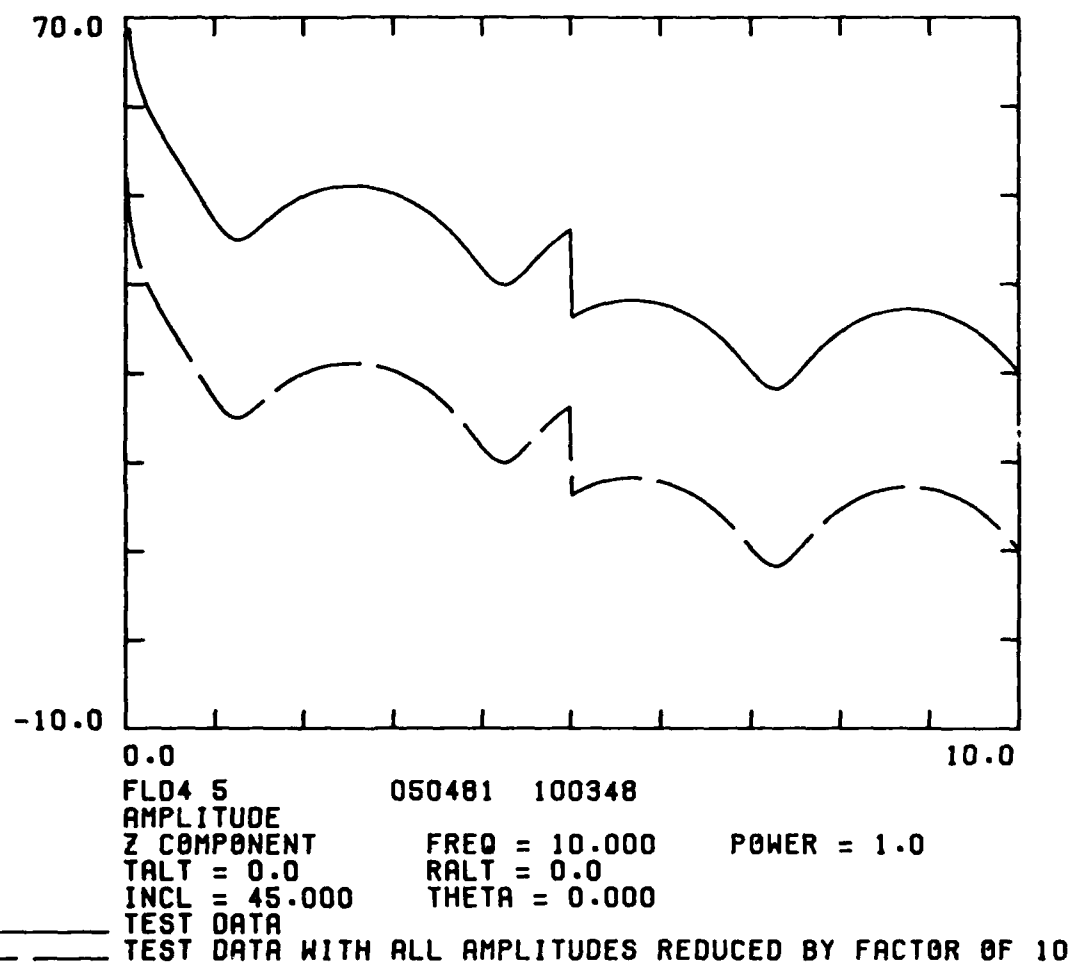


Figure 10. Plotted output generated by lines 40-74 of the sample deck

REFERENCES

1. NELC Interim Report 713, WKB Mode Summing Program for VLF/LF Antennas of Arbitrary Length, Shape, and Elevation, by RA Pappert and LR Shockey, 1971, NTIS, AD728414, Springfield, VA
2. Budden, KG, The Waveguide Mode Theory of Wave Propagation, Logos Press, London, 1961
3. Wait, JR, Electromagnetic Waves in Stratified Media, Macmillan, New York, 1962
4. Galejs, J, Terrestrial Propagation of Long Electromagnetic Waves, Pergamon Press, Oxford, 1972
5. NELC Interim Report 683, A Fortran Program for Mode Constants in an Earth-Ionosphere Waveguide, by CH Sheddy, RA Pappert, Y Gough, and WF Moler, 1968
6. Defense Atomic Support Agency Interim Report 702, A FORTRAN Program for Waveguide Propagation Which Allows for Both Vertical and Horizontal Dipole Excitation, by RA Pappert, WF Moler, and LR Shockey, 1970
7. NELC Interim Report 77T, MODESRCH, an Improved Computer Program for Obtaining ELF/VLF/LF Mode Constants, by DG Morfitt, and CH Shellman, 1976, NTIS, ADA032573, Springfield, VA
8. Wait, JR, Two-dimensional Treatment of Mode Theory of the Propagation of VLF Radio Waves, Radio Science Journal of Research, NBS/USNC-URSI Vol 68D, No 1, 1964
9. Computation Laboratory Staff at Cambridge, MA, Tables of the Modified Hankel Function of Order One-Third and of Their Derivatives, Harvard University Press, Cambridge, MA, 1945

APPENDIX: PROGRAM LISTING

```

C
C
C      FLDA:   WKB MODE SUM
C
C      COMMON/INPUT/STP(30),TP(30),AV(30),EX(3,3,30),EK,ALPHA,SIGMA,EPSR,
C          $      MODS,RHO
C      COMMON/DNE/RHOMAX,RHOD,NEWD,NEWHT,NEWHGR,NEWIP
C      COMMON/TDET/ID(20),FREQ,TALT,RALT,ICOMP,ZYX,IOP,THTA,INCANG,DST,
C          $      RADIUS,POWER
C      COMMON/DIMER/XLNG,YLNG,AMPMAX,AMPMIN,AMPINC,PMSMAX,PHSMIN,
C          $      PHINC,DMAX,DMIN,XINC,TMAX,TMIN,TINC,
C          $      NRCURV,NAPLOT,NPPLOT,NPOIFF,NPRINT
C      COMMON/OUTPUT/XY(501),AMP(501),PHS(501),NRPTS,NRCRV,NRPLTS,
C          $      DATE,TIME
C      COMMON NMODE(30)
C
C      COMPLEX*16 TP,STP,AV,EX,MIX,RATIO,TMP1,TMP2,TMP3,TMP4
C      COMPLEX* 8 SUMOUT
C      REAL*8 DTR/1.74539252D-2/,ALPHA/3.14D-4/,SIGMA,EPSR,
C          $      SC,SINIO,COSIO,CC
C      REAL*4 INCL,INCANG,MAGFLD
C      INTEGER TOTAPE,O/
C      LOGICAL NOMODE
C      CHARACTER*8 DATE,TIME
C      CHARACTER*4 BCD,NAME,INPT,EXEC,ENDF
C      CHARACTER LABEL,ZYX
C
C      DIMENSION BCD(20),LABEL(3),RATIO(4),SUMOUT(501),
C          $      DIST(20),INCL(20),THETA(20),SINT(73),SC(3,73)
C
C      NAMELIST/DATUM/IOP,T,ICOMP,TALT,RALT,POWER,TOTAPE,TLONG,TLAT,RBEAR,
C          $      SIZEZ,SIZEY,
C          $      SIZEX1,SIZEX2,SIZEY1,SIZEY2,AMPMAX,AMPMIN,AMPINC,PMSMAX,
C          $      PHSMIN,PHSINC,DMAX,DMIN,XINC,NRCURV,NPRINT,NAPLOT,
C          $      NPLOT,NPOIFF,RADIUS,DIST,NRD,INCL,THETA,NRA,NRDATA
C
C      ...COMMON INITIALIZATION
C      DATA AMPMAX/70.,AMPMIN/-10.,PHSMAX/360.,PHSMIN/-360./
C      DATA DMAX/10.,DMIN/0.,TMAX/360.,TMIN/0./
C      DATA TALT,RALT/0.,0.,ICOMP/1.,RADIUS/O.,POWER/1./
C      DATA NRCURV/4.,NAPLOT/1.,NPLOT/O.,NPOIFF/O/
C      DATA NPRINT/1/
C      DATA AMPINC/10.,PHSINC/90.,XINC/1./
C      DATA ICOMP/O.,NRCRV/O.,NRPLTS/O.,NEWD/-1/
C
C      DATA INPT/4HDATA/,NAME/4HNAME/,EXEC/4HSTAR/,ENDF/4HENDF/,
C          $      LABEL/'Z','Y','X','X',STATL,SRALT/2*-1./,IOP/1/,NRDATA/1/,
C          $      SIZEZ /-1./,SIZEY /-1./,
C          $      SIZEX1/10./,SIZEY1/ 8./,NRPTS1/501/,
C          $      SIZEX2/ 1./,SIZEY2/ 4./,NRPTS2/ 73/,
C          $      DIST,INCL,THETA/1..59*0./,NRD,NRA/2*1/,TLONG,TLAT,RBEAR/3*0./
C
C      CALL ADATE(DATE,TIME)
C      PRINT 999,DATE,TIME
C
C      C...READ AND TEST CONTROL CARD
C      1C      PRINT 1005

```

```

57 11 READ(5,1001,END=990) BCD
58 PRINT 1002,BCD
59 IF(BCD(1)) .EQ. NAME) GO TO 15
60 IF(BCD(1)) .EQ. EXEC) GO TO 30
61 IF(BCD(1)) .EQ. INPT) GO TO 20
62 IF(BCD(1)) .EQ. ENDF) GO TO 56
63 GO TO 910
64
65 C
66 C...READ AND PRINT NAMELIST DATA
67 READ(5,DATUM,END=989)
68 PRINT DATUM
69 IF(INCURV .GT. 4) GO TO 908
70 IF(SIZE .LT. 0.) GO TO 160
71 GO TO (151,152,912,151),IOPT
72 SIZE1=SIZE
73 GO TO 159
74 SIZE2=SIZE
75 SIZE3=SIZE
76 IF(SIZE .LT. 0.) GO TO 170
77 GO TO (161,169,912,161),IOPT
78 SIZE1=SIZE
79 SIZE2=SIZE
80 IF(SIZE1 .GT. 8.) GO TO 913
81 GO TO 11
82
83 C...READ PROPAGATION PATH PARAMETERS
84
85 C...SET COUNTER FOR IOPT=4
86 NDAT=0
87 READ(5,1001,END=989) ID
88 PRINT 1002,ID
89 REWIND 3
90 MNMODE=31
91 NR=0
92 RHO=-1.
93
94 C...READ SEGMENT CONSTANTS
95 READ(5,1020,END=989) R,F,A,C,B,S,E
96 IF(R .EQ. 40.) GO TO 25
97 B=B*10000.
98 PRINT 1021,R,F,A,C,B,S,E
99 IF(NPRINT .LT. 2) GO TO 210
100 PRINT 1221
101 IF(NR .GT. 0) GO TO 22
102 FREQ=F
103 WN=2*PI*FREQ/C
104 WN=20.950445EQ*FREQ
105 MIX=CMPLX(0.,-WN)
106 EK=682.2408*SQRT(FREQ)
107 NR=NR+1
108 IF(RHO .GT. R) GO TO 911
109 RHO=R
110 RHOMAX=R
111 C...CHECK IF THIS IS JUST A RHO CARD - FOR HOMOGENEOUS SEGMENT
112 IF(S .GT. 0.) GO TO 220
113 PT=N*1220
114 GO TO 241

```

```

114 220 SIGMA=S
115 EPSR=E
116 AZIM=A
117 CODIP=C
118 MAGFLD=B
119
120 C
121 C...READ MODE CONSTANTS
122 NM=0
123 READ(5,1023,END=989) INDX1,TR1,TI1,TMP1,TMP2
124 IF(TR1.EQ.0.) GO TO 24
125 NM=NM+1
126 READ(5,1023,END=989) INDX2,TR2,TI2,TMP3,TMP4
127 IF(NPRINT.LT.2) GO TO 223
128 PRINT 1025, NM,INDX1,TR1,TI1,TMP1,TMP2,INDX2,TR2,TI2,TMP3,TMP4
129 IF(TR1.NE.0) GO TO 919
130 IF(INDX1.EQ.INDX2) GO TO 919
131 IF(INDX1.NE.1.AND.INDX1.NE.2) GO TO 919
132 IF(INDX2.NE.1.AND.INDX2.NE.2) GO TO 919
133 C...TEST IF MAXIMUM NUMBER OF MODES EXCEEDED
134 IF(NM.GT.30) GO TO 23
135 TP(NM)=CMPLX(TR1,TI1)
136 STP(NM)=COSIN(TP(NM)*DTR)
137 AV(NM)=NIK*(STP(NM)-1.00)
138 C...TEST FOR MISSING MODE
139 NOMODE(NM)=.FALSE.
140 IF(CDARS(TMP1).NE.0.00) GO TO 230
141 NOMODE(NM)=.TRUE.
142 TMP1=1.D-20
143 TMP2=1.D-20
144 TMP3=1.D-20
145 TMP4=1.D0
146
147 230 RATIO(2,INDX1-1)=TMP1
148 RATIO(2,INDX1)=TMP2
149 RATIO(2,INDX2-1)=TMP3
150 RATIO(2,INDX2)=TMP4
151 C...DEFINE EXCITATION FACTOR MATRIX
152 EX(1,1,NM)= RATIO(1)*STP(NM)**2
153 EX(2,1,NM)= -RATIO(3)*RATIO(4)*STP(NM)
154 EX(3,1,NM)= -RATIO(1)*STP(NM)
155 EX(1,2,NM)= -RATIO(3)*STP(NM)
156 EX(2,2,NM)= RATIO(2)
157 EX(3,2,NM)= RATIO(3)
158 EX(1,3,NM)= RATIO(1)*STP(NM)
159 EX(2,3,NM)= -RATIO(3)*RATIO(4)
160 EX(3,3,NM)= -RATIO(1)
161 GO TO 23
162
163 24 IF(NM.EQ.0) GO TO 909
164 IF(NPRINT.NE.2) PRINT 1026,NM
165 IF(NM.GT.30) OR. NM .GT. MNMODE) PRINT 1014
166
167 241 MODES=MINO(30,NM)
168 MODES=MINO(MODES,MNMODE)
169
170 C
171 C...SAVE SEGMENT DATA
172 WRITE(3) STP,TP,AV,EX,SIGMA,EPSR,RHO,MODES,NOMODE
173 MNMODE=MODES
174 GO TO 21
175
176 25 IF(NR.LE.1) GO TO 915

```

```

171 NEWD=1
172 NDATA=NDATA+1
173 IF(IOPT .EQ. 4) GO TO 30
174 GO TO 11
175
176 IF(NEWD .EQ. -1) GO TO 916
177 ZYX=LABEL(ICOMP)
178 PRINT 1004,ZYX,IOPT
179
180 C...CHECK IF NEW HEIGHT GAIN CALCULATIONS ARE NEEDED
181 NEWP=0
182 IF(ICOMP .EQ. ICOMPS .AND. NEWD .EQ. 0) GO TO 38
183 NEWP=1
184 ICOMPS=ICOMP
185 IF(IALT .EQ. STALT .AND. NEWD .EQ. 0) GO TO 40
186 NEWP=1
187 NEWHGT=1
188 STALT=TALT
189 IF(RALT .EQ. SRALT .AND. NEWD .EQ. 0) GO TO 41
190 NEWP=1
191 NEWHGR=1
192 SRALT=RALT
193
194 C...BRANCH TO OPTION
195 41 GO TO (50,60,912,90),IOPT
196
197 C...FIELDS VS DISTANCE PARAMETRIC IN INCL AND THETA
198 50 NRPTS=NRPTS1
199 XLNG=SIZEKI
200 YLNG=SIZEYI
201 XYMAX=AMIN1(DMAX,RHOMAX)
202 DINC=(XYMAX-DMIN)/(NRPTS-1)
203 XY(1)=DMIN
204 DO 52 J=2,NRPTS
205 XY(J)=XY(J-1)+DINC
206 C...LOOP OVER ANTENNA ORIENTATIONS
207 DO 55 I=1,NRA
208 INCANG=INCL(I)
209 THTA=THETA(I)
210 SC(1,1)=DCOS(INCANG*DTR)
211 SINIO=DSIN(INCANG*DTR)
212 SC(2,1)=SINIO*DSIN(THTA*DTR)
213 SC(3,1)=SINIO*DCOS(THTA*DTR)
214 RHOD=0.
215 C...LOOP OVER DISTANCE
216 DO 54 J=1,NRPTS
217 CALL SUMS(J,XY(J),AMP(J),PHS(J),SUMOUT(J),SC(1,1),0.)
218 CONTINUE
219 NEWP=0
220 NEWD=0
221 NEWHGT=0
222 NEWHGR=0
223 CALL POUT1(I,NRA)
224 IF(TOTAPE .EQ. 1) WRITE(2) SUMOUT,FREQ,TIDONG,TLAT,RBEAR,POWER,
225 $ INCANG,THTA,TALT,RALT,DMIN,XYMAX
226 IF(DMAX .LT. RHOMAX) NEWHGR=1
227 GO TO 10

```

```

228 50 IF(TOTAPE .EQ. 1) END FILE 2
229 GO TO 1;
230 C
231 C...FIELDS VS THETA PARAMETRIC IN DISTANCE
232 60 NRPTS=NRPTS2
233 XLNG=SIZE X2
234 YLNG=4.
235 IMAX=NRD-1
236 IF(NRD .EQ. 1) GO TO 420
237 C...MAKE SURE DISTANCES ARE IN ORDER OF INCREASING VALUE
238 DO 42 I=1,IMAX
239 JMIN=I+1
240 DO 42 J=JMIN,NRD
241 IF(DIST(J) .GT. DIST(I)) GO TO 42
242 TEMPA=DIST(J)
243 DIST(J)=DIST(I)
244 DIST(I)=TEMPA
245 42 CONTINUE
246 C...MAKE SURE DISTANCES ARE NOT BEYOND END OF DATA
247 420 DO 43 J=1,NRD
248 IF(DIST(J) .LE. RHOMAX) GO TO 43
249 NRD2=J-1
250 IF(NRD2 .EQ. 0) GO TO 421
251 PRINT 1017,RHOMAX
252 GO TO 44
253 421 PRINT 1018
254 GO TO 10
255 43 CONTINUE
256 C
257 C...SET UP ANTENNA ORIENTATION PARAMETERS
258 NRD2=NRD
259 INCANG=INCL(1)
260 SINIO=DSIN(INCANG*DTR)
261 COSIO=DCOS(INCANG*DTR)
262 TINC=(IMAX-TMIN)/(NRPTS-1)
263 XY(1)=0.
264 SINT(1)=0.
265 SC(1,1)=COSIO
266 SC(2,1)=0.DO
267 SC(3,1)=SINIO
268 DO 61 J=2,NRPTS
269 XY(J)=XY(J-1)+TINC
270 SINT(J)=DSIN(XY(J)*DTR)
271 SC(1,J)=COSIO
272 SC(2,J)=SINIO*DSIN(XY(J)*DTR)
273 SC(3,J)=SINIO*DCOS(XY(J)*DTR)
274 C
275 C...SET UP PLOT
276 CALL PLOT(1.5,.5,-3)
277 NEWP=0
278 RHOD=0.
279 IF(NPRINT .LT. 1) PRINT 1030
280 C...LOOP OVER DISTANCES
281 DO 68 I=1,NRD2
282 DST=DIST(I)
283 IF(DST .EQ. 0.) GO TO 68
284 C...LOOP OVER ORBITS

```

```

285 R=0.
286 CC= 1.00
287 DO 66 JJ=1,3
288 C...LOOP OVER ANTENNA AZIMUTHS
289 DO 62 J=1,NRPTS
290 SC(2,J)=CC*SC(2,J)
291 CALL SUMS(J,DST,AMP(J),PHS(J),SUMOUT(1),SC(1,J),R*SINT(J))
292 NEWD=0
293 NEWHT=0
294 CALL POUT2(JJ,1)
295 IF(JJ.GT. 1) GO TO 65
296 SUM1=0.
297 DO 63 J=1,NRPTS
298 SUM1=SUM1+AMP(J)
299 AM=SUM1/NRPTS
300 SUM1=0.
301 DO 64 J=1,NRPTS
302 SUM1=SUM1+(AMP(J)-AM)**2
303 AS=SQRT(SUM1/(NRPTS-1))
304 IF(AMPRINT .GT. 0) PRINT 1030
305 PRINT 1031,DST,AM,AS
306 IF(RADIUS .EQ. 0.) GO TO 67
307 R=RADIUS
308 CC=-1.00
309 CONTINUE
310 CALL PLOT(XLNG+1., 0.,-3)
311 CONTINUE
312 CALL PLOT(0.,0.,-4)
313 IF(DST .GE. RHOMAX) NEWHGR=0
314 GO TO 10
315
316 C...MULTIPLE DATA FOR SINGLE COMPONENT, TALT, RALT, INCL AND THETA
317 IF(INDATA .GT. 1) GO TO 91
318 NRPTS=NRPTS1
319 XLNG=SIZE1
320 YLNG=SIZE1
321 INCANG=INCL(1)
322 THTA=THETA(1)
323 SC(1,1)=DCOS(INCANG*DTR)
324 SINIO=DSIN(INCANG*DTR)
325 SC(2,1)=SINIO*DSIN(THTA*DTR)
326 SC(3,1)=SINIO*DCOS(THTA*DTR)
327 RHOD=0.
328 DINC=(AMIN1(DMAX,RHOMAX)-DMIN)/(NRPTS-1)
329 XY(1)=DMIN
330 DO 92 J=2,NRPTS
331 XY(J)=XY(J-1)+DINC
332 DO 94 J=1,NRPTS
333 CALL SUMS(J,XY(J),AMP(J),PHS(J),SUMOUT(J),SC(1,1),0.)
334 CONTINUE
335 IF(TOTAPE .EQ. 1) WRITE(2) SUMOUT,FREQ,TLONG,TLAT,RBEAR,POWER,
336 INCANG,THTA,TALT,RALT,DMIN,DMAX
337 CALL POUT1(NDATA,NPDATA)
338 IF(INDATA .EQ. NRDATA) GO TO 95
339 PRINT 1005
340 GO TO 200
341 NEL=0

```

```

342 NEWD=0
343 NEWGT=0
344 IF (OMAX .GE. RHOMAX) NEWHGR=0
345 GO TO 10
346
347 C...FIND EXITS
348 PRINT 1008
349 GO TO 940
350 PRINT 1009
351 GO TO 940
352 PRINT 1010
353 GO TO 940
354 PRINT 1011
355 GO TO 940
356 PRINT 1012
357 GO TO 940
358 PRINT 1013
359 GO TO 940
360 PRINT 1015
361 GO TO 940
362 PRINT 1016
363 GO TO 940
364 PRINT 1019
365 PRINT 1025, NM, IND1, TR1, TI1, TMP1, TMP2, IND2, TR2, TI2, TMP3, TMP4
366 GO TO 990
367 PRINT 998
368
369 C...CLOSE PLOT FILE
370 IF (NRCURV5 .GT. 0) CALL PLOT(0.,0.,999)
371 PRINT 1000, NRCURV5, NRPLTS
372 STOP
373
374 C
375 FORMAT('0***** END OF DATA SET ON UNIT 5 *****')
376 FORMAT('1ADDITIONAL PLOT IDENTIFICATION: ',A8,1X,A8)
377 FORMAT('2END OF JOB:',14,' CURVES AND',14,' GRAPHS GENERATED')
378 FORMAT(1X,20A4)
379 FORMAT(1X,20A4)
380 FORMAT(1X,A2,' COMPONENT OPTION',12)
381 FORMAT(1X)
382 FORMAT(1X,5(' '), ' NRCURV GT 4')
383 FORMAT(1X,5(' '), ' NUMBER OF MODES EQ 0')
384 FORMAT(1X,5(' '), ' UNIDENTIFIED CONTROL CARD')
385 FORMAT(1X,5(' '), ' INPUT RHO VALUES OUT OF ORDER')
386 FORMAT(1X,5(' '), ' NO OPTION NUMBER 3')
387 FORMAT(1X,5(' '), ' SIZEY CANNOT BE GT 8')
388 FORMAT(1X,5(' '), ' NUMBER OF MODES REDUCED')
389 FORMAT(1X,5(' '), ' INSUFFICIENT DATA FOR WKB MODE SUM')
390 FORMAT(1X,5(' '), ' NO MODE DATA INPUT')
391 FORMAT(1X,5(' '), ' DIST BEYOND ',F7.3,' WILL BE IGNORED')
392 FORMAT(1X,5(' '), ' NO USABLE DISTANCE DATA')
393 FORMAT(1X,5(' '), ' ERROR IN DATA')
394 FORMAT(1X,F7.0,3(2X,F8.0),2(2X,E10.0),2X,E5.0)
395 FORMAT('OR',F7.3,' F',F8.4,' A',F8.3,' C',F8.3,' M',F6.3,
396 ' S',1PE10.3,' E',0PFS.1)
397 FORMAT(11,2F9.0,1X,4E15.0)
398 FORMAT(10X,12,3X,11,0P2F10.5,2(1X,1P2E16.8)/
399 15X, 11,0P2F10.5,2(1X,1P2E16.8))

```

```

399
400
401
402
403
404
1026 FORMAT('+.66X','MODES',I3)
1030 FORMAT('0 DIST MEAN A STD')
1031 FORMAT(1X,F8.3,2F10.3)
1220 FORMAT(/11X,'USING DATA FROM PREVIOUS RHO')
1221 FORMAT(/11X,'M ID THETA')
END

```

```

1 SUBROUTINE SUNS(J,D,AMP,PHS,SUMM,T,RSINT)
2 IMPLICIT REAL*8 (A-H,O-Z)
3
4 C
5 COMMON/INPUT/STP(30),TP(30),AV1(30),AV2(30),EX(3,3,30),EXC0,ALPHA,SIGMA,
6 EPSR,MODES,RHO,SKIP0(3)
7 COMMON/ONE/RMAX,RSUM,NEW,NEWGT,NEWHGR,NEWP
8 COMMON/IDENT/SKIP1(20),FRQ,TLT,RLT,RCOMP,SKIP2(6),POWER
9 COMMON/DIMEN/SKIP3(18),NPRINT
10 COMMON NMODE(30)
11
12 C
13 COMPLEX*16 STP,TP,AV1,AV2,AVT,AVR,EX,EX1,EX2,EXR,HG,HG1,HG2,HGT,
14 HGR,SAV,SEX,SHG,SUM,SUMA,SUME,SUM,TMP1,TMP2,TMP3,TMP4,
15 MI/(0.D0,-1.D0)/
16 COMPLEX*8 SUMM
17 REAL*8 LMO
18 REAL*4 D,AMP,PHS,RSINT,RHO,SKIP1,FRQ,TLT,RLT,SKIP2,POWER,
19 RMAX,RSUM,PHZ,REV,EXC0,SKIP3
20 INTEGER TCOMP,RCOMP
21 LOGICAL NMODE
22
23 C
24 DIMENSION SAV( 30),AVT( 30), AV2( 30),
25 SEX(3,30), EX1(3,30),EX2(3,30),EXR(3,30),
26 SHG( 30),HGT(3,30),HG1( 30),HG2( 30),HG (3,30),
27 XMT(3,30),XAT(3,30),XAR(3,30),SUMA(30),T(3)
28 DIMENSION S(30),LMO(3,30)
29
30 C
31 DATA PI/3.1415926535897931D0/,TWOPI/6.28318531D0/,RTD/57.29578D0/
32 DATA RHUINC/.02D0/
33
34 C
35 IF(J.GT.1) GO TO 1
36 FREQ=FRQ
37 TALT=TLT
38 RALT=RLT
39 SUMO=EXC0*SQRT(POWER)
40 WAVEN=20.958445E0*FREQ
41 PHZ=0.
42 REV=0.
43
44 C...FOR PRINT
45 ACONST=-8.685D0*WAVEN
46 C...REFERENCE EXCITATION TO REFLHT=70
47 TMP4=DCMPLX(0.D0,-.035D0*WAVEN)
48
49 C
50 C...CHECK IF RECEIVER IS AT TRANSMITTER
51 IF(D.GT.0.) GO TO 9
52 SUMM=SUMO*80.D0
53 AMP=20.D0*DLOG10(SUMO*80.D0)
54 PHS=0.
55 RETURN
56
57 C
58 DST=D
59 RST=RSINT
60 IF(RSUM.GT.0.) GO TO 29
61 C...FIRST POINT ON PATH
62 RH00=0.D0
63 RHOSUM=0.D0
64 RHOMAX=RMAX

```

```

57      REWIND 3
58      REWIND 4
59
60      C...TRANSMITTER DATA
61      READ(3) STP,TP,AV1,EX,SIGMA,EPSR,RHO,MODES,NOMODE
62      RHO1=RHO
63      IF(NEW .EQ. 0 .AND. NEWHT .EQ. 0) GO TO 10
64      CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,TP,TALT,HGT)
65
66      10 IF(NEW .EQ. 0 .AND. NEWHT .EQ. 0) GO TO 11
67      C...RECEIVER HEIGHT GAINS
68      CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,TP,RALT,HG)
69      WRITE(4) HG
70      GO TO 12
71
72      11 READ(4) HG
73      C
74      C...SET UP MODE CONSTANTS
75      DO 14 M=1,MODES
76      IF(NOMODE(M)) GO TO 14
77      SUMA(M)=0.00
78      AVT(M)=AV1(M)
79      HG1(M)=HG(RCOMP,M)
80      DO 13 TCOMP=1,3
81      EX1(TCOMP,M)=EX(TCOMP,RCOMP,M)
82      XMT(TCOMP,M)=CDABS(EX1(TCOMP,M))
83      X=EX1(TCOMP,M)
84      Y=EX1(TCOMP,M)*MI
85      XAT(TCOMP,M)=DATAN2(Y,X)
86      XAR(TCOMP,M)=XAT(TCOMP,M)
87      CONTINUE
88      IF(NEW .EQ. 0 .OR. NPRINT .EQ. 0) GO TO 20
89
90      C...PRINT TABLE OF MODE CONSTANTS AT TRANSMITTER
91      PRINT 1040,RHO1
92      DO 16 M=1,MODES
93      IF(NOMODE(M)) GO TO 15
94      STPR=STP(M)
95      STPI=STP(M)*MI
96      VOVERC=1.00/STPR
97      TMP1=TMP4*EX1(1,M)*HGT(1,M)*HG1(M)
98      X=TMP1
99      Y=TMP1*MI
100      AMP1=10.00*DLOG10(X*X+Y*Y)
101      ANG1=DATAN2(Y,X)
102      TMP2=TMP4*EX1(2,M)*HGT(2,M)*HG1(M)
103      X=TMP2
104      Y=TMP2*MI
105      AMP2=10.00*DLOG10(X*X+Y*Y)
106      ANG2=DATAN2(Y,X)
107      TMP3=TMP4*EX1(3,M)*HGT(3,M)*HG1(M)
108      X=TMP3
109      Y=TMP3*MI
110      AMP3=10.00*DLOG10(X*X+Y*Y)
111      ANG3=DATAN2(Y,X)
112      S(M)=0.00
113      LMO(1,M) = AMP1

```

```

114 LMO(2,M) = AMP2
115 LMO(3,M) = AMP3
116 PRINT 1041,M,ATTEN,VOVERC,AMP1,ANG1,AMP2,ANG2,AMP3,ANG3,
117 $ AMP1,AMP2,AMP3
118 GO TO 16
119 PRINT 1041,M
120 CONTINUE
121 C
122 C...RECEIVER POINT DATA
123 READ(3) STP,1P,AV2,EX,SIGMA,EPSR,RHO,MODES,NOMODE
124 RHO2=RHO
125 IF(NEWP.EQ.0.AND.NEWHGR.EQ.0) GO TO 21
126 CALL HTGAIN(1,FREQ,SIGMA,EPSR,ALPHA,MODES,1P,RALT,HG)
127 WRITE(4) HG
128 GO TO 22
129 READ(4) HG
130 DO 23 M=1,MODES
131 HG2(M)=HG(RCOMP,M)
132 DO 23 TCOMP=1,3
133 EX2(TCOMP,M)=EX(TCOMP,RCOMP,M)
134 CONTINUE
135 IF(NEWP.EQ.0.OR.NPRINT.EQ.0) GO TO 25
136 C
137 C...PRINT TABLE OF MODE CONSTANTS AT RECEIVER
138 PRINT 1040,RHO2
139 DRHO=8.686D0*(RHO2-RHO1)
140 DO 24 M=1,MODES
141 IF(NOMODE(M)) GO TO 240
142 STPR=STP(M)
143 STPI=STP(M)*MI
144 ATTEN=ACONST*STPI
145 VOVERC=1.00/STPR
146 TMP1=TMP4*EX2(1,M)*HGT(1,M)*HG2(M)
147 X=TMP1
148 Y=TMP1*MI
149 AMP1=10.00*DLOG10(X*X+Y*Y)
150 ANG1=DATAN2(Y,X)
151 TMP2=TMP4*EX2(2,M)*HGT(2,M)*HG2(M)
152 X=TMP2
153 Y=TMP2*MI
154 AMP2=10.00*DLOG10(X*X+Y*Y)
155 ANG2=DATAN2(Y,X)
156 TMP3=TMP4*EX2(3,M)*HGT(3,M)*HG2(M)
157 X=TMP3
158 Y=TMP3*MI
159 AMP3=10.00*DLOG10(X*X+Y*Y)
160 ANG3=DATAN2(Y,X)
161 DAV=AV1(M)+AV2(M)
162 S(M)=S(M)+DRHO*DAV
163 C
164 C...RELATIVE EXCITATION FACTORS AT BEGINNING OF SEGMENT
165 REL1=.500*(LMO(1,M)+AMP1+S(M))
166 REL2=.500*(LMO(2,M)+AMP2+S(M))
167 REL3=.500*(LMO(3,M)+AMP3+S(M))
168 PRINT 1041,M,ATTEN,VOVERC,AMP1,ANG1,AMP2,ANG2,AMP3,ANG3,
169 $ REL1,REL2,REL3
170 GO TO 24

```

```

171 240 PRINT 1041,M
172 C
173 C...SET UP LINEAR INTERPOLATION ARRAYS
174 24 CONTINUE
175 25 DRHO=RHO2-RHO1
176 IF(DRHO.EQ. 0.00) GO TO 27
177 DO 260 M=1,MODES
178 IF(NOMODE(M)) GO TO 260
179 SAV(M)=(AV2(M)-AV1(M))/DRHO
180 SHG(M)=(HG2(M)-HG1(M))/DRHO
181 DO 28 TCOMP=1,3
182 SEX(TCOMP,M)=(EX2(TCOMP,M)-EX1(TCOMP,M))/DRHO
183 CONTINUE
184 IF(RHOSUM.EQ. DST) GO TO 99
185 GO TO 30
186
187 C
188 C...DUPLICATE RHO DATA. ABRUPT CHANGE IN PATH ASSUMED
189 27 DO 28 M=1,MODES
190 AV1(M)=AV2(M)
191 HG1(M)=HG2(M)
192 DO 28 TCOMP=1,3
193 EX1(TCOMP,M)=EX2(TCOMP,M)
194 CONTINUE
195 GO TO 20
196
197 C
198 29 IF(RHOSUM.EQ. DST) GO TO 40
199 RHOSUM=RHOSUM+RHOINC
200 IF(RHOSUM.GT. DST) RHOSUM=DST
201 IF(RHOSUM.GT. RHOMAX) GO TO 31
202 IF(RHOSUM.GT. RHO2) RHOSUM=RHO2
203 DRHO=RHOSUM-RHO0
204 DRHO1=RHOSUM-RHO1
205 DRHO2=DRHO1-.500*DRHO
206
207 C
208 C...LOOP OVER MODES AT RECEIVER
209 DO 34 M=1,MODES
210 IF(NOMODE(M)) GO TO 34
211 C...INTEGRAL OVER S
212 SUMA(M)=SUMA(M)+(AV1(M)+SAV(M)*DRHO2)*DRHO
213 C...LOOP OVER TRANSMITTED COMPONENTS - FOR PHASE CONTINUITY
214 DO 33 TCOMP=1,3
215 EXR(TCOMP,M)=EX1(TCOMP,M)+SEX(TCOMP,M)*DRHO1
216 PHI1=XAR(TCOMP,M)
217 X=EXR(TCOMP,M)*MI
218 Y=EXR(TCOMP,M)*MI
219 PHI2=DATAN2(Y,X)
220 IF(PHI2-PHI1.LE. PI) GO TO 32
221 PHI2=PHI2-TWOPI
222 GO TO 33
223 IF(PHI1-PHI2.LE. PI) GO TO 33
224 PHI2=PHI2+TWOPI
225 XAR(TCOMP,M)=PHI2
226 CONTINUE
227 RHOO=RHOSUM
228
229 C
230 IF(RHOSUM.LT. DST) GO TO 50
231 C

```

```

228 C...MODE PARAMETERS AT RECEIVER DISTANCE
229 STERMS=SUMO/DSORT('ABS(DSIN(DST/6.366D0)))
230 DO 39 M=1,MODES
231 IF(NOMODE(M)) GO TO 39
232 HGR=HG1(M)+SHG(M)*DRHO1
233 DO 38 TCOMP=1,3
234 XMR=CDABS(EXR(TCOMP,M))
235 EXM=DSORT(XMT(TCOMP,M))*XMR
236 EXA=.SDU*(XAT(TCOMP,M)+XAR(TCOMP,M))
237 EXR(TCOMP,M)=EXM*DCPLX(DCOS(EXA),DSIN(EXA))*HGT(TCOMP,M)*HGR
238
239 C
240 C...MODE SUMMATION
241 SUM=0.D0
242 DO 42 M=1,MODES
243 IF(NOMODE(M)) GO TO 42
244 SUME=0.D0
245 DO 41 TCOMP=1,3
246 SUNE=SUME+EXR(TCOMP,M)*T(TCOMP)
247 SUM=SUM+CDEXP(SUMA(M)-RST*AVT(M))*SUNE
248
249 C
250 C...STORE MODE SUM PARAMETERS
251 SUM=SUM+STERM
252 SUMM=SUM
253 X=SUM
254 Y=SUM*M1
255 AMP=10.D0*DLOG10(X*X+Y*Y)
256 PHS=DATAN2(Y,X)*RTD
257 IF(PHS-PHZ.LE.180.) GO TO 43
258 REV=REV-360.
259 GO TO 44
260 IF(PHZ-PHS.LE.180.) GO TO 44
261 REV=REV+360.
262 PHZ=PHS
263 PHS=PHS+REV
264 IF(RHOSUM.EQ.RHO2.AND.RHO2.NE.RHOMAX) GO TO 51
265 GO TO 99
266 C
267 IF(RHOSUM.LT.RHO2.OR.RHO2.EQ.RHOMAX) GO TO 30
268 RHO1=RHO2
269 C...GO TO REASSIGN MODE CONSTANTS
270 GO TO 27
271 C
272 RSUM=RHOSUM
273 RETURN
274 C
275 FORMAT('ORHO =',F6.3,' MODE ATTN V/C',9X,'VERTICAL',9X,
276 'BROADSIDE',6X,'END FIRE',11X,'V',10X,'B',10X,'E')
277
278 FORMAT(15X,13,F8.3,F9.5,3(F10.3,F7.3),3(4X,F7.2))
279 END

```

```

1 SUBROUTINE POUT1(JJ, JUMAX)
2 COMMON/DIMEN/SIZE, SIZE, AMPMAX, AMPMIN, AMPINC, PHSMAX, PHSMIN,
3   PHINC, XMAX, XMIN, XINC, SKIP1(3),
4   NR CURV, NAPLOT, NPLOT, NPDIFF, NPRINT
5 COMMON/IDENT/ID(20), FREQ, TALT, RALT, ICOMP, ZYX, IOPT, THET, INCL,
6   DST, RADIUS, POWER
7 COMMON/OUTPUT/XY(501), OUT1(501), OUT2(501), NRPTS, NR CRVS,
8   NRPLTS, DT(4)
9 COMMON PH11(501), UP(501), XL(2), YL(2), UL(2)
10 LOGICAL UP, UL
11 REAL INCL
12
13 C
14 IR=-1
15 KK=MOD(JJ, NR CURV)
16 IF(KK .EQ. 0) KK=NR CURV
17 IF(JJ .GT. 1) GO TO 10
18 NFRAME=1
19 OFFSET=AMAX1(10.5, SIZE+2.5)
20 DO 1 I=1, NRPTS
21   PH11(I)=OUT2(I)
22
23 IF(NPRINT .EQ. 0) GO TO 20
24 PRINT 1001, ZYX, INCL, THET, TALT, RALT
25 NL=NRPTS/4+1
26 DO 19 I1=1, NL
27   PRINT 1011, (XY(I), OUT1(I), OUT2(I), I=11, NRPTS, NL)
28
29 C
30 IF(NAPLOT .EQ. 0) GO TO 30
31 IR=IR+1
32 NPLOT=1
33 AMAX=AMP MAX
34 AMIN=AMP MIN
35 AINC=AMP INC
36 DO 29 I=1, NRPTS
37   UP(I)=.FALSE.
38   IF(OUT1(I) .LE. AMAX) GO TO 27
39   OUT1(I)=AMAX
40   GO TO 28
41
42 IF(OUT1(I) .GE. AMIN) GO TO 29
43 OUT1(I)=AMIN
44 UP(I)=.TRUE.
45 CONTINUE
46 YMAX=AMAX
47 YMIN=AMIN
48 YINC=AINC
49 GO TO 100
50
51 C
52 IF(NPLOT .EQ. 0) GO TO 40
53 IR=IR+1
54 IF(IR .NE. 0) CALL PLOT(OFFSET, 0., -3)
55 NPLOT=2
56 FK=0.
57 DO 39 I=1, NRPTS
58   OUT1(I)=OUT2(I)+FK
59   UP(I)=.FALSE.
60   IF(OUT1(I) .LT. PHSMIN) GO TO 36

```

```

57 IF(OUT1(I) .GT. PHSMAX) GO TO 37
58 GO TO 39
59 FK=FK-PHSMIN
60 OUT1(I)=OUT1(I)-PHSMIN
61 GO TO 38
62 FK=FK-PHSMAX
63 OUT1(I)=OUT1(I)-PHSMAX
64 UP(I)=.TRUE.
65 GO TO 35
66 CONTINUE
67 YMAX=PHSMAX
68 YMIN=PHSMIN
69 YINC=PHSINC
70 GO TO 100
71 C
72 IF(NPDIFF .EQ. 0) GO TO 50
73 IR=IR+1
74 IF(IR .NE. 0) CALL PLOT(OFFSET,0.,-3)
75 NPLOT=3
76 FK=0.
77 DO 49 I=1,NRPTS
78 OUT1(I)=OUT2(I)-FH1(I)+FK
79 UP(I)=.FALSE.
80 IF(OUT1(I) .LT. PHSMIN) GO TO 46
81 IF(OUT1(I) .GT. PHSMAX) GO TO 47
82 GO TO 49
83 FK=FK-PHSMIN
84 OUT1(I)=OUT1(I)-PHSMIN
85 GO TO 48
86 FK=FK-PHSMAX
87 OUT1(I)=OUT1(I)-PHSMAX
88 UP(I)=.TRUE.
89 GO TO 45
90 CONTINUE
91 YMAX=PHSMAX
92 YMIN=PHSMIN
93 YINC=PHSINC
94 GO TO 100
95 C
96 IF(KK .EQ. NRCURV .OR. JJ .EQ. JUMAX) GO TO 51
97 IF(IR .EQ. 0) GO TO 99
98 CALL PLOT(-IR-OFFSET,0.,-3)
99 GO TO 99
100 CALL PLOT(0.,0.,-4)
101 NFRAME=1
102 RETURN
103 C
104 IF(KK .NE. 1) GO TO 130
105 IF(NFRAME .EQ. 1) CALL PLOT(1.5,2.0,-3)
106 NFRAME=0
107 NRPLTS=NRPLTS+1
108 XP=0.
109 YP=-.4
110 CALL SYMBOL(XP,YP,.1,4HFLOD,0.,4)
111 XP=XP+0.5
112 CALL NUMBER(XP,YP,.1,FLOAT(NRPLTS),0.,-1)
113 XP=XP+1.0

```

```

114 CALL SYMBOL(XP,YP,.1,DT,0.,.16)
115 XP=0.
116 YP=YP-.15
117 IF(NPLOT-2) 101,102,103
118 CALL SYMBOL(XP,YP,.1,9HAMPLITUDE,0.,9)
119 GO TO 104
120 CALL SYMBOL(XP,YP,.1,14HRELATIVE PHASE,0.,14)
121 GO TO 104
122 CALL SYMBOL(XP,YP,.1,12HPHASE-PHASE1,0.,12)
123 XP=0.
124 YP=YP-.15
125 CALL SYMBOL(XP,YP,.1,2YX,0.,1)
126 XP=XP+0.2
127 CALL SYMBOL(XP,YP,.1,9HCOMPONENT,0.,9)
128 XP=XP+1.5
129 CALL SYMBOL(XP,YP,.1,6HFREQ =,0.,6)
130 XP=XP+0.7
131 CALL NUMBER(XP,YP,.1,FREQ,0.,3)
132 XP=XP+1.0
133 CALL SYMBOL(XP,YP,.1,7HPOWER =,0.,7)
134 XP=XP+0.8
135 CALL NUMBER(XP,YP,.1,POWER,0.,1)
136 XP=0.
137 YP=YP-.15
138 CALL SYMBOL(XP,YP,.1,6HTALT =,0.,6)
139 XP=XP+0.7
140 CALL NUMBER(XP,YP,.1,TALT,0.,1)
141 XP=XP+1.0
142 CALL SYMBOL(XP,YP,.1,6HRAIT =,0.,6)
143 XP=XP+0.7
144 CALL NUMBER(XP,YP,.1,RAIT,0.,1)
145 XP=XP+1.0
146 IF(10PT .EQ. 1) GO TO 118
147 XP=0.
148 YP=YP-.15
149 CALL SYMBOL(XP,YP,.1,6HINCL =,0.,6)
150 XP=XP+0.7
151 CALL NUMBER(XP,YP,.1,INCL,0.,3)
152 XP=XP+1.0
153 CALL SYMBOL(XP,YP,.1,7HTHETA =,0.,7)
154 XP=XP+0.8
155 CALL NUMBER(XP,YP,.1,ET,0.,3)
156 XP=XP+1.0
157 GO TO 119
158 XP=0.
159 YP=YP-.15
160 CALL SYMBOL(XP,YP,.1,1D,0.,80)
161 CALL BORDER(SIZE,XMIN,XMAX,XINC,1,SIZE,YMIN,YMAX,YINC,1)
162 YP=YP
163 C
164 NRCRVS=NRCRVS+1
165 XP=0.
166 YP=YP+0.15*KK
167 XL(1)=-1.1
168 XL(2)=-0.1
169 YL(1)=YP
170 YL(2)=YP

```

```

171 UL(1)=.FALSE.
172 UL(2)=.FALSE.
173 CALL CURVE(XL,YL,UL,2,0.,0.,1.,1.,KK)
174 IF(IOPT.EQ.4) GO TO 134
175 CALL SYMBOL(XP,YP,.1,6HINCL=0.,6)
176 XP=XP+0.7
177 CALL NUMBER(XP,YP,.1,INCL,0.,3)
178 XP=XP+1.0
179 CALL SYMBOL(XP,YP,.1,7HTHETA=0.,7)
180 XP=XP+0.7
181 CALL NUMBER(XP,YP,.1,THET,0.,3)
182 GO TO 151
183 CALL SYMBOL(XP,YP,.1,ID,0.,80)
184 C
185 C...DRAW CURVES
186 151 CALL CURVE(XY,OUT1,UP,NRPTS,XMIN,YMIN,(XMAX-XMIN)/SIZE,X,
187 $ (YMAX-YMIN)/SIZEY,KK)
188 199 IF(NPLOT-2) 30,40,50
189 C
190 1001 FORMAT('0',A1,' COMP INCL = ',F7.3,' THETA = ',F8.3,' TALT = ',
191 $ F5.1,' RALT = ',F5.1/4,' DIST AMPLITUDE PHASE',7X))
192 1011 FORMAT(4(F7.3,2F10.4,SX))
193 END

```

```

1 SUBROUTINE POUT2(JJ,II)
2 COMMON/IDENT/ID(20),FREQ,TALT,RALT,ICOMP,ZYX,IOPT,THANG,INCANG,
3     DIST,RADIUS,POWER
4 COMMON/DIMEN/SIZEZ,SKIP2(10),TMAX,TMIN,SKIP3(5),NPRINT
5 COMMON/OUTPUT/T(501),AMP(501),PHS(501),NRPTS,NRCRVS,NRPLTS,DT(4)
6 COMMON UP(501)
7 LOGICAL UP
8 CHARACTER ZYX
9 REAL INCANG
10
11 IF(II.GT.1.OR.JJ.GT.1) GO TO 9
12 NRPLTS=NRPLTS+1
13 YP=9.6
14 CALL SYMBOL(0.0,YP,.1,4HFLD4,0.,.4)
15 CALL NUMBER(0.5,YP,.1,FLOAT(NRPLTS),0.,-1)
16 CALL SYMBOL(1.0,YP,.1,DT,0.,16)
17 YP=YP-.2
18 CALL SYMBOL(0.0,YP,.1,ID,0.,80)
19 YP=YP-.2
20 CALL SYMBOL(0.0,YP,.1,ZYX,0.,1)
21 CALL SYMBOL(0.2,YP,.1,9HCOMPONENT,0.,9)
22 YP=YP-.2
23 CALL SYMBOL(0.0,YP,.1,23HFREQ = POWER = ,0.,23)
24 CALL NUMBER(0.7,YP,.1,FREQ,0.,3)
25 CALL NUMBER(2.3,YP,.1,POWER,0.,1)
26 YP=YP-.2
27 CALL SYMBOL(0.0,YP,.1,23HT ALT = R ALT = ,0.,23)
28 CALL NUMBER(0.8,YP,.1,TALT,0.,1)
29 CALL NUMBER(2.3,YP,.1,RALT,0.,1)
30 YP=YP-.2
31 CALL SYMBOL(0.0,YP,.1,7HINCL = ,0.,7)
32 CALL NUMBER(0.7,YP,.1,INCANG,0.,3)
33 YP=YP-.2
34 CALL SYMBOL(0.0,YP,.1,9HRADIUS = ,0.,9)
35 CALL NUMBER(0.9,YP,.1,RADIUS,0.,4)
36 YP=YP-.2
37
38 IF(JJ.GT.1) GO TO 33
39
40 IF(NPRINT.EQ.0) GO TO 20
41 PRINT 1000,ZYX,DIST,INCANG
42 NL=NRPTS/4+1
43 DO 19 II=1,NL
44     PRINT 1011,(T(I),AMP(I),PHS(I),I=1,NRPTS,NL)
45
46 CALL SYMBOL(0.00,-.40,.10,7HDIST = ,0.,7)
47 CALL NUMBER(0.70,-.40,.10,DIST,0.,3)
48 CALL BORDER(SIZEZ,TMIN,TMAX,90.,1,4.,-360., 360.,90.,1)
49 CALL SYMBOL(-.2,1.7,.1,7HDEGREES,90.,7)
50
51 NRCRVS=NRCRVS+1
52 FK=0.
53 DO 38 J=1,NRPTS
54     YP=PHS(J)+FK
55     UP(J)=.FALSE.
56 IF(YP.LT.-360.) GO TO 35

```

```

57 IF(YP .GT. 360.) GO TO 36
58 GO TO 38
59 FK=FK+360.
60 YP=YP+360.
61 GO TO 37
62 FK=FK-360.
63 YP=YP-360.
64 UP(J)=.TRUE.
65 GO TO 34
66 PHS(J)=YP
67 CALL CURVE(T,PHS,UP,NRPTS,TMIN,-360.,(TMAX-TMIN)/SIZE,180.,JJ)
68 C
69 NRCVS=NRCVS+1
70 CALL PLOT(0.,4.3,-3)
71 IF(JJ .GT. 1) GO TO 44
72 AMAX=-100.
73 AMIN= 100.
74 DO 40 J=1,NRPTS
75 AMPJ=AMP(J)
76 IF(AMIN .GT. AMPJ) AMIN=AMPJ
77 IF(AMAX .LT. AMPJ) AMAX=AMPJ
78 CONTINUE
79 AMAX=10.*AINT((.5*(AMAX+AMIN)+5.)/10.)+20.
80 AMIN=AMAX-40.
81 CALL BORDER(SIZE, TMIN, TMAX, 90., 1, 4., AMIN, AMAX, 10., 1)
82 CALL SYMBOL(-2, 1, 5., 1, 10HD8/UV/M/KW, 90., 10)
83 DO 48 J=1,NRPTS
84 AMPJ=AMP(J)
85 UP(J)=.FALSE.
86 IF(AMPJ .LE. AMAX) GO TO 46
87 AMPJ=AMAX
88 GO TO 47
89 IF(AMPJ .GE. AMIN) GO TO 48
90 AMPJ=AMIN
91 UP(J)=.TRUE.
92 AMP(J)=AMPJ
93 CALL CURVE(T,AMP,UP,NRPTS,TMIN, AMIN,(TMAX-TMIN)/SIZE, 10.,JJ)
94 C
95 CALL PLOT(0.,-4.3,-3)
96 RETURN
97 FORMAT('0',A1,' COMP DIST = ',F7.3,' INCL = ',F7.3/
98 $ 4(' THETA AMPLITUDE PHASE',7X))
99 FORMAT(4(F7.3,2F10.4,5X))
100 END

```

```

1  SUBROUTINE CURVE(X,Y,UP,NRPTS,XMIN,YMIN,XINC,YINC,LINE)
2  C X,Y,UP MUST BE DIMENSIONED AT LEAST NRPTS
3  C XMIN,YMIN ARE X,Y ORIGIN IN USER UNITS
4  C XINC,YINC ARE X,Y SCALES IN USER UNITS PER INCH
5  C
6  C LINE=1: SOLID
7  C LINE=2: LONG DASH
8  C LINE=3: MEDIUM DASH
9  C LINE=4: SHORT DASH
10 C LINE=5: DOTTED
11 C LINE=6: SHORT + LONG DASH
12 C LINE=7: SHORT + SHORT + LONG DASH
13 C
14 C
15 C LOGICAL UP,UP1,UP2
16 C DIMENSION IPEN(10),JOC(7),X(NRPTS),Y(NRPTS),UP(NRPTS)
17 C DATA IPEN/3,2,3,2,3,2,2,2,2,2,JOC/18, 61, 56, 54, 52, 11, 36/
18 C DATA DELR/.1/
19 C
20 C IF(NRPTS .LE. 1) GO TO 99
21 C
22 C IF(LINE) 1,2,3
23 C KK=MOD(LINE,7)+7
24 C GO TO 4
25 C KK=0
26 C GO TO 4
27 C KK=MOD(LINE,7)
28 C KK=KK+1
29 C JO=JOC(KK)/10
30 C JC=JOC(KK)-10*JO
31 C
32 C J=1
33 C IP=2
34 C IF(KK .EQ. 6) IP=3
35 C DR=0.
36 C RHO1=0.
37 C RHO2=DELR
38 C PX1=(X(1)-XMIN)/XINC
39 C PY1=(Y(1)-YMIN)/YINC
40 C UP1=UP(1)
41 C IF(UP1) GO TO 10
42 C
43 C GO TO FIRST POSITION WITH PEN UP
44 C CALL PLOT(PX1,PY1,3)
45 C
46 C DO 40 I=2,NRPTS
47 C PX2=(X(I)-XMIN)/XINC
48 C PY2=(Y(I)-YMIN)/YINC
49 C UP2=UP(I)
50 C IF(UP2) GO TO 22
51 C IF(UP1) GO TO 37
52 C IF(KK .EQ. 2) GO TO 38
53 C DELX=PX2-PX1
54 C DELY=PY2-PY1
55 C RHO=SQRT(DELX**2+DELY**2)
56 C RHO1=RHO1+RHO
57 C
58 C

```



```

1  SUBROUTINE BORDER(XLNG,XMIN,XMAX,XINC,NX,YLNG,YMIN,YMAX,YINC,NY)
2  DIMENSION XINC(NX),YINC(NY)
3  LOGICAL FY,FX
4  FX=.FALSE.
5  FY=.FALSE.
6  IF(NX.EQ.1) FX=.TRUE.
7  IF(NY.EQ.1) FY=.TRUE.
8  XT=XLNG-.1
9  YT=YLNG-.1
10 XSCALE=XLNG/(XMAX-XMIN)
11 YSCALE=YLNG/(YMAX-YMIN)
12 YM=ABS(YMIN)
13 YLN=-.4
14 IF(YM.GE.10.) YLN=YLN-.1
15 IF(YM.GE.100.) YLN=YLN-.1
16 IF(YM.GE.1000.) YLN=YLN-.1
17 IF(YMIN.LT.0.) YLN=YLN-.1
18 YM=ABS(YMAX)
19 YLM=-.4
20 IF(YM.GE.10.) YLM=YLM-.1
21 IF(YM.GE.100.) YLM=YLM-.1
22 IF(YM.GE.1000.) YLM=YLM-.1
23 IF(YMAX.LT.0.) YLM=YLM-.1
24 XM=ABS(XMAX)
25 XLM=-.3
26 IF(XM.GE.10.) XLM=XLM-.1
27 IF(XM.GE.100.) XLM=XLM-.1
28 IF(XM.GE.1000.) XLM=XLM-.1
29 IF(XMAX.LT.0.) XLM=XLM-.1
30 IF(FX) DX=XINC(1)
31 IF(FY) DY=YINC(1)
32 IY=1
33 YL=0.
34 CALL NUMBER(YLN,0.,.1,YMIN,0.,1)
35 CALL PLOT(0.,0.,3)
36 IF(FY) GO TO 110
37 YP=(YINC(IY)-YMIN)*YSCALE
38 GO TO 111
39 YL=YL+DY
40 YP=YL+YSCALE
41 IF(YP.LT.0.) GO TO 99
42 IF(YP.GE.YLNG) GO TO 11
43 CALL PLOT(0.,YP,2)
44 CALL PLOT(.1,YP,2)
45 CALL PLOT(0.,YP,2)
46 IF(FY) GO TO 110
47 IY=IY+1
48 IF(IY.LE.NY) GO TO 10
49 CALL PLOT(0.,YLNG,2)
50 CALL NUMBER(YLM,YLNG-.1,.1,YMAX,0.,1)
51 CALL PLOT(0.,YLNG,3)
52 IX=1
53 XL=0.
54 IF(FX) GO TO 112
55 XP=(XINC(IX)-XMIN)*XSCALE
56 GO TO 120

```

```

57 112 XL=XL+DX
58 XP=XL*XSCALE
59 IF(XP .LT. 0.) GO TO 99
60 IF(XP .GE. XLNG) GO TO 13
61 CALL PLOT(XP,YLNG,2)
62 CALL PLOT(XP,YT,2)
63 CALL PLOT(XP,YLNG,2)
64 IF(FX) GO TO 112
65 IX=IX+1
66 IF(IX .LE. NX) GO TO 12
67 CALL PLOT(XLNG,YLNG,2)
68 IF(FY) GO TO 130
69 IF(YV-1
70 IF(YV .LE. 0) GO TO 15
71 YP=(YINC(IY)-YMIN)*YSCALE
72 GO TO 14
73 YL=YL-DY
74 YP=YL*YSCALE
75 IF(YP .LE. 0.) GO TO 15
76 CALL PLOT(XLNG,YP,2)
77 CALL PLOT(XT,YP,2)
78 CALL PLOT(XLNG,YP,2)
79 IF(FY) GO TO 130
80 GO TO 113
81 CALL PLOT(XLNG,0.,2)
82 CALL NUMBER(XLNG+XLM,-2.,.1,XMAX,0.,1)
83 CALL PLOT(XLNG,0.,3)
84 IF(FX) GO TO 150
85 IX=IX-1
86 IF(IX .LE. 0) GO TO 17
87 XP=(XINC(IX)-XMIN)*XSCALE
88 GO TO 16
89 XL=XL-DX
90 XP=XL*XSCALE
91 IF(XP .LE. 0.) GO TO 17
92 CALL PLOT(XP,0.,2)
93 CALL PLOT(XP,.1,2)
94 CALL PLOT(XP,0.,2)
95 IF(FX) GO TO 150
96 GO TO 115
97 CALL PLOT(0.,0.,2)
98 CALL NUMBER(0.,-2.,.1,XMIN,0.,1)
99 RETURN
100 PRINT 100,XLNG,XMIN,XMAX,XINC(1),NX,YLNG,YMIN,YMAX,YINC(1),NY
101 FORMAT('0*** ERROR IN BORDER: XLNG, XMIN, XMAX, XINC(1), NX =',
102 $ 1PAE15.5,15/24X,'YLNG, YMIN, YMAX, YINC(1), NY =',1PAE15.5,
103 $ 15/'0***')
104 CALL PLOT(0.,0.,.999)
105 STOP
106 END

```

```

1  SUBROUTINE HTGAIN(IOPT,FREQ,SIGMA,EPSP,ALPHA,NRMODE,TP,Z,HG)
2  IMPLICIT REAL*8 (A-H,O-Z)
3  COMPLEX*16 TP(1),HG(3,1),HGO/(0.00,1.4574954400)/,
4  $      S,C,SSQ,CSQ,NGSQ,SQROOT,RATIO,A1,A2,A3,A4,
5  $      P0,H10,H20,H1PRM0,H2PRM0,PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,EXPZ,
6  $      1/(0.00,1.00)/,M1/(0.00,-1.00)/,ONE/(1.00,0.00)/
7  REAL*8 K,KA13,KA23
8  DATA DTR/1.745329252D-02/
9
10  OMEGA=6.2831853072D03*FREQ
11  NGSQ=DCMPLX(EPSP,-SIGMA/(8.85434D-12*OMEGA))
12  K=2.0956426D-02*FREQ
13  IF(ALPHA.EQ. 0.00) GO TO 5
14  AK=ALPHA/K
15  AK13=DEXP(DLOG(AK)/3.00)
16  AK23=AK13**2
17  KA13=1.00/AK13
18  KA23=KA13**2
19  P1=KA23*ALPHA*Z
20  EXPZ=DEXP(.5D0*ALPHA*Z)
21  DO 20 M=1,NRMODE
22  S=CSIN(TP(M)*DTR)
23  SSQ=S*S
24  CSQ=ONE-SSQ
25  SQROOT=CSQRT(NGSQ-SSQ)
26  TEST=TP(M)*I
27  IF(TEST.GT. 10.00 .OR. ALPHA.EQ. 0.00) GO TO 10
28  P0=KA23*CSQ
29  CALL MDHKNL(P0,H10,H20,H1PRM0,H2PRM0,TP(M),'HG 1')
30  PZ=P0*P1
31  CALL MDHKNL(PZ,H1Z,H2Z,H1PRMZ,H2PRMZ,TP(M),'HG 2')
32  A1=H10 *H2Z -H1Z *H20
33  A2=H1PRM0*H2Z -H1Z *H2PRM0
34  A3=H10 *H2PRMZ-H1PRMZ*H20
35  A4=H1PRM0*H2PRMZ-H1PRMZ*H2PRM0
36  RATIO=SQROOT/NGSQ
37  C=.500*AK23+KA13*M1*RATIO
38  HG(1,M)=EXPZ*(C*A1+A2)
39  HG(2,M)=KA13*M1*SQROOT*A1+A2
40  HG(3,M)=.500*AK*M1*HG(1,M)+AK13*M1*EXPZ*(C*A3+A4)
41  IF(IOPT.EQ. 1) GO TO 20
42  HG(1,M)=HG(1,M)/HGO
43  HG(2,M)=HG(2,M)/HGO
44  HG(3,M)=HG(3,M)/(RATIO*HGO)
45  GO TO 20
46  C=CSQRT(CSQ)
47  EXPZ=DEXP(DCMPLX(0.00,K*Z)*C)
48  A1=(NGSQ*C*SQROOT)/(NGSQ*C+SQROOT)
49  A2=(C*SQROOT)/(C+SQROOT)
50  HG(1,M)=EXPZ+A1/EXPZ
51  HG(2,M)=EXPZ+A2/EXPZ
52  HG(3,M)=(EXPZ-A1/EXPZ)*C
53  IF(IOPT.EQ. 1) GO TO 20
54  HG(1,M)=HG(1,M)/(ONE+A1)
55  HG(2,M)=HG(2,M)/(ONE+A2)
56  HG(3,M)=HG(3,M)/((ONE-A1)*C)

```

HTGAIN00
HTGAIN00
HTGAIN00

CONTINUE
RETURN
END

20

57
58
59

```

1  SUBROUTINE MDHNL (Z,H1,H2,H1PRME,H2PRME,THETA,IDBG)
2  IMPLICIT COMPLEX*16 (A-H,D-Z)
3  COMPLEX*16 I,M1,MPOWER,MTERM
4  REAL*8 A,B,C,D,CAP,PART1,PART2,ZMAG
5  DIMENSION A(30),B(30),C(30),D(30),CAP(30),PART1(2),PART2(2)
6  EQUIVALENCE (PART1,TERM4), (PART2,SUM4)
7
8  DATA A / 9.304367169292944819D-01, 3.1014557230974314911D+01, MDHNL00
9  2.0676371487316209897D+02, 5.74343652424545027449D+02, MDHNL00
10 8.7021765519007617234D+02, 8.2877871922864397320D+02, MDHNL00
115.4168543740434246542D+02, 2.5794544363830202211D+02, MDHNL00
129.3458495066311674231D+01, 2.662651870744066662D+01, MDHNL00
136.121004300561072794D+00, 1.159280384480323472D+00, MDHNL00
141.8401275944132116616D-01, 2.4833030953741048003D-02, MDHNL00
152.884208009726021830D-03, 2.9133414239656786138D-04, MDHNL00
162.5827494893312753646D-05, 2.0256858739853140063D-06, MDHNL00
171.4155736366074870734D-07, 8.809509013000443124D-09, MDHNL00
185.011022034632793388D-10, 2.565807493411568552D-11, MDHNL00
191.1961806496091228666D-12, 5.0368092481207283185D-14, MDHNL00
201.9948392989517716388D-15, 7.1886100863126905797D-17, MDHNL00
212.3938095525516785112D-18, 7.3683010881224645255D-20, MDHNL00
222.1194208514407528762D-21, 5.6653858632471341093D-23, MDHNL00
236.7829872514427588456D-01, 1.30498752404598033D+01, MDHNL00
245.3833232154307609704D+01, 1.196294047873502437D+02, MDHNL00
251.5337103177865415841D+02, 3.2780919314887846509D+02, MDHNL00
267.4742218215718400631D+01, 3.23593862152311706D+01, MDHNL00
271.0785312873841039006D+01, 2.853257374032020905D+00, MDHNL00
286.1360373635097223595D-01, 1.0937678009821251963D-01, MDHNL00
291.6422939954686564465D-02, 2.105505122395713391D-03, MDHNL00
302.3316778764072130571D-04, 2.252828866093256561D-05, MDHNL00
311.9156708045016374595D-06, 1.4446989475879618839D-07, MDHNL00
329.7286124416697769730D-09, 5.8854279743918795891D-10, MDHNL00
333.216080860324314644D-11, 1.595278245255116351D-12, MDHNL00
347.2151886229105003778D-14, 2.9876557444763976717D-15, MDHNL00
351.1368553061173507104D-16, 3.9889659863766691603D-18, MDHNL00
361.2946984700995355913D-19, 3.8985193340546088228D-21, MDHNL00
371.0920223904914870636D-22, 2.8527230681595795812D-24, MDHNL00
384.6521835846461472410D-01, 6.202911446194862982D+00, MDHNL00
392.5845464359145252382D+01, 5.2213050311404570392D+01, MDHNL00
406.2158403942148298012D+01, 4.8751689366390821897D+01, MDHNL00
412.7084271870217123228D+01, 1.1215019407957400903D+01, MDHNL00
423.5945575025504490022D+00, 9.1515006450841609147D-01, MDHNL00
431.9128126343925335194D-01, 3.3122296599437809740D-02, MDHNL00
444.8424410379295643444D-03, 6.0568368204246458321D-04, MDHNL00
456.555018203927768583D-05, 6.1985987743950608612D-06, MDHNL00
461.1654989786625507119D-07, 3.8220488188402150981D-08, MDHNL00
472.5276100653705126277D-09, 1.5033065103898380141D-10, MDHNL00
488.0822936042464409157D-12, 3.9473961437101054471D-13, MDHNL00
491.7590891906016512675D-14, 7.181421476226377892D-16, MDHNL00
502.6957287823672589641D-17, 9.3358572549515461865D-19, MDHNL00
512.9922619406805981315D-20, 8.9015675760511620701D-22, MDHNL00
522.4644428505125033375D-23, 3.65602093536105740D-25, MDHNL00
536.7829872514427588456D-01, 4.5219915009618392131D+01, MDHNL00
543.768326250801532677D+02, 1.1962940478735024344D+03, MDHNL00
551.993823413125040548D+03, 2.0449470903820554375D+03, MDHNL00
561.4201021460986496090D+03, 7.1183064967350857463D+02, MDHNL00

```

```

57 $ 2.6963282184603597492D+02, 7.989120647289658511D+01, MDHNL00
58 1.9021715826080139294D+01, 3.7188105233392256682D+00, MDHNL00
59 6.0764877832340288572D-01, 8.422020489582853564D-02, MDHNL00
60 1.002621486851016145D-02, 1.036301278403205802D-03, MDHNL00
61 9.386786942058023544D-05, 7.512434527457401796D-06, MDHNL00
62 5.350736842918377336D-07, 3.413548225147290163D-08, MDHNL00
63 1.9618093247972931935D-09, 1.0209780508963274472D-10, MDHNL00
64 4.8311763773500352579D-12, 2.0913590211334783723D-13, MDHNL00
65 8.2990437346566602039D-15, 3.031614149645268564D-16, MDHNL00
66 1.0228117913786331176D-17, 3.1967863459247792364D-19, MDHNL00
67 9.2821903191776400453D-21, 2.510396299980430030D-22, MDHNL00
68 1.04166666666666663D-01, 8.3503472222222216D-02, MDHNL00
69 1.2822657455632716019D-01, 2.9184902646414046315D-01, MDHNL00
70 8.8162726744375764874D-01, 3.3214082818627675264D+00, MDHNL00
71 1.4995762986862554546D+01, 7.8923013011586517530D+01, MDHNL00
72 4.7445153886826431887D+02, 3.2074900808906619004D+03, MDHNL00
73 2.4086549840874004605D+04, 1.9892311916950979121D+05, MDHNL00
74 1.791902007753438063D+06, 1.7484377180034121023D+07, MDHNL00
75 1.8370737967633072978D+08, 2.0679040329451551508D+09, MDHNL00
76 2.4827519375935888472D+10, 3.1669454981734887315D+11, MDHNL00
77 4.2771126865134715582D+12, 6.0971132411392560749D+13, MDHNL00
78 9.1486942234356396792D+14, 1.441352517009350101D+16, MDHNL00
79 2.3788844395175757942D+17, 4.1046081600946921885D+18, MDHNL00
80 7.3900049415074853993D+19, 1.385922004603943141D+21, MDHNL00
81 2.7030825930275761623D+22, 5.4747478619645573335D+23, MDHNL00
82 1.1498937014388333524D+25, 2.5014180692753603969D+26, MDHNL00
83 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00
84 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00 MDHNL00
85 DATA 1/(0.0D,1.0D)/(0.0D,-1.0D)/
86 DATA ONE/(1.0D,0.0D)/(2.0D,0.0D)/,ZERO/(0.0D,0.0D)/
87 DATA ROOT3/(1.732050807568880D,0.0D)/
88 DATA ALPHA/(8.53667218838951D-1,0.0D)/
89 DATA CONST1/(2.58819045102522D-01,-9.65925826289067D-01)/
90 DATA CONST2/(2.58819045102522D-01,9.65925826289067D-01)/
91 DATA CONST3/(-9.65925826289067D-01,2.58819045102522D-01)/
92 DATA CONST4/(-9.65925826289067D-01,-2.58819045102522D-01)/
93 ZPOWER=ONE
94 SUM3=ZERO
95 SUM4=ZERO
96 IF(ZMAG.GT.6.10D) GO TO 70
97 SUM1=ZERO
98 SUM2=ZERO
99 ZTERM=-2**3/(200.0D,0.0D)
100 DO 50 M=1,30
101 SUM1=SUM1+DCMPLX(A(M),0.0D)*ZPOWER
102 SUM2=SUM2+DCMPLX(B(M),0.0D)*ZPOWER
103 SUM3=SUM3+DCMPLX(C(M),0.0D)*ZPOWER
104 TERM4=DCMPLX(D(M),0.0D)*ZPOWER
105 SUM4=SUM4+TERM4
106 IF(DABS(PART1(1)/PART2(1)).LE.1.0D-17.AND.
107 DABS(PART1(2)/PART2(2)).LE.1.0D-17) GO TO 60
108 ZPOWER=ZPOWER*ZTERM
109 CONTINUE
110 $
111 GM2F=1*(Z*SUM2-TWO*SUM1)/ROOT3
112 GPMFP=I*(SUM4+TWO*Z*SUM3)/ROOT3
113 H1=Z*SUM2+GM2F

```

```

114 H2=H1-TWO*GM2F
115 H1PRME=SUM4+GPMFP
116 H2PRME=H1PRME-TWO*GPMFP
117 GO TO 999
118
119 C
120 70
121 MPOWER=ONE
122 SUM1=ONE
123 SUM2=ONE
124 RTZ=CDSORT(Z)
125 SQRZG=RTZ*Z
126 ZTERM=1/SQRZB
127 MTERM=-ZTERM
128 DM=ZERO
129 TERM3=ONE
130 DO 80 M=1,30
131 ZPOWER=ZPOWER*ZTERM
132 MPOWER=MPOWER*MTERM
133 DM=DM+ONE
134 TERM1=DCMPLX(CAP(M),0.00)*ZPOWER
135 TERM2=DCMPLX(CAP(M),0.00)*MPOWER
136 IF(CDABS(TERM2/TERM3) .GE. 1.00) GO TO 81
137 SUM4=SUM1+TERM1
138 SUM2=SUM2+TERM2
139 SUM3=SUM3+DM*TERM1
140 TERM4=DM*TERM2
141 SUM4=SUM4+TERM4
142 IF(DABS(PART1(1)/PART2(1)) .LE. 1.D-17 .AND.
143 $ DABS(PART1(2)/PART2(2)) .LE. 1.D-17) GO TO 81
144 TERM3=TERM2
145 CONTINUE
146 ZTERM=(-1.500,0.00)/Z
147 SUM3=SUM3*ZTERM
148 SUM4=SUM4*ZTERM
149 TERM1=((1-0.250,0.00)-I*SQRZB)/Z
150 TERM2=((1-0.250,0.00)+I*SQRZB)/Z
151 EXP1=CDEXP((0.00,0.6666666666666667D0)*SQRZB)
152 EXP2=CONST1*EXP1
153 EXP3=CONST2/EXP1
154 EXP4=CONST3*EXP1
155 EXP5=CONST4/EXP1
156 ZTERM=ALPHA/CDSORT(RTZ)
157 TERM4=Z
158 IF(PART1(1) .GE. 0.00 .OR. PART1(2) .GE. 0.00) GO TO 90
159 H1=ZTERM*(EXP2*SUM2+EXP5*SUM1)
160 H1PRME=ZTERM*(EXP2*(SUM2*TERM2+SUM4)+EXP5*(SUM1*TERM1+SUM3))
161 GO TO 110
162 H1=ZTERM*EXP2*SUM2
163 H1PRME=ZTERM*EXP2*(SUM2*TERM2+SUM4)
164 IF(PART1(1) .GE. 0.00 .OR. PART1(2) .LT. 0.00) GO TO 120
165 H2=ZTERM*(EXP3*SUM1+EXP4*SUM2)
166 H2PRME=ZTERM*(EXP3*(SUM1*TERM1+SUM3)+EXP4*(SUM2*TERM2+SUM4))
167 GO TO 999
168 H2=ZTERM*EXP3*SUM1
169 H2PRME=ZTERM*EXP3*(SUM1*TERM1+SUM3)
170
171 C
172 CALCULATE WRONSKIAN AS PARTIAL CHECK ON VALIDITY
173 SUM4=H1+H2PRME-H1PRME-H2
174

```

MDHNKLOO
MDHNKLOO
MDHNKLOO
MDHNKLOO
MDHNKLOO
MDHNKLOO

IF(DABS(PART2(1)) .LE. 1.D-8 .AND.
\$ DABS(PART2(2))+1.457495441040461D0) .LE. 1.D-8) GO TO 1000
PRINT 1001,SUM4,THETA,IDBG
1000 RETURN
1001 FORMAT(' ***** POSSIBLE ERROR IN MDHNKL: W = ',1P2E15.6,
\$ ' FOR THETA = ',0P2F10.4,' AT ',A4)
END

171
172
173
174
175
176
177

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE
 ASSISTANT SECRETARY OF DEFENSE
 CMD, CONT, COMM & INTELL
 DEPARTMENT OF DEFENSE
 WASHINGTON, DC 20301
 M EPSTEIN
 J BABCOCK

DIRECTOR
 COMMAND CONTROL TECHNICAL CENTER
 11440 ISAAC NEWTON SQUARE, N
 RESTON, VA 22091
 C-650

DIRECTOR
 COMMAND CONTROL TECHNICAL CENTER
 ROOM ME682, THE PENTAGON
 WASHINGTON, DC 20301
 C-312

DIRECTOR
 DEFENSE ADVANCED RESEARCH PROJECT
 AGENCY
 1400 WILSON BLVD
 ARLINGTON, VA 22209
 NUCLEAR MONITORING RSCH
 STRATEGIC TECH OFFICE

DEFENSE COMMUNICATION ENGINEERING CENTER
 1860 WIEHLE AVENUE
 RESTON, VA 22090
 CODE R220 (M HOROWITZ)
 CODE R720 (JOHN WORTHINGTON)
 CODE R410 (JAMES W McLEAN)
 CODE R103

DIRECTOR
 DEFENSE COMMUNICATIONS AGENCY
 WASHINGTON, DC 20305
 CODE 810 (RW ROSTRON)
 CODE 480
 CODE 101B (MAJ ROOD)

DEFENSE COMMUNICATIONS AGENCY
 WWMCCS SYSTEM ENGINEERING ORG
 WASHINGTON, DC 20305
 RL CRAWFORD

DEFENSE TECHNICAL INFORMATION CENTER
 CAMERON STATION
 ALEXANDRIA, VA 22314
 TC (12)

DIRECTOR
 DEFENSE INTELLIGENCE AGENCY
 WASHINGTON, DC 20301
 DIAST-5
 DB-4C (EDWARD OFARRELL)

DIRECTOR
 DEFENSE NUCLEAR AGENCY
 WASHINGTON, DC 20305
 DDST
 TISI ARCHIVES (3)
 TITL TECH LIBRARY (3)
 RAAE
 STVL

COMMANDER
 FIELD COMMAND
 DEFENSE NUCLEAR AGENCY
 KIRTLAND AFB, NM 87115
 FCPR

DIRECTOR
 INTERSERVICE NUCLEAR WEAPONS SCHOOL
 KIRTLAND AFB, NM 87115
 DOCUMENT CONTROL

CHIEF
 LIVERMORE DIVISION FLD COMMAND DNA
 LAWRENCE LIVERMORE LABORATORY
 PO BOX 808
 LIVERMORE, CA 94550
 FCPR

DIRECTOR
 NATIONAL SECURITY AGENCY
 FT GEORGE G MEADE, MD 20755
 W65
 OLIVER H BARTLETT W32
 TECHNICAL LIBRARY
 JOHN SKILLMAN R52

OJCS J-3
 THE PENTAGON
 WASHINGTON, DC 20301
 OPERATIONS (WWMCCS EVAL
 OFF, MR TOMA)

OJCS J-5
 THE PENTAGON
 WASHINGTON, DC 20301
 PLANS & POLICY (NUCLEAR DIVISION)

UNDER SECY OF DEFENSE FOR RESEARCH
 AND ENGINEERING
 DEPARTMENT OF DEFENSE
 WASHINGTON, DC 20301
 S&SS (OS)

DEPARTMENT OF THE ARMY
 COMMANDER/DIRECTOR
 ATMOSPHERIC SCIENCES LABORATORY
 US ARMY ELECTRONICS COMMAND
 WHITE SANDS MISSILE RANGE, NM 88002
 DELAS-AE-M (FE NILES)

COMMANDER
 HARRY DIAMOND LABORATORIES
 2800 POWDER MILL RD
 ADELPHI, MD 20783
 DELHD-NP (FRANCIS N WIMENITZ)
 MILDRED H WEINER DRXDO II

COMMANDER
 US ARMY ELECTRONICS RESEARCH &
 DEVELOPMENT COMMAND
 FORT MONMOUTH, NJ 07703
 DRSEL-RD
 (JE QUIGLEY)

COMMANDER
US ARMY FOREIGN SCIENCE & TECH CENTER
220 7TH STREET, NE
CHALOTTESVILLE, VA 22901
R JONES
PA CROWLEY

COMMANDER
US ARMY NUCLEAR AGENCY
7500 BACKLICK ROAD
BUILDING 2073
SPRINGFIELD, VA 22150
MONA-WE (J BERBERET)

CHIEF
US ARMY RESEARCH OFFICE
PO BOX 12211
TRIANGLE PARK, NC 27709
DRXRD-ZC

DEPARTMENT OF THE NAVY
CHIEF OF NAVAL OPERATIONS
NAVY DEPARTMENT
WASHINGTON, DC 20350
OP 941
OP-604C3
OP 943 (LCDR HUFF)
OP 981

CHIEF OF NAVAL RESEARCH
NAVY DEPARTMENT
ARLINGTON, VA 22217
CODE 402
CODE 420
CODE 421
CODE 461
CODE 464

COMMANDING OFFICER
NAVAL INTELLIGENCE SUPPORT CENTER
4301 SUITLAND RD BLDG 5
WASHINGTON, DC 20390

COMMANDER
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152
CODE 81 (HD SMITH)
CODE 532 (3)
CODE 532 (RICHARD A PAPPART)
CODE 532 (JERRY F FERGUSON)

COMMANDING OFFICER
NAVAL RESEARCH LABORATORY
WASHINGTON, DC 20375
CODE 5410 (JOHN DAVIS)
CODE 7701 (JACK D BROWN)
CODE 5461 TRANS IONO PROP
CODE 5465 PROP APPLICATIONS
CODE 5460 ELECTROMAG PROP BR
CODE 2600 TECH LIBRARY (2)

OFFICER IN-CHARGE
WHITE OAK LABORATORY
NAVAL SURFACE WEAPONS CENTER
SILVER SPRING, MD 20910
CODE WA501 NAVY NUC PRGMS OFF
CODE WX21 TECH LIBRARY

COMMANDER
NAVAL TELECOMMUNICATIONS COMMAND
NAVTELCOM HEADQUARTERS
4401 MASSACHUSETTS AVE, NW
WASHINGTON, DC 20390
CODE 24C

COMMANDING OFFICER
NAVY UNDERWATER SOUND LABORATORY
FORT TRUMBULL
NEW LONDON, CT 06320
PETER BANNISTER
DA MILLER

DIRECTOR
STRATEGIC SYSTEMS PROJECT OFFICE
NAVY DEPARTMENT
WASHINGTON, DC 20376
NSP-2141

DEPARTMENT OF THE AIR FORCE
COMMANDER
ADC/DC
ENT AFB, CO 80912
DC (MR LONG)

COMMANDER
ADCOM: XPD
ENT AFB, CO 80912
XPQDQ
XP

AF GEOPHYSICS LABORATORY, AFSC
HASCOM AFB, MA 01731
CRU (S HOROWITZ)
PHP (JULES AARONS)
OPR (JAMES C ULWICK)
OPR (ALVA T STAIR)
SUOL (RESEARCH LIBRARY) (2)

AF WEAPONS LABORATORY, AFSC
KIRTLAND AFB, NM 87117
SUL (2)
SAS (JOHN M KAMM)
DYC (CAPT L WITTWER)

AFTAC
PATRICK AFB, FL 32925
TN
TD-3
TD-5
TF/MAJ WILEY

AIR FORCE AVIONICS LABORATORY, AFSC
WRIGHT-PATTERSON AFB, OH 45433
AAD

COMMANDER
FOREIGN TECHNOLOGY DIVISION, AFSC
WRIGHT-PATTERSON AFB, OH 45433
ETD BL BALLARD

HQ USAF/RD
WASHINGTON, DC 20330
RDQ

HEADQUARTERS
NORTH AMERICAN AIR DEFENSE COMMAND
1500 EAST BOULDER
COLORADO SPRINGS, CO 80912
CHIEF SCIENTIST

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
GRIFFISS AFB, NY 13440
EMTLD DOC LIBRARY

COMMANDER
ROME AIR DEVELOPMENT CENTER, AFSC
HANSCOM AFB, MA 01731
EEP JOHN RASMUSSEN

SAMSO/MN
NORTON AFB, CA 92409
MINUTEMAN (NMML LTC KENNEDY)

COMMANDER IN CHIEF
STRATEGIC AIR COMMAND
OFFUTT AFB, NB 68113
NRT
XPFS (MAJ BRIAN G STEPHAN)
DOK (CHIEF SCIENTIST)

US ENERGY RESEARCH AND DEV ADMIN
DEPARTMENT OF ENERGY
ALBUQUERQUE OPERATIONS OFFICE
PO BOX 5400
ALBUQUERQUE, NM 87115
DOC CON FOR D W SHERWOOD

DIVISION OF MILITARY APPLICATION
DEPARTMENT OF ENERGY
WASHINGTON, DC 20545
DOC CON FOR DONALD I GALE

LAWRENCE LIVERMORE NATIONAL
LABORATORY
PO BOX 808
LIVERMORE, CA 94550
GLENN C WERTH L-216
TECH INFO DEPT L-3

LOS ALAMOS NATIONAL SCIENTIFIC
LABORATORY
PO BOX 1663
LOS ALAMOS, NM 87545
DOC CON FOR T F TASCHEK
DOC CON FOR D R WESTERVELT
DOC CON FOR P W KEATON
DOC CON FOR J H COON

SANDIA LABORATORY
LIVERMORE NATIONAL LABORATORY
PO BOX 969
LIVERMORE, CA 94550
DOC CON FOR B E MURPHEY
DOC CON FOR T B COOK ORG 8000

SANDIA NATIONAL LABORATORY
PO BOX 5800
ALBUQUERQUE, NM 87115
DOC CON FOR SPACE PROJ DIV
DOC CON FOR A D THORNBROUGH, ORG 1245
DOC CON FOR W C MYRA
DOC CON FOR 3141 SANDIA RPT COLL

OTHER GOVERNMENT
DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, DC 20234
RAYMOND T MOORE

DEPARTMENT OF COMMERCE
OFFICE OF TELECOMMUNICATIONS
INSTITUTE FOR TELCOM SCIENCE
BOULDER, CO 80302
WILLIAM F UTLAUT
L A BERRY
A GLENN JEAN
D D CROMBIE
J R WAIT

DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY
TAD-44 1, ROOM 10402-B
400 7TH STREET, SW
WASHINGTON, DC 20590
R L LEWIS
R H DOHERTY

DEPARTMENT OF DEFENSE CONTRACTORS
AEROSPACE CORPORATION
PO BOX 92957
LOS ANGELES, CA 90009
IRVING M GARFUNKEL

ANALYTICAL SYSTEMS ENGINEERING CORP
5 OLD CONCORD RD
BURLINGTON, MA 01803
RADIO SCIENCES

THE BOEING COMPANY
PO BOX 3707
SEATTLE, WA 98124
GLENN A HALL
J F KENNEY

UNIVERSITY OF CALIFORNIA
AT SAN DIEGO
MARINE PHYSICAL LAB OF THE
SCRIPPS INSTITUTE OF OCEANOGRAPHY
SAN DIEGO, CA 92132
HENRY G BOOKER

COMPUTER SCIENCES CORPORATION
PO BOX 530
6565 ARLINGTON BLVD
FALLS CHURCH, VA 22046
D BLUMBERG

UNIVERSITY OF DENVER
COLORADO SEMINARY
DENVER RESEARCH INSTITUTE
PO BOX 10127
DENVER, CO 80210
DONALD DUBBERT
HERBERT REND

ESL, INC
495 JAVA DRIVE
SUNNYVALE, CA 94086
JAMES MARSHALL

GENERAL ELECTRIC COMPANY
SPACE DIVISION
VALLEY FORGE SPACE CENTER
GODDARD BLVD KING OF PRUSSIA
PO BOX 8555
PHILADELPHIA, PA 19101
SPACE SCIENCE LAB (MH BORTNER)

GENERAL ELECTRIC COMPANY
TEMPO-CENTER FOR ADVANCED STUDIES
816 STATE STREET
PO DRAWER QQ
SANTA BARBARA CA 93102
B GAMBILL
DASIAC (2)
DON CHANDLER
WARREN S KNAPP

GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
FAIRBANKS, AK 99701
T N DAVIS
NEAL BROWN
TECHNICAL LABORATORY

GTE SYLVANIA, INC
ELECTRONICS SYSTEMS GRP
EASTERN DIVISION
77 A STREET
NEEDHAM, MA 02194
MARSHAL CROSS

IIT RESEARCH INSTITUTE
10 WEST 35TH STREET
CHICAGO, IL 60616
TECHNICAL LIBRARY

UNIVERSITY OF ILLINOIS
DEPARTMENT OF ELECTRICAL ENGINEERING
URBANA, IL 61803
AERONOMY LABORATORY (2)

JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
J NEWLAND
PT KOMISKE

LOCKHEED MISSILES & SPACE CO, INC.
3251 HANOVER STREET
PALO ALTO, CA 94304
E E GAINES
W L IMHOF D/52-12
J B REAGAN D652-12
R G JOHNSON D/52 12

LOWEL RESEARCH FOUNDATION
450 AIKEN STREET
LOWELL, MA 01854
DR BIBL

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY
PO BOX 73
LEXINGTON, MA 02173
DAVE WHITE
J H PANNELL L 246
D M TOWLE

MISSION RESEARCH CORPORATION
735 STATE STREET
SANTA BARBARA, CA 93101
R HENDRICK
F FAJEN
M SCHEIBE
J GILBERT
C L LONGMIRE

MITRE CORPORATION
PO BOX 208
BEDFORD, MA 01730
G HARDING

PACIFIC SIERRA RESEARCH CORP
1456 CLOVERFIELD BLVD
SANTA MONICA, CA 90404
E C FIELD, JR

PENNSYLVANIA STATE UNIVERSITY
IONOSPHERIC RESEARCH LABORATORY
318 ELECTRICAL ENGINEERING EAST
UNIVERSITY PARK, PA 16802
IONOSPHERIC RSCH LAB (2)

R&D ASSOCIATES
PO BOX 9695
MARINA DEL REY, CA 90291
FORREST GILMORE
WILLIAM J KARZAS
PHYLLIS GREIFINGER
CARL GREIFINGER
A ORY
BRYAN GABBARD
R P TURCO
SAUL ALTSCHULER

RAND CORPORATION
1700 MAIN STREET
SANTA MONICA, CA 90406
TECHNICAL LIBRARY (2)
CULLEN CRAIN

SRI INTERNATIONAL
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025
DONALD NEILSON
GEORGE CARPENTER
W G CHETNUT
J R PETERSON
GARY PRICE

STANFORD UNIVERSITY
RADIO SCIENCE LABORATORY
STANFORD, CA 94305
R A HELLIWELL
FRASER SMITH
J KATSUFRAKIS

TRW DEFENSE & SPACE SYS GROUP
ONE SPACE PARK
REDONDO BEACH, CA 90278
DIANA DEE

CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
4800 OAK GROVE DRIVE
PASADENA, CA 91103
ERNEST K SMITH
(MAIL CODE 144 B13)

DATE
LMED