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WEDCOM IV: A FORTRAN CODE FOR THE CALCULATION OF ELF, VLF, AND LF PROPAGATION IN A NUCLEAR ENVIRONMENT

Volume II-Computer Routines

General Electric Company—TEMPO
Center for Advanced Studies
816 State Street
Santa Barbara, California 93101

1 November 1978

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This document describes computer routines used in WEDCOM IV, a computer code that calculated ELF, VLF, and LF electric and magnetic field strengths in nuclear disturbed environments. The code replaces the previous version of the WEDCOM code (WEDCOM III) documented in DNA2875F.

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SECTION 1
INTRODUCTION

The WEDCOM code is a digital computer program that provides calculations of ELF, VLF, and LF electric and magnetic field strengths in ambient and nuclear disturbed environments. The code is intended for use when a relatively detailed analysis of the propagation between two terminals is required in nuclear disturbed environments. The code can be used alone to study effects of weapon, atmosphere, and propagation parameters on received signals or can be used in conjunction with receiver antenna and signal processing models to evaluate system performance.

Operational information for WEDCOM IV is given in Volume 1 (User's Manual). In this volume a description of computer routines is given for use in conjunction with FORTRAN source listings. A mathematical description of computational models used in the routines is given in Volume 3.

The WEDCOM IV code consists of a main driver routine and a number of subroutines and functions. The FORTRAN names and a brief description of the purpose of each routine are given in Table 1. As indicated in Table 1, many of the environment and geometry routines are taken directly from the WEPH VI code. These routines are described in Reference 1 and are not further discussed here.

Section 2 of this volume contains intermediate level descriptions of each routine. Except for the main driver routine, which is described first, the descriptions are presented in alphabetical order. A number of the routines are the same as routines used in a code developed for the MEECN office designated DCOM (Reference 2) and the

descriptions given in Section 2 for these routines have been taken from the DCOM documentation. Table 2 lists WEDCOM IV routines, library routines, and labeled common blocks used by each routine.

Table 1. Description of WEDCOM IV routines.

Name of Routine	Description
Control	Determines sequence of calculations
ABFACR	Computes terms used in an approximate mode equation
AIRY	Computes the Airy functions and their derivatives
*ANLYT2	Computes solution to differential equation used in deionization above 100 km
APPROX	Computes eigenvalue solutions to the approximate mode equation by employing the Newton iteration algorithm after an appropriate initial value is derived
*ARRLIM	Determines debris location and size from debris marker particle locations
*ATMOSF	Provides properties of the normal or heaved atmosphere above 100 km
*ATMOSU	Provides properties of the normal atmosphere
*AZELR	Computes true azimuth, elevation, and slant range of one point relative to another point (points specified by vectors)
*AZF	Determines azimuth of vector from the x-axis measured in x-y plane
*BFIELD	Computes properties of magnetic dipole field at a point
BHRHS	Computes starting and stopping altitudes for the reflection coefficient integration for LF propagation

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*BLKATM	Block data for atmospheric routines
*BLKCHM	Block data for E- and F-region chemistry routines
*BLKDEP	Block data for heavy particle energy deposition calculations
*BLKUV	Block data for UV energy deposition calculations
BUDDEN	Driver routine for determining value of reflection coefficient for ELF or VLF propagation
CANG	Calculates the argument of a complex number
*CHEMD2	Driver routine for D-region chemistry module
CHEMDQ	Driver routine for steady-state D-region chemistry
*CHEMEF	Determines chemistry and ionization for E- and F-regions
*CHEMQ	Determines steady-state ionization above 100 km
*CHMION	Determines species concentrations in E- and F-regions
*CHXLOS	Determines energy emitted in charge exchange particles
*CHXSPC	Determines energy histogram for charge exchange particles
*CLOSE	Determines location of closest point of approach between two vectors
*CMFEDT	Edits burst list for bursts to be used in E- and F-region chemistry calculations
CONFAC	Computes ionospheric convergence factor
CONMAP	Contains a modified version of the ITS world conductivity map

*Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*CONSET	Sets constants used in low-altitude fireball/ debris models
*CONSPC	Determines energy histogram for loss-cone particles
*COORDV	Determines vector coordinates from latitude, longitude, and altitude
*COORDX	Transforms coordinates of a point in one coordinate system to any of the other three systems; the coordinate systems are 1. Ground range, azimuth, altitude 2. X (east), Y (north), Z (vertical) 3. Slant range, azimuth, elevation 4. Elevation, azimuth, altitude
*CROSS	Calculates cross product for two vectors
*DATE	Computes Gregorian date and zone time after specified time interval
*DBMHT	Determines time-dependent debris region quantities for high-altitude bursts
*DBMLT	Determines time-dependent debris region quantities for low-altitude bursts (RANC model)
*DBMLTR	Determines time-dependent debris region quantities for low-altitude bursts (ROSCOE model)
*DBSTAM	Driver routine for post-stabilization debris geometry
*DEBRIS	Driver routine to determine energy deposition by heavy particles
*DEDEP	Determines delayed energy deposition rate
DELTAT	Computes correction to an approximate root of the mode equation
*DISTF	Computes normalized debris radial distribution parameter
*DOT	Calculates vector dot product

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*DRATE	Determines reaction rate coefficients for D-region chemistry solutions
*DTNE	Computes positive ion and electron concentrations at a point at or below 100 km
*DTNEP	Computes D-region positive ion and electron concentrations due to prompt radiation
*DTNEQ	Computes steady-state D-region positive ion and electron concentrations due to delayed radiation
*DUSTMI	Computes dust scaling quantities
*EDEPB	Determines energy deposition rate due to beta particles
*EDEPC	Determines energy deposition rate due to Compton electrons
*EDEPG	Determines energy deposition rate due to gamma rays
*EDEPM	Determines energy deposition rate due to Bremsstrahlung radiation
*EDEPNB	Determines energy deposition rate due to neutron decay beta particles
*EDEPND	Determines energy deposition rate due to neutron elastic collisions and capture reactions
EHOP	Computes vertical and horizontal field strength for Jth hop in LF propagation
*EIF	Calculates the exponential integral function for positive arguments
EIGENV	Calculates the eigenvalue and derivative to the mode equation using Newton-Raphson procedure
*EIGSRH	Computes VLF mode characteristics from NELC mode search model

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
ELCOL	Computes colatitude and east longitude of a point on the earth
ELDEN2	Driver routine for chemistry and ionization calculations
*ELF	Determines elevation of vector from the x-y plane
ELFMOD	Driver routine for the calculation of ELF
EMATRX	Computes elements of a susceptibility matrix including magnetic field effects and earth curvature for ELF propagation.
*ENEF	Driver routine for E- and F-region chemistry module
ENVIRM	Driver routine for calculating environment quantities along a given path
ENNU	Computes electron and ion densities and collision frequencies through an exponential interpolation between data points
EPRIME	Computes reflection coefficient derivatives with respect to altitude
*EQRAT	Determines effective ambient photodissociation rates for D-region
ERINT	Finds reflection coefficients using Runge-Kutta integration for ELF propagation
ESMAT	Computes coefficient matrix for the reflection coefficient differential equation
ESTART	Computes starting values for reflection coefficient integration for ELF propagation
ETGAIN	Calculates height gain function for ELF
EXCFAC	Calculates anisotropic excitation factors
*EUXFIT	Determines total UV radiation and fraction radiated in five radiation groups

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*EXINTP	Provides exponential interpolation
*E2	Evaluates function used in beta particle energy deposition routine
*FBMHI	Determines time-independent fireball quantities for high-altitude bursts
*FBMHT	Determines time-dependent fireball quantities for high-altitude bursts
*FBMLI	Determines time-independent fireball quantities for low-altitude bursts (RANC model)
*FBMLT	Determines time-dependent fireball quantities for low-altitude bursts (RANC model)
*FHMNMX	Determines top and bottom altitude of a tube fireball and altitude of fireball at magnetic equator if fireball reaches equator
*FZET	Solves heavy particle range-energy equation
FDELH	Computes ionospheric incidence angle and half the hop and ray path distances
FG	Computes the value of a variable in the approximate mode equation
FINDHP	Finds the minimum altitude for reflection of LF propagation
FINGEO	Computes hop geometry between LF transmitter and receiver antennas
FMAG	Computes horizontal and vertical groundwave multipliers, and diffraction losses
*GEOCOR	Computes latitude and longitude of position vector
GNDWV	Computes the ground-wave attenuation function for a specified path length, wave frequency, and ground impedance
GREFL	Computes the Fresnel ground reflection coefficient

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
GUESS	Computes eigenvalue assuming an isotropic ionosphere
*HDPART	Driver routine to partition hydro energy into heavy particle energy sources
*HEAVE	Computes the vertical velocity and time history of the altitude, expansion ratio, and density scale height of a cell in a vertically heaving atmosphere
*HELP	Prints an error message and can continue or terminate the problem
*HPCHEM	Partitions energy lost by heavy particles and determines change in neutral and ion species
HTGAIN	Calculates antenna height gain factors for VLF propagation
*HTOS	Calculates slant ranges along vector to points that are at specified altitude
*HYDMRG	Determines time-independent parameters for fireball formed by hydro merge
*INITAL	Determines D-region neutral species concentrations at end of Phase 2 following a burst
INPUT	Reads and writes input quantities and performs preliminary geometry calculations
*IONLEK	Determines energy in ion leak particles and spatial distribution parameter
IONOSU	Provides normal ionospheric quantities
ISOREF	Computes VLF isotropic ionospheric reflection coefficient
ISORLF	Computes LF isotropic ionospheric reflection coefficient
*JULIAN	Computes Gregorian calendar date to a Julian day number
*LAGRAN	Computes the initial location and final properties of a Lagrangian cell

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*LEKSPC	Determines energy histogram for ion leak particles
LENTRP	Interpolates linearly to obtain electron and positive ion density values for normal and disturbed conditions
LFHOP	Driver routine for the calculation of LF propagation
LINKER	Used on the Honeywell machine for linking (overlay)
*LOCLAX	Calculates vector transformation matrix
*LOSCON	Determines energy in loss cone particles and spatial distribution parameter
*MAGFIT	Fits a dipole magnetic field to the local magnetic field at specified point
*MAGFLD	Determines location of the point on a magnetic field line that is at a specified altitude
MATINV	Solves a set of linear simultaneous equations
*MATMUL	Performs matrix multiplication between two real matrices
MDHNKL	Computes terms used in forming modified Hankel functions
MMATRX	Computes elements of a susceptibility matrix including magnetic field effects and earth curvature for VLF and LF propagation
MODCON	Computes mode conversion coefficients
*MODEL	Driver routine for ROSCOE low-altitude fireball/debris model
*MODELT	Determines time-dependent fireball/debris quantities for low-altitude bursts (ROSCOE model)

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
MODEZ	Computes VLF mode characteristics from TEMPO mode search model
*MODLON	Determines time-independent fireball/debris quantities for low-altitude bursts (ROSCOE model)
*OFFSET	Determines effects of shock wave on low-altitude fireballs
*ONEMG5	Calculates magnetic field at specified point
OUTION	Computes the ionospheric profile index of refraction values, the reference altitude for VLF reflection, and the top and bottom altitudes for VLF and VLF reflection coefficient calculations
*PCHEM	Determines change in species densities at altitudes above 100 km due to prompt radiation
*PEDEP	Computes the energy deposited due to prompt radiation
*PHEAVE	Determines the heave disturbed atmosphere profile
*PHENOM	Driver routine for the RANC phenomenology (fireball, debris, and dust) model module
*PHENOR	Driver routine for the ROSCOE phenomenology (fireball, debris, and dust) model module
*PHOTOD	Computes the fraction of O_3 remaining after thermal radiation
*PHOTOR	Calculates the negative ion photodetachment and photodissociation rates due to thermal radiation
*PIONF	Obtains the initial ion concentrations at a point above 100 km
*PLINTP	Obtains the power law interpolation, $y = ax^b$

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*PMASS	Computes the mass penetrated between two points assuming that the air density varies exponentially with altitude
*PSDM	Driver routine for post-stabilization debris module for specified debris region
QSUBI	Computes the normalized ionospheric surface impedance
REFLCO	Driver routine for determining value of reflection coefficient for LF propagation
*RADMRG	Determines time-independent quantities for fireball formed by radiation merge
*RADOUT	Computes the radiation power for a burst of a given yield at a specified altitude
*RATE	Calculates the reaction rate coefficient for a specified reaction
REORDR	Reorders environmental data for use by propagation modules
RGND	Calculates the ground reflection coefficients for ELF and VLF propagation
*RICATT	Computes the transient electron density based on an approximate solution to the Ricatti equation
RINT	Calculates reflection coefficients using Runge-Kutta integration for VLF and LF propagation
*RINTER	Computes intersections between ray path and right circular and skewed spheroids, cones, magnetically defined tubes, and torus
ROOT	Computes root of approximate characteristic equation, using Newton's procedure
RPRIME	Computes reflection coefficient derivative with respect to altitude
RSTART	Computes starting values for reflection coefficient integration for VLF and LF propagation

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
RUNG	Performs Runge-Kutta integration in ground-wave calculation
*SEPA	Calculates the angle between two vectors
SMAT	Computes coefficient matrix for the reflection coefficient differential equation
*SOIL	Provides the mass density and dielectric constant for a given soil
*SOLCYC	Computes the 10.7-cm solar flux
*SOLORB	Computes the latitude and longitude of the subsolar point
*SOLVE	Solves a set of linear algebraic equations using the Gauss-Jordan method
*SOLZEN	Calculates the cosine of the solar zenith angle
*SPCMIN	Computes the minor neutral atmospheric species
*SPECDP	Computes the neutral species concentrations at the end of Phase 3
*SPECDQ	Computes the modification of the neutral species due to delayed radiation
*STRIAT	Provides the striation ionization parameters in a late-time, high-altitude fireball
*SUBVEC	Calculates the difference between two vectors
*SUB2	Determines region center altitude for ROSCOE fireball model
*SUB3	Determines debris parameters for ROSCOE model
*SUB4	Determines smoothing parameter for ROSCOE low-altitude fireball model
*SUB5	Determines region altitude for ROSCOE fireball model
*SUB6	Determines region radii for ROSCOE fireball model

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*SUB10	Determines time for region radius to grow by specified factor during power-law expansion
*SUB11	Determines time for region radius to grow by specified factor during deceleration phase
*SUB12	Determines time when radius reaches specified value in a specified direction
*SUB13	Determines vortex radii at specified time
*SUB14	Determines offset of fireball
SURFQ	Computes normalized surface impedance for vertical or horizontal polarization
TEM	Calculates transverse electromagnetic mode field value at reveiver for ELF propagation
*TEXK	Computes the excitation temperature for a given energy density equilibrated between the N_2(VIB), $O(^1D)$, $N(^2D)$, and the electron kinetic energy
TFIELD	Computes total electric field from hop fields for LF propagation
*TOROID	Computes the intersection points of a ray path with a toroidal region
*TUBE	Computes the intersection point of a ray path with a magnetically contained region
UANTD	User supplied routine to determine transmitter antenna orientation as a function of time
*UNITV	Computes a unit vector from a given input vector
*UVWAV	Determines average wind velocity over a vertical mixing length
*UVWDH	Determines horizontal wind field above 25-km altitude
*UVWDL1	Determines average horizontal wind field below 25-km altitude for months of January, February, March, and April

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*UVWLD2	Determines average horizontal wind field below 25-km altitude for months of May, June, July, and August.
*UVWLD3	Determines average horizontal wind field below 25-km altitude for months of September, October, November, and December
*U25	Determines average horizontal wind field at 25-km altitude
*VECLIN	Computes the linear combination of two vectors each multiplied by an arbitrary constant
*VECM	Computes the product of a vector with a scalar
*VECSUM	Computes the sum of two arbitrary vectors and adds it to a given vector
*VFUNC1	Computes a function used in ROSCOE fireball model
*VFUNC2	Computes a function used in ROSCOE fireball model
VLFMCV	Determines VLF electric and magnetic field strengths including effects of mode conversion
VLFMOD	Driver routine for calculation of VLF propagation
VLFWKB	Determines VLF electric and magnetic field strengths neglecting mode conversion
*VOLUME	Computes the volume of a given geometrical region
WDNATN	Driver routine that determines ambient atmosphere and ionosphere properties
WFCTVL	Determine F function values at mesh points for NOSC mode search model
WFDFDT	Determines F function values for NOSC code search model
WFINDF	Used in finding roots in NOSC mode search model

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
WFSINT	Performs integration for the ionisphere reflection matrix for NOSC mode search model
WFZERO	Determines zero's of complex function for NOSC mode search model
WINIFS	Multiple entry of routine WFSINT
WINILG	Multiple entry of routine WLGRNG
WINIRB	Multiple entry of routine WRBARS
WLGDER	Multiple entry of routine WLGRNG
WLGRNG	Determines Lagrange interpolation of reflection coefficients for NOSC mode search model
WNOMES	Determines location of zeros of the function F for NOSC mode search routine
*WOBD	Computes the beta energy deposition coefficient, particle release rate, and average energy
*WOGD	Computes the delayed gamma-ray energy deposition parameters
*WOGP	Provides prompt gamma energy deposition parameters
*WOGI	Initializes the gamma-ray energy deposition parameters
*WOND	Provides the time-dependent neutron energy deposition parameters
*WONP	Provides prompt neutron energy deposition parameters
*WONI	Initializes the neutron energy deposition parameters
*WOXC	Computes the X-ray energy containment

* Unmodified WEPH VI routine.

(Continued)

Table 1. (Continued)

Name of Routine	Description
*WOXP	Computes the prompt X-ray energy deposition parameters
*WOX1	Initializes the neutron energy deposition parameters
WQUAD	Determines roots of a quadratic equation for NOSC mode search routine
WRBARS	Determines values for variables used in RBAR matric for NOSC mode search program
WSETLG	Multiple entry of routine WLGRNG
WSETRH	Determines given points in Lagrange interpolation for NOSC mode search program
XFER	Transfers one array to another
*XMAG	Computes the absolute magnitude (length) of a vector
*ZTTOUT	Converts a local time and Gregorian calendar date to the local time and Gregorian calendar date to Greenwich

* Unmodified WEPH VI routine.

Table 2. WEDCOM IV routines, library routines, and common blocks called directly in WEDCOM IV routines.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
Control	AIRY ATMOSU AZELR COORDV COORDX LINKER MAGFIT VOLUME ZTTOUT	FXOPT* LENTRY** SQRT	ATMOSN ATMOUP BREG BURST CINPUT CMPLXJ CONBB CONST DBREG DCREG DEPDAT DEVICE EDTOVL FBREG FDPAR FILES FREQX GCOND HEACOM IONOSN MAGLNK OPTION ORIGIN PARAM PATH PHEN RANTEN SYSPAR TANTEN TIME USECB WEDEPO WOG WON WOX

*FXOPT is a Honeywell system subroutine used to control error messages in the event of underflows and overflows.

**LENTRY is a Honeywell system subroutine used in linking (overlaying).

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
ABFACR	AIRY		AIRY1 FREQX GESCOM
AIRY		CABS CEXP CLOG CSQRT	AIRY1 CMPLXJ
APPROX	ABFACR FG QSUBI ROOT SURFQ	CABS CEXP CSQRT	CMPLXJ CONST FREQX GESCOM GND
BHRHS		ALOG	CINPUT FREQX IONOSN PATHIN
BUDDEN	ENNU ERINT EMATRX ESTART MMATRX RINT RSTART	COS SIN	CONST FIELD FREQX INMM RCCOM SEBUG TCURVE
CANG		ATAN2	
CHEMDQ	ATMOSU DRATE DTNEQ IONOSU SPECDQ	ALOG EXP SQRT	ATMOSN ATMOST CINPUT FDSRAT
CONFAC		COS SIN SQRT TAN	CONST GEOCOM PATHIN PROPO

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
CONMAP		COS SIN	CONST
DELTAT			CMPLXJ FREQX GESCOM
EHOP	CONFAC FMAG LENTRP REFLCO	CEXP	CMPLXJ COVER1 COVER2 FREQX FVCOM GEOCOM OPTION OUTREF SEBUG TCURVE
EIGENV	BUDDEN HELP RGND	CABS CEXP	CANGLE CMPLXJ CONST FREQX RGNDOU RPRIME SEBUG SYSTEM TCURVE
EIGSRH	EXCFAC HELP HTGAIN RGND WFDFDT WFZERO WINIFS WINIRB WSETRH	CABS CCOS CEXP CLOG COS CSIN CSQRT SQRT	CANGLE CMPLXJ CONST DCOM EXCCOM FREQX F1F2C HCOM HTGMC INTEGR MODCOM OPTION PARAMC PATH RBCOM

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
			RGNDOU SIDESC SYSTEM TCURVE
ELDEN2	DATE JULIAN LINKER RINTER SOLORB SOLZEN UNITV VECLIN VECM XMAG ZTTOUT	LENTRY*	ATMOUP BTUBE CHMOVL CINPUT CONST DBREG OPTION ORIGIN PROP TIME
ELFMOD	BFIELD BUDDEN EIGENV GEOCOR OUTION TEM	CEXP CLOG CSQRT	CANGLE CINPUT CMPLXJ CONST ENEENP FIELD FREQX GCOND GND IONOSN OPTION PATH RCCOM RGNDOU RPRIM SEBUG TANTEN TCURVE XMINS

*LENTRY is a Honeywell system subroutine used in linking (overlaying).

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
EMATRX		CABS	CMPLXJ EOUTM FIELD FREQX INMM SEBUG TCURVE XMINS
ENNU		ALOG EXP	CINPUT ENEENP INMM
ENVIRM	ATMOSU AZELR CONMAP COORDV COORDX DATE EDEPNB ELCOL ELDEN2 GEOCOR LINKER LOCLAX MAGFIT MAGFLD MATMUL SUBVEC UNITV VECM XMAG ZTTOUT	ACOS COS LENTRY* SIN SQRT	ATMOSS BREG CINPUT COMINT CONST DTUBE EDTOVL FREQX GCOND IONOSN MAGLNK OPTION ORIGIN PATH PRECAL PROP RANTEN SOURCE TANTEN TIME WRATE
EPRIME		CEXP	CANGLE EOUT FIELD FREQX RPRIM SEBUG

*LENTRY is a Honeywell system subroutine used in linking (overlaying).

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
ERINT	EMATRX ENNU EPRIME ESMAT	CLOG SQRT	CINPUT FIELD OUTRST RPRIM SEBUG TCURVE XMINS
ESMAT			CANGLE EOUT EOUTM FIELD SEBUG
ESTART	HELP	CABS CEXP CLOG CSQRT	CANGLE CONST EOUTM FIELD OUTRST SEBUG
OTGMN		CEXP	CMPLXD FREQX HGCOM
EXCFAC		CSQRT	CANGLE EXCCOM RGNDOU
FEDELA		ASIN COS SIN	CONST PROPO
FINDHP	FEDELH	ALOG COS	PATHIN
FINGEO	FDELH FINDHP	COS SIN TAN	CONST FGNDC GEOCOM PATHIN PROPO

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
FG	AIRY	ATAN2 CABS CEXP CLOG CSQRT	AIRY1 CMPLXJ CONST
FMAG	AIRY GREFL RUNG SURFQ	CABS CEXP COS SQRT	AIRY1 CMPLXJ CONST COVER1 FGNDC FREQV FVCOM GEOCOM PATHIN PROPO
GNDWV	FMAG		FVCOM GCOND OPTION PATHIN
GREFL		COS CSQRT SIN	PROPO
GUESS	ABFACR AIRY APPROX ISOREF QSUBI SURFQ	CLOG CSQRT	AIRY1 CANGLE CMPLXJ CONST EXCCOM FREQX GESCOM GND MODCOM RGNDOU SYSTEM TCURVE

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
HTGAIN	AIRY	CEXP CSQRT EXP	AIRY1 CANGLE CMPLXJ CONST EXCCOM FREQX GND HTGMC RGNDOU TCURVE
IONOSU	RATE	EXP SIN SQRT	
INPUT	AZELR COORDX GEOCOR HELP LOCLAX MATMUL UANTD VECLIN VECM XMAG WOG1 WON1 WOX1	EXIT	BURST CINPUT CONST DEVICE FILES FREQX GCOND OPTION ORIGIN PATH RANTEN SYSPAR TANTEN USECB
ISOREF	CANG ENNU	ALOG CABS CEXP CSQRT EXP	CINPUT CMPLXJ CONST FREQX GESCOM INMM SEBUG TCURVE

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
ISORLF	ENNU	ALOG CEXP CSQRT EXP	CINPUT CMPLXJ FREQX GESX INMM TCURVE
LENTRP			CINPUT CONST ENEENP GCOND IONOSN PATHIN
LFHOP	AZELR BFIELD BHRHS COORDX EHOP FINGEO GEOCOR GNDWV OUTION TFIELD UNITV VECM XMAG	ALOG10 CABS CANG COS CSQRT EXP SIN SQRT	CINPUT CONST COVER1 COVER3 ENEENP FIELD FREQX FVCOM GCOND IONOSN OPTION PATH PATHIN PROPO SEBUG SYSPAR TANTEN VHFLD XMINS
MATINV	HELP	CABS SQRT	
MDHNKL		CABS CEXP CSQRT	

Table 2.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
MATRX		CABS	CMPLXJ FIELD FREQX INMM OUTMM TCURVE XMINS
MODCON	HTGAIN MATINV	ATAN2 CABS CANG CCOS CEXP CSIN	ACOM AIRY1 CANGLE CMPLXJ CONST FREQX HTGMC MODCOM OPTION TCURVE VLFCOM
MODEZ	EIGENV EXCFAC GUESS HTGAIN	CABS CEXP	CANGLE CMPLXJ CONST EXCCOM FREQX HTGMC MODCOM OPTION PATH RGNDOU SYSTEM TCURVE
OUTION	ENNU	CSQRT	CINPUT CMPLXJ CONST FIELD FREQX INMM OPTION TCURVE XMINS

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
QSUBI		CEXP CSQRT	CMPLXJ CONST FREQX GESCOM
REFLCO	ENNU ISORLF MMATRX RINT RSTART	CEXP COS CSQRT SIN	CANGLE CINPUT CMPLXJ CONST FIELD FREQX GESX INMM OPTION OUTREF PARAM PROPO RPRIM TCURVE XMINS
RGND	AIRY	CSQRT	AIRY1 CANGLE CONST FREQX GND RGNDOU SEBUG TCURVE
RINT	ENNU MATRX RPRIME SMAT	SQRT	CINPUT FIELD OUTRST RPRIME TCURVE XMINS
ROOT	ABFACR DELTAT HELP QSUBI	CABS	

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
RPRIME			FIELD FREQX OUTS RPRIM
RSTART		CABS CEXP CLOG CSQRT	CANGLE CONST FIELD OUTMM OUTRST
RUNG			
SMAT			CANGLE FIELD OUTMM OUTS
SURQ		CSQRT	CMPLXJ FREQX
TEM	AZELR COORDX ETGAIN GEOCOR	CABS CANG CEXP COS CSQRT SIN SQRT	CINPUT CMPLXJ CONST FREQX HGCOM OPTION PATH SYSPAR TANTEN
TFIELD		CABS CEXP CLOG SQRT	CMPLXJ COVER2 COVER3 GEOCOM OPTION VHFLD
UANTD			CINPUT TANTEN

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
VLFMCV	MODCON	ACOS ALOG10 ATAN CABS CANG CEXP CSIN EXP SIN SQRT	ACOM CINPUT CMPLXJ CONST FREQX MODCOM OPTION PATH SYSPAR SYSTEM VLFCOM
VLFMOD	AZELR BFIELD COORDX GEOCOR LINKER OUTION XMAG	COS LENTRY* SIN	ACOM CINPUT CONST ENEENP FIELD FREQX GCOND GND HCOM IONOSN MODCOM OPTION PARAM PATH RCCOM SEBUG SYSPAR SYSTEM TANTEN TCURVE XMINS VLFCOM

*LENTRY is a Honeywell system subroutine used in linking (overlaying).

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
VLFWKB		ACOS ALOG10 ATAN CABS CANG CEXP CSIN CSQRT EXP SIN SQRT	CINPUT CMPLXJ CONST FREQX MODLOM OPTION PATH SYSPAR SYSTEM VLFCOM
WDNATM	ATMOSU CHEMDQ IONOSU RATE	ALOG SQRT	ATMOSN ATMOSS ATMOST ATMOUP CINPUT IONOSN OPTION OUT
WFCTVL	WLGRNG WRBARS		IDERVC INTEGR RBCOM THETAC
WFDFDT	WLGDER WRBARS	CSIN	CONST IDERVC INTEGR RBCOM THETAC
WFINDF	WFCTVL		TMCCOM
WFSINT	MDHNKL	ALOG CCOS CEXP EXP	CANGLE CMPLXJ CONST FREQX HCOM IDERVC INTEGR THETAC

Table 2. Continued.

Routine	WEDCOM IV Routines Called Directly	Library Routines Called Directly	Common Blocks Used
WFZERO	HELP WFINDF WNOMES WQUAD		TMCCOM ZLSLOM
WLGRNG		CCOS	CONST INTEGR THETAC WLGINT
WNOMES	HELP WFDFDT WFINDF WQUAD	CABS	ZLSCOM
WQUAD		SQRT	
WRBARS	MDHNKL	ALOG CCOS CEXP CSQRT EXP	CMPLXJ CONST DCOM F1F2C FREQX GND HCOM IDERVC RBCOM THETAC
WSETRH	BUDDEN HELP WFSINT WINIFS WINILG WLGDER WSETLG XFER	CABS CCOS CSIN	CANGLE CONST DCOM IDERVC INTEGR PARAMC RPRIM SIDESC TCURVE THETAC WLGINT
XFER			

SECTION 2
ROUTINE DESCRIPTIONS

CONTROL ROUTINE

This routine is the main driver routine for WEDCOM IV. A simplified flowchart for the routine is shown in Figure 1.

Before starting the problem, parameters, constants, and input default values are defined. The problem loop refers to a given input specification and the problem number is changed each time control is transferred to the input module and new input data obtained.

After input data are obtained a check is made to see if phenomenology or environmental calculations have been previously made for the specified input conditions. If phenomenology or environmental calculations are required, a check is made to see if the ambient atmosphere and magnetic dipole field parameters are to be calculated at only the input origin (input option). If they are (MAMB = 0) the ambient atmosphere and ambient magnetic field routines are initialized and the time of day at the input origin determined.

Next, a loop over calculation times is started and the phenomenology module (driver routine PHENOM for the RANC IV phenomenology or driver routine PHENOR for the ROSCOE phenomenology) is called to obtain fireball and debris quantities. If the atmospheric wind model is to be used (input option), the wind module (driver routine DBSTAM) is called to determine wind effects on debris regions. If the ROSCOE phenomenology is used, the low-altitude debris regions are converted to equivalent RANC debris regions. This is done in the current version of the WEDCOM code to simplify geometry calculations required when determining ionization and absorption. Use of the ROSCOE

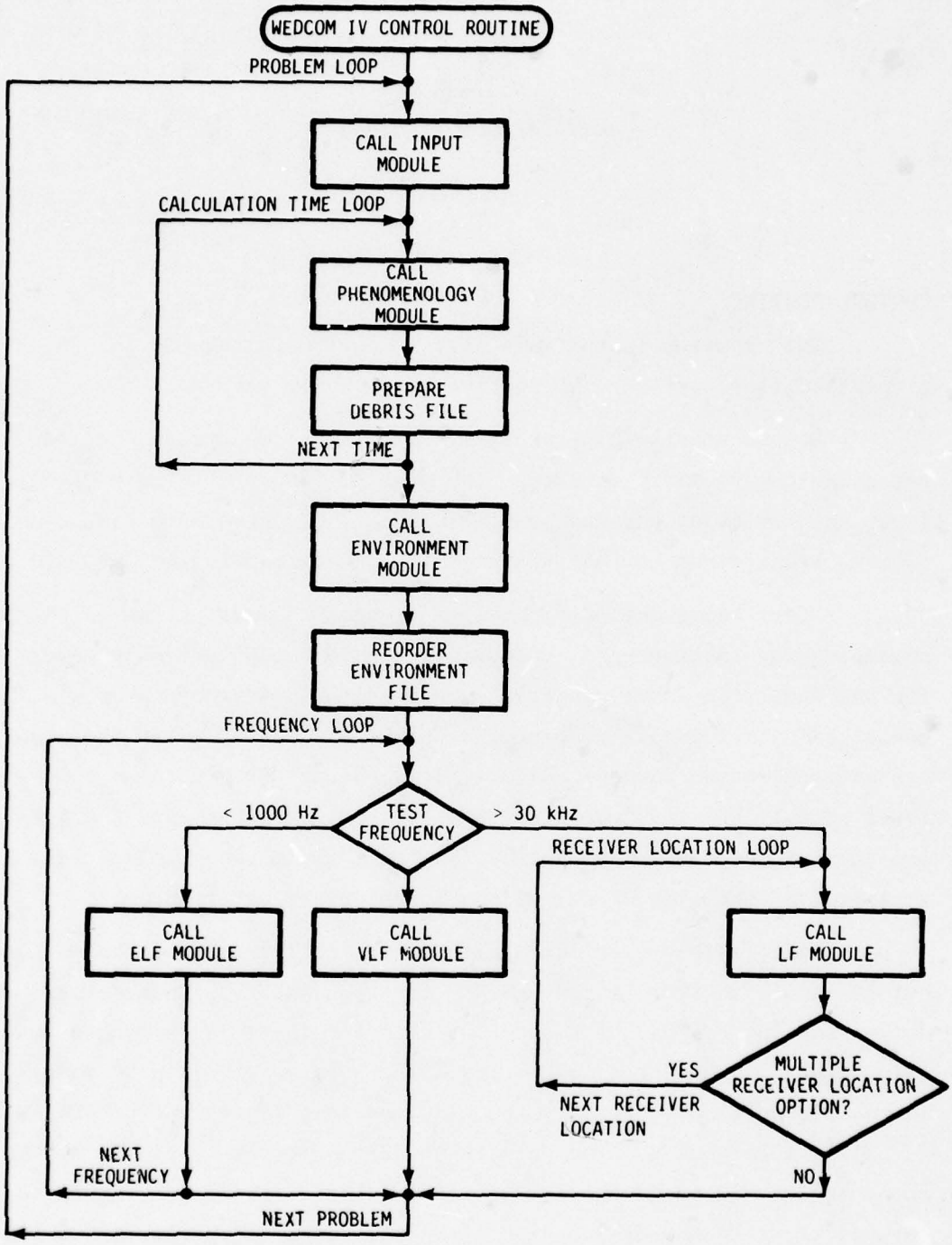

Figure 1. Flowchart for WEDCOM IV control routine.

low-altitude model retains multiburst effects and simplification of the detailed geometry (eg, modified Oval of Cassini) is not critical. To reduce storage requirements the debris region data are stored in a weapon file. Nominal and detailed outputs describing the debris regions are also written out.

After the debris region data have been determined environmental quantities between the transmitter and receiver are found by calling the environment module (driver routine ENVIRM). Calculations in the environment module are made at specified altitudes on vertical paths uniformly spaced along the great circle path between transmitter and receiver. Calculations are made for all calculation times and the results stored in a file to reduce storage requirements. The environmental data are then reordered so that the data are available for all paths at each calculation time (order necessary to determine propagation effects) by calling routine REORDR.

Propagation effects are found by starting a frequency loop and calling the ELF, VLF, or LF propagation modules. For ELF and VLF, calculations are made within the module for either a single receiver location or for multiple receiver locations, depending on user input. In the LF propagation module, calculations are made for a single receiver location. A loop over multiple receiver locations is made in the control routine if multiple receiver location data are requested.

SUBROUTINE ABFACR

This routine calculates terms in the isotropic VLF mode equation.

The terms A and B, defined in Equations 3-6 and 3-7 in Section 3, Volume 3, are computed. In addition, the calculated values for some parameters are saved for later use in routine DELTAT.

SUBROUTINE AIRY

This routine calculates Airy function values and their derivatives.

The Airy functions as defined by Wait (Reference 3) can be written

$$W_1(t) = ay_1(t) + by_2(t) \tag{1}$$

$$W_2(T) = a^*y_1(t) + b^*y_2(t) \tag{2}$$

$$W_1'(t) = ay_1'(t) + by_2'(t) \tag{3}$$

$$W_2'(t) = a^*y_1'(t) + b^*y_2'(t) \quad , \tag{4}$$

where

$$a = 1.089929069 - i\ 0.629270841 \tag{5}$$

$$b = 0.794570425 + i\ 0.458745449 \tag{6}$$

and the asterisk indicates complex conjugate. The functions $y_1(t)$ and $y_2(t)$ are infinite series in the argument (t), and the prime indicates derivative with respect to the argument. The y functions can be written in a form suitable for computation as follows:

$$y_1 = 1 + \sum_{n=1}^{m} y_{1n} \tag{7}$$

$$y_2 = t\left(1 + \sum_{n=1}^{m} y_{2n}\right) \tag{8}$$

$$y_1' = t^2/2\left(1 + \sum_{n=1}^{m} y_{1n}'\right) \tag{9}$$

$$y_2' = 1 + \sum_{n=1}^{m} y_{2n}' \tag{10}$$

where

$$y_{10} = y_{20} = y'_{10} = y'_{20} = 1 \tag{11}$$

and the additional terms are obtained from the recursion relations

$$y_{1n} = y_{1,n-1} \frac{1}{3n(3n - 1)} t^3 \tag{12}$$

$$y_{2n} = y_{2,n-1} \frac{1}{3n(3n + 1)} t^3 \tag{13}$$

$$y'_{1n} = y'_{1,n-1} \frac{1}{3n(3n + 2)} t^3 \tag{14}$$

$$y'_{2n} = y'_{2,n-1} \frac{1}{3n(3n - 2)} t^3 \tag{15}$$

The number of terms, m, required for a given value of the argument, t, is defined so that the magnitude of the mth term in any of the series 7 through 10 is less than 10^{-8}. The number of terms required for the desired accuracy as a function of the magnitude of t can be approximated by a straight line defined by

$$m = 4 + 2.8|t| \quad . \tag{16}$$

SUBROUTINE APPROX

This routine calculates initial values for the approximate mode equation. A flowchart for the routine is shown in Figure 2.

Solutions to the approximate mode equation are obtained employing the Newton iteration algorithm after an appropriate guess is calculated. Four approximate solutions are used in obtaining the guess (see Section 3, Volume 3). The solution starts with a modified flat-earth approximation (Branch 1) for the mode angle. If the flat-earth approximation cannot be used, a test is made to see if it can be used as a first guess for the iterative solution of the mode equation. If this test fails, a grazing-earth incident-angle approximation (Branch 2) is computed and tested. The first two branches provide an adequate guess for modes greater than 1. If neither of these approximations is good for a mode 1 solution, a third guess is obtained assuming that the mode belongs to the "whispering gallery" type (Branch 3). If this third calculation does not provide a good guess, either the best guess from the first three branches is found or a search through a matrix of initial values is made (Branch 4), where the matrix elements belong to the transition region between whispering gallery and grazing incidence approximations. The Branch 4 calculation is used only for mode 1 vertical field calculations, since the first three approximations normally provide a good guess for higher order vertical or horizontal field calculations.

After the best guess is determined, the solution of the mode equations is calculated employing routine ROOT. Occasionally, for the smaller ground conductivities, the iteration technique in routine ROOT does not converge to a proper solution. If a good solution is not obtained, an increased ground conductivity is chosen for which a mode solution can be accurately determined. The code then returns to the flat-earth approximation, and the process described above is repeated to determine the best guess for this new conductivity. The solution for the mode equation is determined (Branch 5) and used as

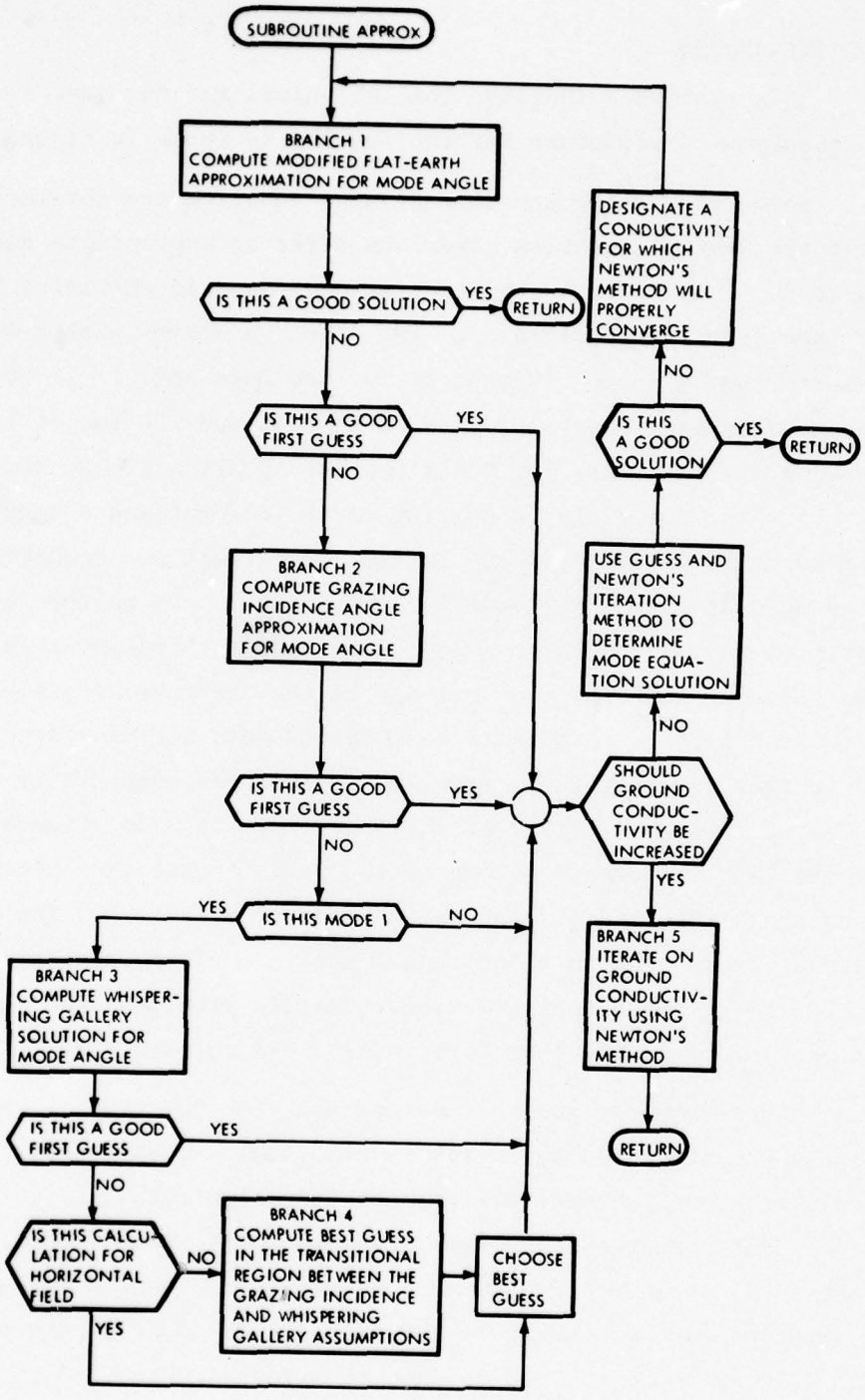

Figure 2. Flowchart for subroutine APPROX.

a guess for a reduced conductivity. This process is repeated until the conductivity is equivalent to the original specified value.

SUBROUTINE BHRHS

This routine calculates starting and stopping altitudes for the reflection coefficient integration. A flowchart for the routine is shown in Figure 3.

The starting and stopping altitudes are defined by first computing the imaginary part of the index of refraction, using equations given in Section 3, Volume 3. The stopping (lowest) altitude is the highest trial altitude where B is less than a specified minimum. The starting (highest) altitude is the lowest trial altitude where B exceeds a specified maximum value. An ionospheric scale height, a parameter that is inversely proportional to the vertical gradient of B(h) in the vicinity of the reflection altitude, is computed.

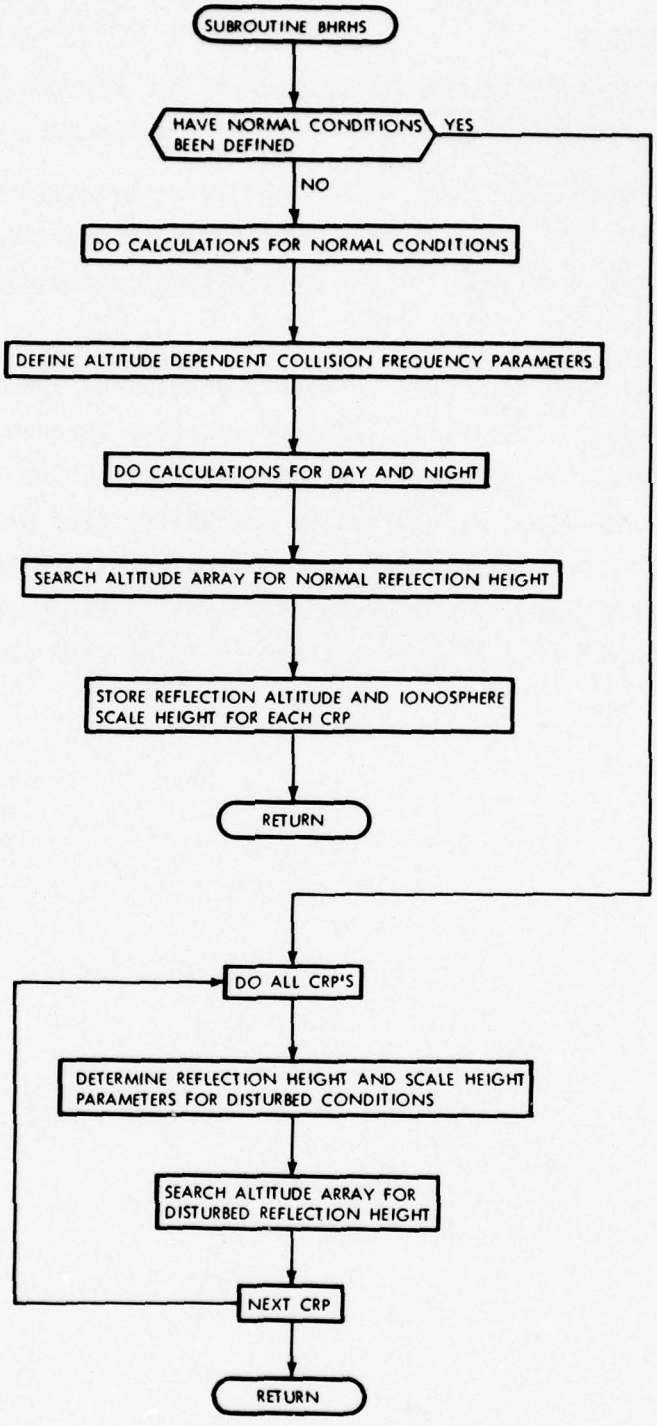

Figure 3. Flowchart for subroutine BHRHS.

SUBROUTINE BUDDEN

This routine is the driver routine for ELF and VLF reflection coefficient calculations in an anisotropic ionosphere.

The reflection coefficients are found by dividing the ionosphere profile into slabs and then performing a numerical integration of differential equations for the reflection coefficients starting at the top slab.

First, magnetic field terms are determined and routine ENNU called to evaluate the ionization and collision frequencies at the top slab. Then the starting values for the reflection coefficients are found by calling routines MMATRX and RSTART (VLF propagation) or routines EMATRX and ESTART (ELF propagation). After the starting values are determined the numerical integration is performed by calling routine RINT (VLF propagation) or ERINT (ELF propagation).

FUNCTION CANG

This routine calculates the argument of a complex number (in radians).

The argument is computed from:

$$\text{CANG} = \tan^{-1} \frac{Im(\text{ARG})}{Re(\text{ARG})} \quad \text{radians} \quad ,$$

where *Re* and *Im* are the real and imaginary parts, and ARG is the complex number.

SUBROUTINE CHEMDQ

This routine is a driver routine to determine steady-state ionization and electron and ion collision frequencies for a given delayed ionization source or an ambient ionization source at a specified D-region altitude. The routine is the same as routine CHEMDQ used in WEPH VI except for the ion-neutral collision frequency calculation.

First, routine ATMOSU is called to obtain the ambient neutral species at the altitude of interest and routine DRATE is called to determine the values of the reaction rate coefficients. Then, if the input value of the ion-pair production rate (Q) is zero, routine IONOSU is called to obtain the ambient ion-pair production rate.

Next, routine SPECDQ is called to determine the change in neutral species and routine DTNEQ is called to determine the electron and ion densities due to the ion-pair production rate. The final calculations are for the electron and ion collision frequencies. A fit to an expression developed at the Naval Ocean Systems Center (Reference 4) is used for the ion-neutral collision frequency.

SUBROUTINE CONFAC

This routine computes the ionospheric convergence factor.

The ionospheric convergence factor is computed for either a uniform or nonuniform ionosphere along the propagation path. For either situation, applicable approximate representations are used for the convergence factor when geometric optics apply or when diffractive corrections are required. The convergence factor is computed by evaluating equations given in Section 4, Volume 3.

SUBROUTINE CONMAP

This routine provides ground conductivity for a specified geographic location. It contains a modified version of the Institute of Telecommunication Sciences world conductivity map.

Fourier analysis is applied to the longitudinal variation in conductivity, while the latitudinal variation is represented by a weighted least squares polynomial in the sine of the latitude.

After the initialization of parameters, the latitudinal values of the Fourier coefficients are determined. The Fourier coefficients are used with the given longitude value to determine a value that is directly related to the conductivity of the desired location.

SUBROUTINE EHOP

This routine computes vertical and horizontal field strengths for individual skywaves. A flowchart for the routine is shown in Figure 4.

Routine EHOP is called after all normal and disturbed ionospheric parameters and the ray path geometry have been established. Two major calculation loops are used. In one, field strengths are obtained for skywaves with a geometry that requires diffractive corrections. In the other, field strengths are calculated for skywaves where geometric optics approximations are appropriate.

In both loops interpolation procedures are used to define ionospheric and ground parameters at the ionospheric or ground reflection points. In the first loop, diffractive correction terms in the vicinity of ground reflection points are defined.

An inner loop is also used for geometric optics approximations when either transmitter or receiver antennas are elevated. In this case, fields for two distinct rays with an equal number of ionospheric reflections are computed and summed.

The actual equations evaluated and the procedures used for defining the number of diffractive paths are discussed in Section 4, Volume 3.

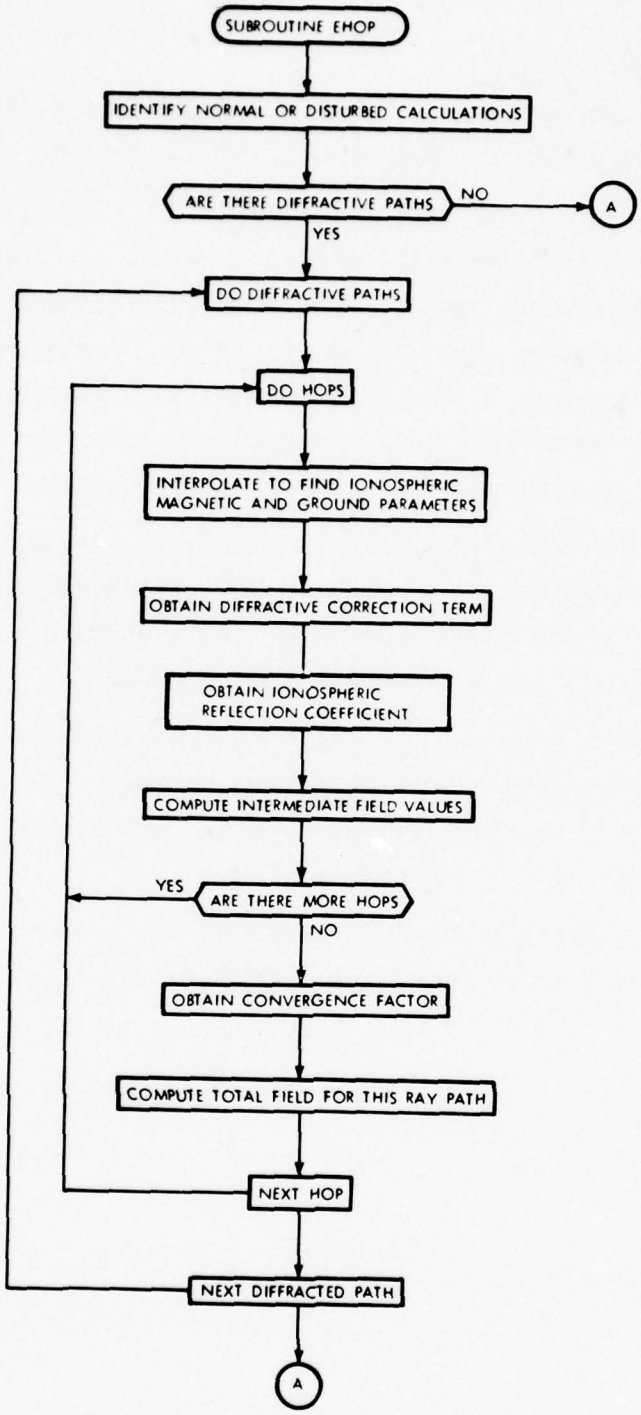

Figure 4. Flowchart for subroutine EHOP.

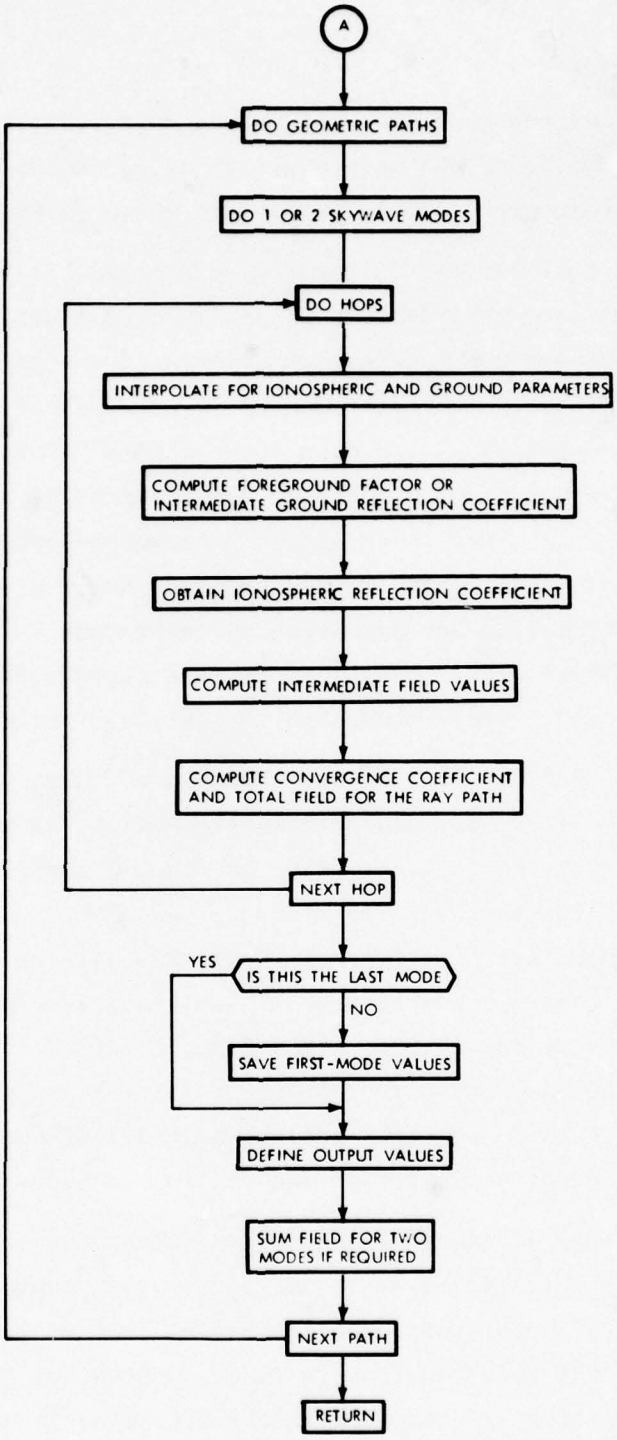

Figure 4. Continued.

SUBROUTINE EIGENV

This routine calculates reflection coefficients and the eigenvalue and derivative of the mode equation using the Newton-Raphson procedure. A flowchart for the routine is shown in Figure 5.

The initialization of iteration parameters is followed by a second-order DO loop that determines an improved eigenvalue for the initial eigenvalue guess (an initial guess given as input is used as the starting value) and the incremented value of the eigenvalue. Both of these calculations are made for the first iteration. For subsequent iterations one or both are done, depending on the computed eigenvalue increment. An input option determines whether the value of the exact mode equation is to be computed, or if a vertical or horizontal polarization approximation is to be made. If the process diverges greatly from the initial guess, the eigenvalue is set to the initial guess and control returns to the calling routine.

The value of the derivative to the mode equation is found, and a test is made to determine if the eigenvalue has been determined. If so, control returns to the calling routine. Otherwise, the eigenvalue increment for the next iteration is calculated, and the iteration index is updated. Control returns to the calling routine if there are more than 20 iterations. If not, tests are made to determine if the convergence criterion has been satisfied. If these tests have been satisfied, a test is made to see if the proper value of the derivative of the mode equation was calculated. If not, it is calculated before returning control to the calling routine.

If another iteration is necessary, an eigenvalue increment is calculated. If this increment is not larger than a predetermined value, one of the prior mode equation values is used and only one new calculation of the mode equation is made. Otherwise, two new values of the mode equation are computed in the determination of the derivative.

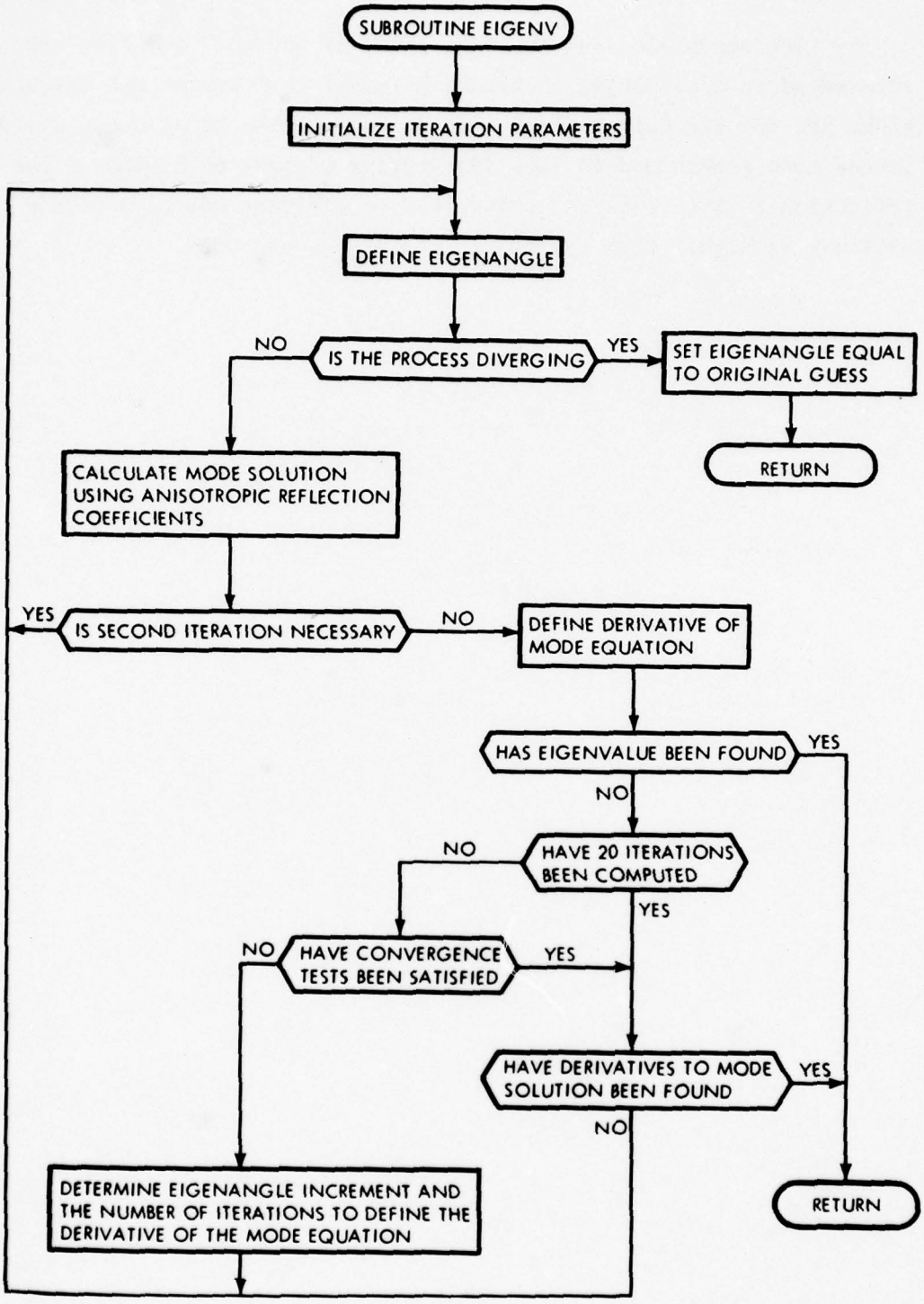

Figure 5. Flowchart for subroutine EIGENV.

The eigenvalue and the derivative of the mode equation are referenced to altitude D. Altitude D is set to 0 km for ELF calculations and for VLF calculations that do not use the Naval Ocean Systems Center mode search models (see description of routine EIGSRH). The reflection coefficients are referenced to altitude HBOT. Altitude HBOT may be higher than altitude D for VLF propagation.

SUBROUTINE EIGSRH

This routine computes solutions to the mode equation for a given ionosphere profile and ground conductivity from a mode search routine developed by the Naval Ocean Systems Center (Reference 5). Height gain and excitation factors are also calculated. A simplified flowchart for the routine is shown in Figure 6.

Solutions to the mode equation (eigenangles) are found using Naval Ocean Systems Center mode search routines to search for solutions within a specified region (rectangle) in the angle of incidence complex plane. A total of three rectangles are defined and a maximum of 15 eigenangles are found. Of these, only the 10 most important are saved for use in determining received field strengths.

For each rectangle in the angle of incidence complex plane routine WHZERO is called to determine eigenangles. The eigenangles are ordered in terms of their real part and solutions outside the current rectangle are discarded. Routines EXCFAC and HTGAIN are called to determine the excitation and height gain factors.

Next, a weighted attenuation rate that includes the effect of excitation factors at the transmitter and for the ionospheric profile for the current vertical path is computed. The attenuation rate is used to select up to 10 modes. After the modes have been selected they are reordered so that the real part of the eigenangles decrease as the mode number increases. Output is prepared describing the modes and if detailed output is requested (input option), details of the mode characteristics height gain factors, and excitation factors are written out.

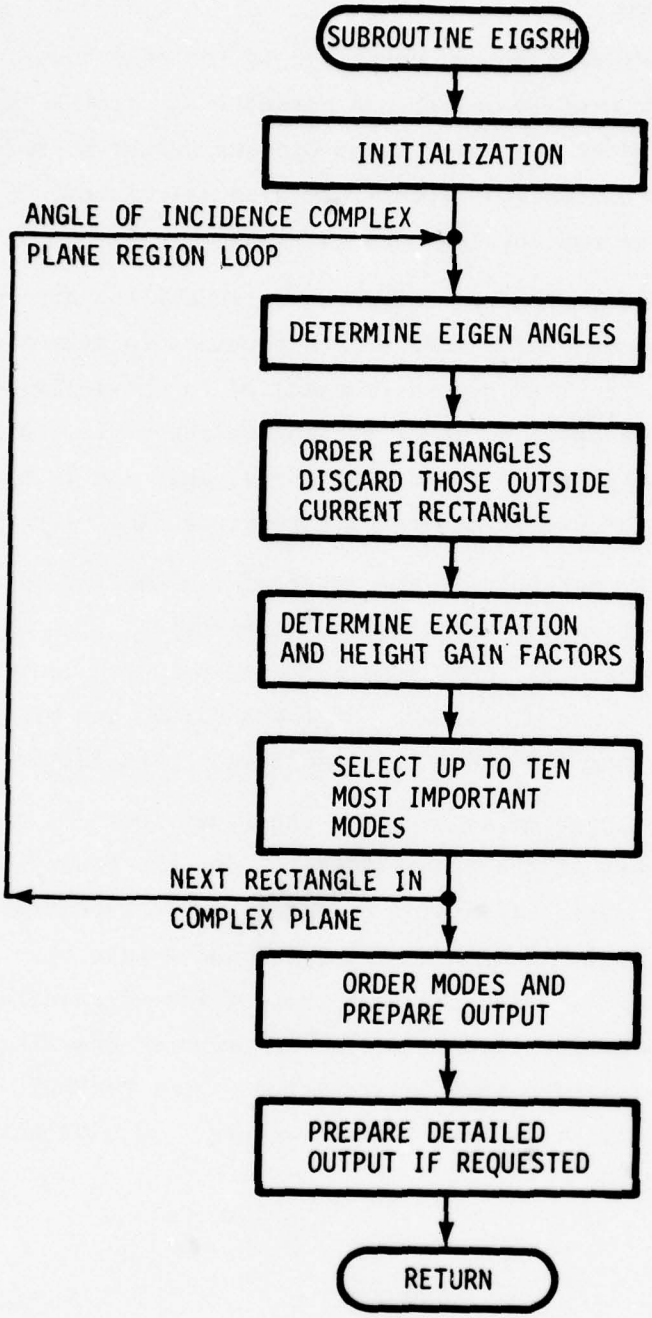

Figure 6. Flowchart for subroutine EIGSRH.

SUBROUTINE ELCOL

This routine computes the colatitude and east longitude of point 2, given the colatitude and east longitude of point 1 and the azimuth (radians) and ground range (km) of point 2 from point 1. The supplement of the azimuth of point 1 from point 2 is also found.

The azimuth of point 2 from point 1 is positive, measured clockwise from north. The supplement of the azimuth of point 1 from point 2 is determined as a positive number.

The colatitude of point 2 is obtained from

$$\cos \phi_2 = \cos \phi_1 \cos R/R_e + \sin \phi_1 \sin R/R_e \cos \alpha \quad , \qquad (1)$$

where

ϕ_2 = colatitude of point 2

ϕ_1 = colatitude of point 1

R = ground range between point 1 and point 2

R_e = earth's radius

$$\alpha = \begin{cases} A_{12} & A_{12} \leq \pi \\ 2\pi - A_{12} & A_{12} > \pi \end{cases}$$

A_{12} = azimuth of point 2 with respect to point 1.

The east longitude of point 2 is obtained from

$$\theta_2 = \begin{cases} \theta_1 + \Delta\theta & A_{12} \leq \pi \\ \theta_1 + 2\pi - \Delta\theta & A_{12} > \pi \end{cases} \qquad (2)$$

$$\Delta\theta = \begin{cases} \sin^{-1}(\sin \Delta\theta) & B_\ell \geq 0 \\ \pi - \sin^{-1}(\sin \Delta\theta) & B_\ell < 0 \end{cases}$$

$$B_\ell = \cos R/R_e - \cos \phi_1 \cos \phi_2$$

$$\sin \Delta\theta = \frac{\sin R/R_e \sin \alpha}{\sin \phi_2} \quad .$$

The supplement of the azimuth of point 1 with respect to point 2 is obtained from

$$\pi - A_{21} = \begin{cases} \pi - A_{21} & A_{12} \leq \pi \\ \pi + A_{21} & A_{12} > \pi \end{cases} \tag{3}$$

where

$$A_{21} = \begin{cases} \sin^{-1}(\sin A_{21}) & B_a \geq 0 \\ \pi - \sin^{-1}(\sin A_{21}) & B_a < 0 \end{cases}$$

$$B_a = \cos \phi_1 - \cos R/R_e \cos \phi_2$$

$$\sin A_{21} = \frac{\sin \phi_1 \sin \alpha}{\sin \phi_2} \quad .$$

SUBROUTINE ELDEN2

This routine is the driver routine for ionization and collision frequency calculations at a specified location. The routine is the same as routine ELDEN2 used in the WEPH VI code except for the collision frequency calculations.

For altitudes at or below 100 km routine CHEMD2 is called to obtain ionization and collision frequency quantities. For altitudes above 100 km a calculation time loop is set up and routine ENEF called for each calculation time. Routine LINKER is called to overlay the D-region (CHEMD2) and E- and F-region (ENEF) routines. The labeled common block CHMOVL is used to transfer input to and obtain output from routines CHEMD2 and ENEF.

For altitudes above 100 km a calculation time loop is set up and for each calculation time the time of day (day or night) is computed. For the first calculation altitude intersection altitudes of the ray path with the beta tube are computed for each debris region. The intersection altitudes are stored on a data file for use at subsequent calculation altitudes. If detailed ionization output is requested (input option), data is obtained from file LFIDO and written out on file LFDO.

SUBROUTINE ELFMOD

This routine is the ELF propagation driver routine and determines anisotropic reflection coefficients, mode solutions, and excitation factors. Only the transverse electromagnetic wave is analyzed. A simplified flowchart for the routine is shown in Figures 7 and 8.

First reflection coefficients, excitation factors, and height gain parameters are initialized. Then a time loop over the calculation times is started and an ambient calculation flag (determines whether calculations will be made for ambient conditions) is set from input parameters.

Next, a loop over the vertical paths between transmitter and receiver is started. For each path, magnetic field and ground conductivity quantities are established and the level of detailed output requested determined. The ionization and collision frequencies along the vertical path for disturbed conditions are obtained from the environment file and routine *OUTION* called to determine the top and bottom altitudes to be used in computing reflection coefficients.

For ELF propagation there are NP-2 vertical paths defined between the transmitter and receiver; NPT2 paths along the short great circle path and the rest along the long great circle path (only defined if calculations along the long great circle path are to be made). The last two paths (L = LP - 1 and L = LP) are located a Fresnel zone distance normal to the short great circle path between transmitter and receiver and are used to determine whether the ionization normal to the great circle propagation path is spherically stratified (an assumption used in the propagation calculations). If the attenuation rate (dB per 1000 km) for either of the last paths is less than one half the attenuation rate at the path midpoint, a diffraction flag is set to indicate that the propagation calculations may be in error.

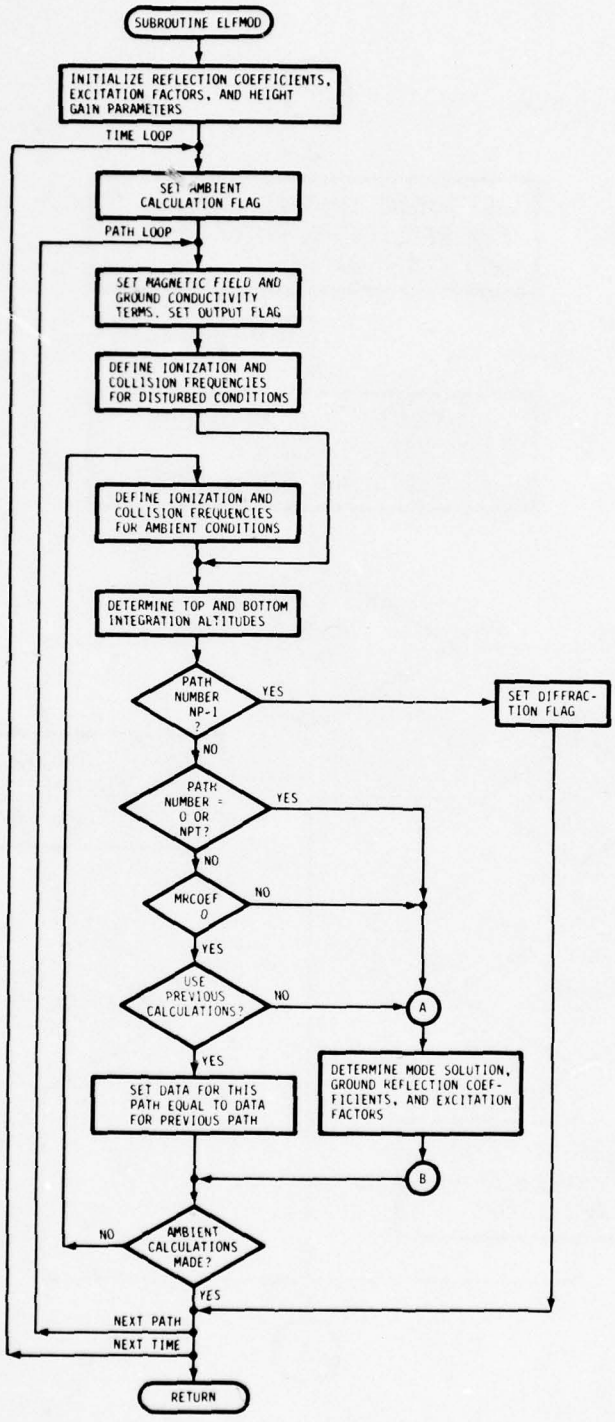

Figure 7. Flowchart for subroutine ELFMOD.

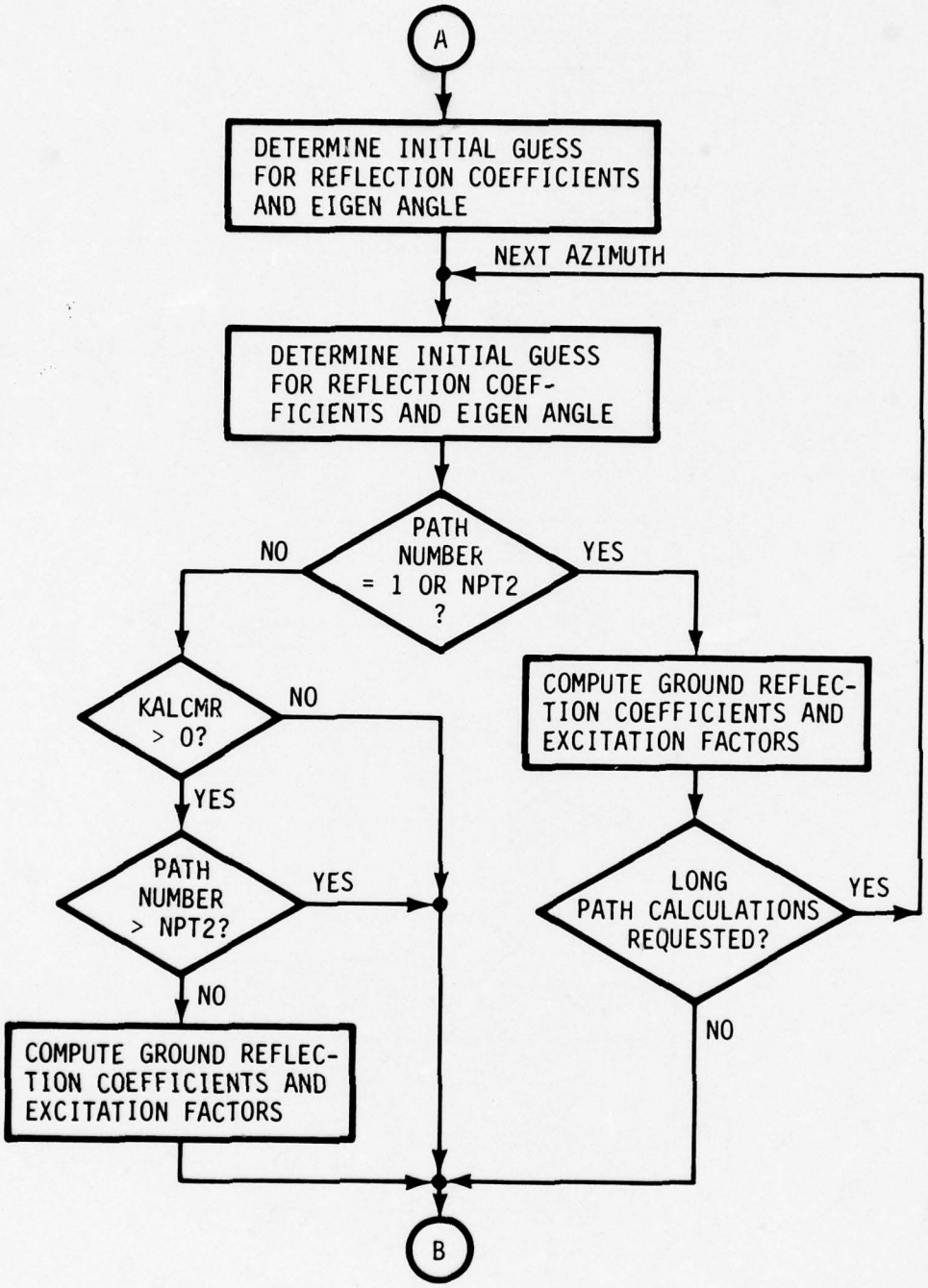

Figure 8. Detail for mode solutions, ground reflection coefficients, and excitation factor calculations.

Calculations for the reflection coefficient and mode solutions are made for vertical paths between the transmitter and receiver ($L \leq NP - 2$). If the input option to minimize the number of reflection coefficient calculations is exercised (MRCOEF = 1), tests are first made to see how much the top altitude obtained from routine OUTION, the magnetic field properties, and the ground conductivity have changed from the values computed for the previous vertical path. If they have not changed by more than specified amounts, the eigenangle, ground reflection coefficient, and excitation factors previously determined are used for the current path.

Otherwise, routine BUDDEN is called and calculations made to obtain initial guesses for the reflection coefficients and eigenangle and routine EIGENV called to obtain final values (see Figure 8). If the multiple receiver location option is exercised (KALCMR = 1), ground reflection coefficients and excitation factors are found for each vertical path on the short great circle path between transmitter and receiver. Otherwise, ground reflection coefficients and excitation factors are only found for the vertical paths above the transmitter and receiver terminals. If field strength calculations for propagation along both the short and long great circle paths are to be made, ground reflection coefficients and excitation factors at the transmitter and receiver terminals are computed for both propagation directions. The ground reflection coefficients and excitation factors for the long great circle path direction are not computed for receiver locations between the transmitter and receiver terminals specified in input.

Detailed output describing the eigenangle, attenuation rate, relative phase velocity, ionosphere reflection coefficients, ground reflection coefficients, and excitation factors are written out on the detailed output file if requested (input option).

SUBROUTINE EMATRX

This routine calculates elements of the ionospheric susceptibility matrix, including magnetic field effects and earth curvature.

The squares of the ratios of electron, positive ion, and negative ion plasma frequencies to the signal frequency are defined. Next, the corresponding ratios of collision frequencies to the signal frequency are defined. The susceptibility matrix is initialized.

The susceptibility matrix is calculated by separately calculating and then summing the contributions due to electrons and positive and negative ions. To reduce numerical problems, the matrix quantities are normalized by the square of the ratio of electron plasma frequency to signal frequency. If magnetic field effects are not important, only the diagonal terms are calculated. The effects due to earth curvature are included by an artificial modification of the diagonal terms in the susceptibility matrix.

SUBROUTINE ENNU

This routine determines electron and ion densities and collision frequencies at specific altitudes.

Electron and ion densities and collision frequencies are determined by exponential interpolation between field points. The field points and ionospheric parameters are predetermined and available through labeled common blocks CINPUT and ENEENP.

SUBROUTINE ENVIRM

This routine is the driver routine for propagation environment calculations. A simplified flowchart for the routine is shown in Figure 9.

First, the number of vertical paths to be located on the short great circle path between the transmitter and receiver terminals are determined and the location of the vertical path closest to the midpoint of the great circle path found. For ELF propagation two additional paths located a Fresnel zone distance normal to the great circle path midpoint are defined. These paths are for use in determining a diffraction flag. Then, the ambient atmosphere and magnetic routines are initialized at the short great circle path midpoint. If calculations are to be made for the long great circle path between transmitter and receiver (KALCLP > 0); the number of vertical paths to be used along the long great circle path are determined. Next, the ambient atmospheric properties at the short great circle path midpoint are found by calling routine WDNATM.

The path loop over the vertical paths to be used in determining the environment is started and the path geometry found. If the environment above 100 km is to be determined (ELF propagation only), calculation flags for debris energy sources (determine whether ionization calculations will be made) are determined and the bursts that produce ionization above 100 km are identified.

Next, an output option flag is set to control the amount of detailed output and the ground conductivity for the path set equal to input values are found by calling routine CONMAP. If neutron decay beta ionization calculations are to be made (input option), routine EDEPNB is initialized. Then an altitude loop is started and the debris data file and a data file used for beta particle and comton electron data are rewound. The electron and ion densities and collision frequencies at each altitude are found by calling routine ELDEN2.

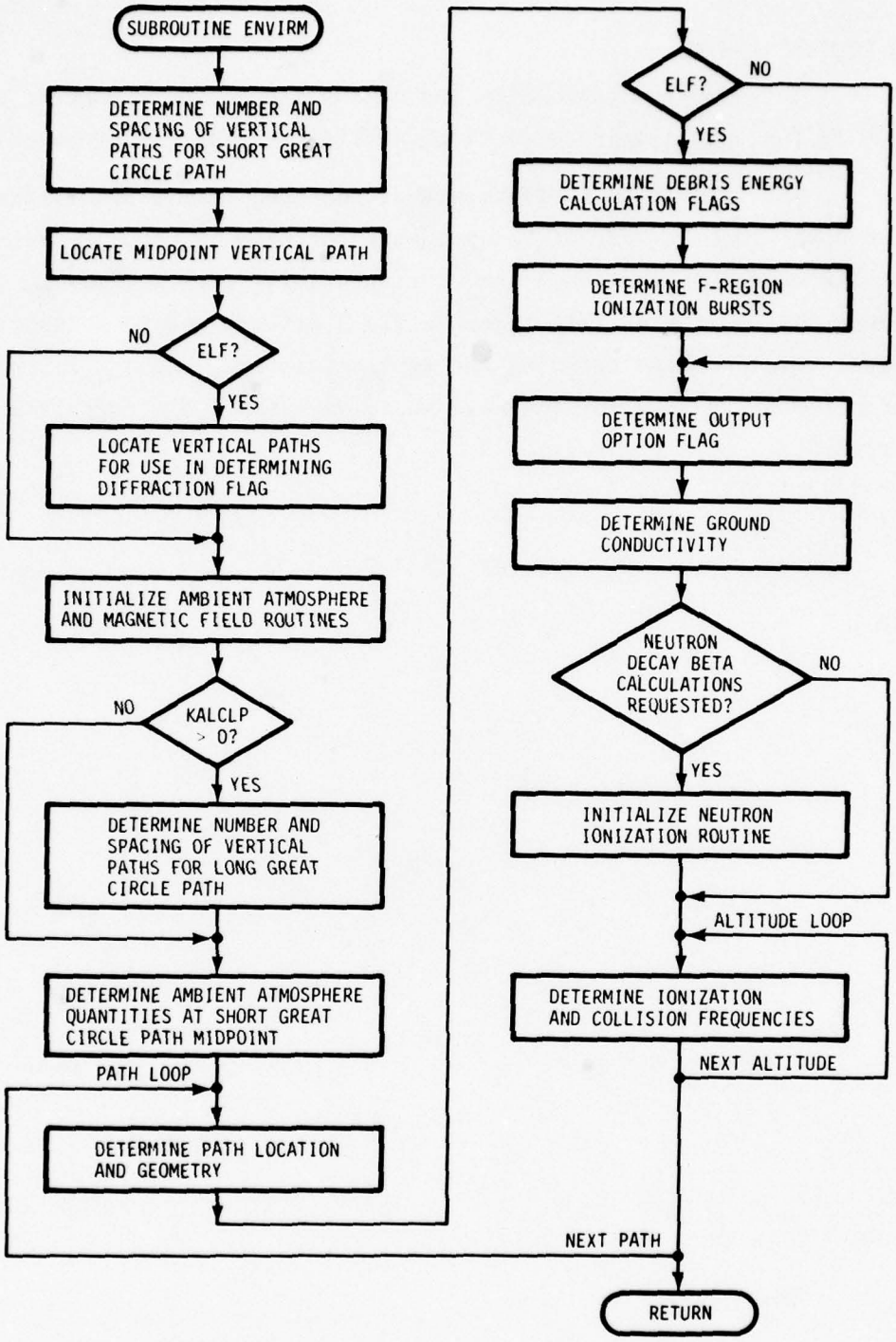

Figure 9. Flowchart for subroutine ENVIRM.

SUBROUTINE EPRIME

This routine calculates the derivatives with respect to altitude of the anisotropic reflection coefficients for ELF propagation.

The reflection coefficients are defined from a prior integration step. Use is made of the property that the $_{\parallel}R_{\parallel}$ and $_{\perp}R_{\perp}$ values for ELF cases approximate 1 and -1 respectively (see Section 2, Volume 3). If the earth's magnetic field effects are to be ignored, simple relationships defining the derivatives are used. More complex definitions are used for the case where magnetic field effects are included.

SUBROUTINE ERINT

This routine calculates ELF reflection coefficients using the Runge-Kutta integration algorithms.

To avoid the possibility of interpolation-induced numerical problems, the integration intervals always start and terminate at adjacent field-point altitudes.

The initial reflection coefficients are defined followed by definition of the lower altitude of the first integration interval. The integration step size is defined as 0.5 km, and the derivatives of the reflection coefficients are calculated.

Second- and fourth-order Runge-Kutta integrations are performed. A measure of the error is made by computing the root mean square of the difference between the two integrations. This error is used to determine the step size for the next integration step, which is halved, held constant, or doubled depending on the magnitude of the error.

When the step size is to remain constant or be halved, a test is made to determine if the bottom of the integration has been reached. If it has, control is returned to the calling routine. If more field altitudes remain to be processed, routine ERINT does the next integration step.

SUBROUTINE ESMAT

This routine calculates the S-matrix of the coefficients for the ELF reflection coefficient differential equation.

The equations used for determining the S-matrix values are in Appendix A, Volume 3.

SUBROUTINE ESTART

This routine calculates the starting values for ELF reflection coefficient integration through an anisotropic ionosphere.

The equations used to determine the initial reflection coefficient values are defined in Appendix B, Volume 3. For isotropic ionospheres the coupled terms ${}_{\perp}R_{\parallel}$ and ${}_{\parallel}R_{\perp}$ are zero, and ${}_{\parallel}R_{\parallel}$ and ${}_{\perp}R_{\perp}$ can be determined from simple expressions.

For the anisotropic case the Booker quartic coefficients are calculated, followed by solving for the roots of the quartic. These solutions are then used as initial values for a Newton-Raphson iteration technique that refines the values. The two roots that correspond to the upgoing waves are selected and used to determine the reflection coefficient matrix values.

SUBROUTINE ETGAIN

This routine calculates ELF height gain functions.

Flat-earth expressions defined in Section 3, Volume 3, are used to calculate the ELF height gain functions.

SUBROUTINE EXCFAC

This routine calculates VLF anisotropic excitation factors.

The excitation factors are determined as a function of the ground reflection coefficients and eigenangle from relations given in Section 3, Volume 3.

SUBROUTINE FDELH

This routine computes ionospheric incidence angles, semi-hop ground distance, and the ray path length for LF propagation.

Standard curved-earth geometry formulations are used.

SUBROUTINE FINDHP

This routine finds the reflection altitude for a ray with a specified ground elevation angle. A flowchart for the routine is shown in Figure 10.

This routine is called in an iterative ray-geometry calculation, with a trial ground elevation angle defined. A nominal reflection altitude and the ionospheric scale height and ionospheric bottom altitude (below which ionization is negligible) are defined at all vertical paths along the great circle path.

Vertical path indices that bracket the reflection region are defined, and a conservative estimate of the lowest possible reflection altitude is made. Then an iteration loop is initiated to find the actual reflection height. Within the iteration loop the following steps occur:

1. The distance from the ray origin to a point on the ray that is at the trial altitude is computed, given the ray ground elevation angle. The ionospheric incidence angle is also computed.
2. Interpolation is used to define a nominal reflection altitude and ionospheric scale height.
3. The actual reflection altitude is computed using the interpolated values from Step 2 and the computed ionospheric incidence angle.
4. The trial altitude is incremented upward and Steps 1 through 4 repeated until the trial altitude differs by a specified minimum value from the computed reflection altitude.
5. The value computed for the reflection altitude in the last iteration is defined to be the required reflection altitude.

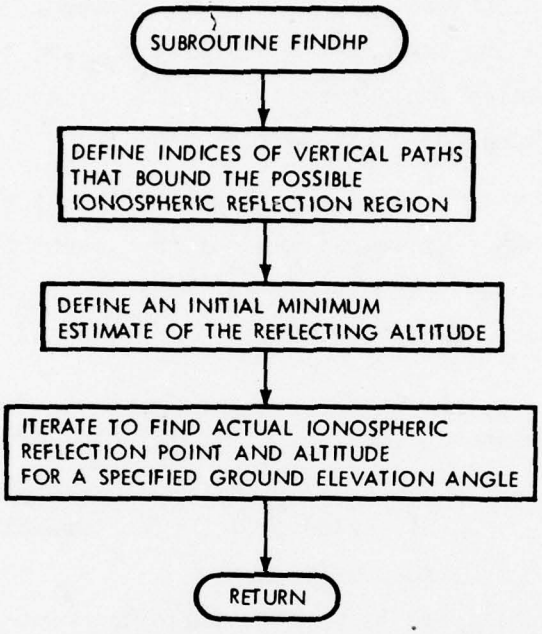

Figure 10. Flowchart for subroutine FINDHP.

The nominal reflection altitude and ionospheric scale height and the definition of the reflection altitude in terms of these quantities and the ionospheric incidence angle are explained and formulas given in Section 4, Volume 3.

SUBROUTINE FINGEO

This routine computes hop geometry between transmitter and receiver antennas. A flowchart for the routine is shown in Figure 11.

Subroutine FINGEO contains iteration loops for defining skywave geometry when the ionospheric reflection altitude varies along the propagation path. Five skywave paths are sought with N - 2, N - 1, N, N + 1, and N + 2 ionospheric reflections, where N is the minimum number of hops required to traverse the total distance between transmitter and receiver without diffraction. When N - 2 or N - 1 is zero or negative, the corresponding path is not considered. A maximum limit on the number of hops is set at nine.

The iteration starts with a one-hop path. The ground elevation angle is initialized to zero, and the total distance traveled by a one-hop ray is computed in FINDHP. If the distance traveled is less than the path distance, the hop counter is incremented and the path geometry for a two-hop path is sought. This process is continued until the sum of the hop distance exceeds the total path distance. Then the ground elevation angle is incremented in an iteration loop to make the total hop distance agree with the total path length within a specified tolerance.

The number of hops that produces the first hop-length sum that exceeds the path distance defines N (described above). The maximum number of hops is defined as N + 2, and the diffracted path with the greatest number of hops is defined as N - 1.

After defining N, the hop geometry for N + 1 and N + 2 hop skywaves is defined by iterating on ground elevation angle.

Finally, after defining the geometry for all the rays where geometric optics apply, the geometry for diffracted paths is computed when N exceeds 1. The diffraction path geometry is obtained by dividing the path into equal increments, assuming the ionospheric reflection point occurs at the middle of the increment and that the ground elevation angle is zero.

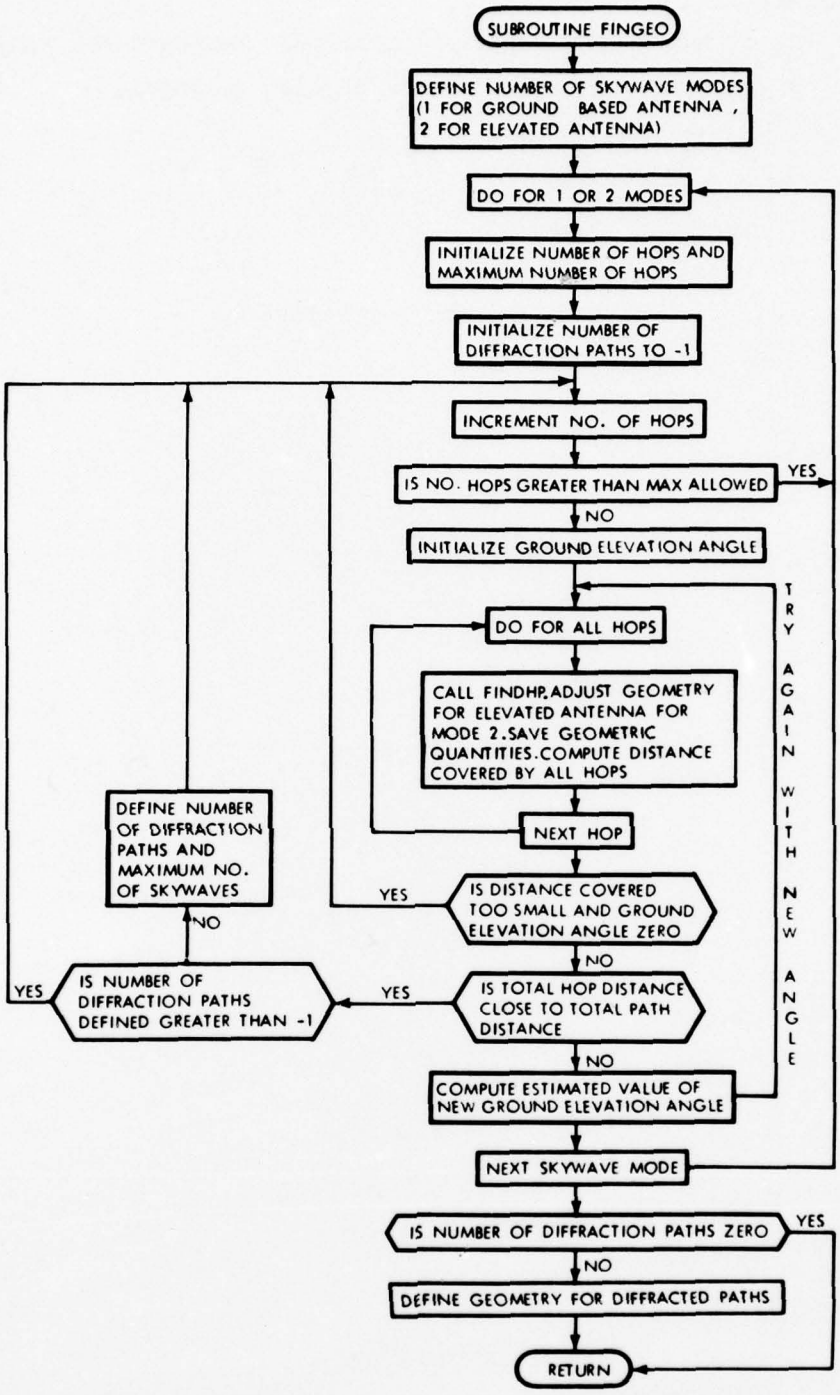

Figure 11. Flowchart for subroutine FINGEO.

The equations and description of the procedure for searching out the hop geometry are described in Section 4, Volume 3.

SUBROUTINE FMAG

This routine computes horizontal and vertical groundwave loss functions, and diffraction losses. A flowchart for the routine is shown in Figure 12.

Subroutine FMAG computes all parameters used to define the influence of the ground on the skywave fields. The groundwave loss term is computed using Airy functions representations. The antenna foreground factors are computed using either a geometric representation for ground elevation angles greater than 2 degrees or Airy function formulations for smaller ground elevation angles. Ground reflection loss or diffraction loss is computed at intermediate ground reflection points.

Both geometrical optical approximations (Fresnel coefficients) and the Airy function formulations are described in detail in Section 4, Volume 3.

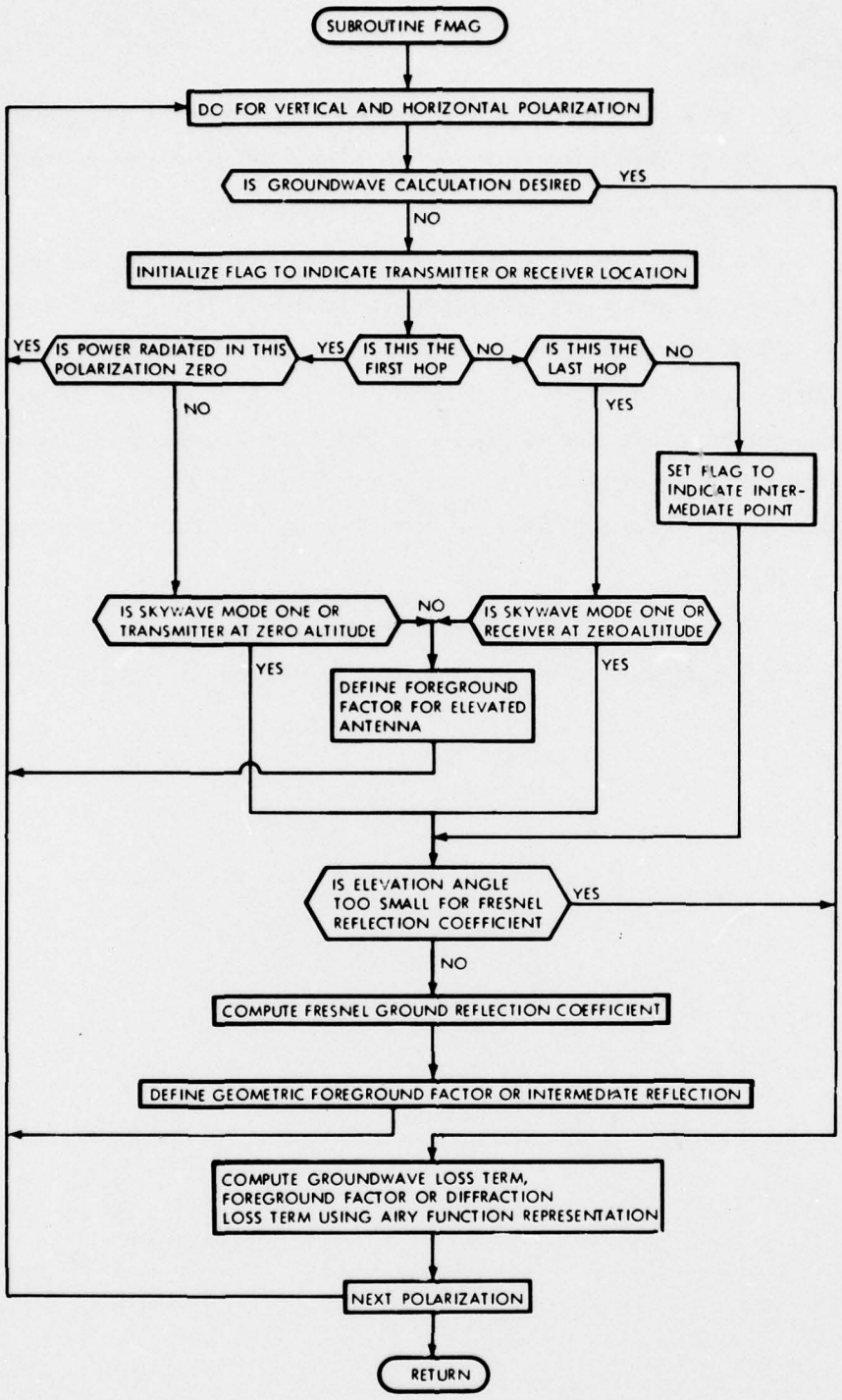

Figure 12. Flowchart for subroutine FMAG.

SUBROUTINE GNDWV

This routine computes the groundwave attenuation function for a specified path length, wave frequency, and ground impedance.

An average value for the ground conductivity is first computed. The groundwave loss function for a homogeneous curved earth is obtained from Subroutine FMAG. The formulas evaluated in FMAG are described in Section 4 of Volume 3.

SUBROUTINE GREFL

This routine computes the Fresnel ground reflection coefficient.

This routine computes the ground reflection coefficient using standard Fresnel formulas for both horizontal and vertical polarization. It is used for ground elevation angles greater than 2 degrees.

SUBROUTINE GUESS

This routine determines isotropic mode solutions for VLF propagation.

First, the polarization (horizontal or vertical) is determined and routine ISOREF is called to determine the isotropic reflection coefficients. Then, a call to routine APPROX is made to determine the eigenangle. The eigenangle is referenced to the altitude where the index of refraction is assumed to be unity and excitation and height gain factors are determined.

SUBROUTINE HTGAIN

This routine calculates the anisotropic antenna height-gain factors for VLF propagation.

The VLF height gain factors are calculated as defined by equations in Section 3, Volume 3. The first time routine HTGAIN is called, an initialization is performed for all parameters independent of antenna altitude. For subsequent calls to routine HTGAIN, only altitude-dependent parameters are computed. If the imaginary part of the eigenvalue that is input to HTGAIN exceeds 10 degrees, flat-earth approximations are used. Otherwise curved-earth calculations are made.

SUBROUTINE INPUT

This routine reads input quantities for the WEDCOM IV code, converts input problem geometry into coordinate systems used within the code, performs preliminary calculations, and writes out a description of the problem to be run.

A detailed description of the input data format and input quantities is given in Section 2 of Volume 1. First, input data (Input Blocks 1 through 9) are read. If input data for particular Input Blocks are not given, previously specified data (stacked problem cases) or default data are used.

In conjunction with reading input data, the number of calculation times are determined if these inputs are specified. Also, if weapon spectral data are given, routines WOG1, WON1, and WOX1 are called to process the data for use in the WEDCOM code.

After the input data are read in, a printout describing the problem case is prepared and geometry calculations for the transmitter and receiver terminal locations and burst point locations determined. The geometry calculations are performed to convert the input geometry specification to an earth-centered geographic vector description and to provide output in all of the several allowable input geometry systems.

If in a stacked problem case the location of the origin is changed and the location of the transmitter and receiver terminal are not (input group 6 changed and input group 7 not given), the terminal locations will be taken as the geographic locations determined in the problem case they were specified. Thus, even if the terminal locations were specified in relation to the origin they will not move unless the input cards (input group 7) are given. The same comment applies to burst locations.

SUBROUTINE IONOSU

This routine computes properties of the ambient ionosphere. The routine is a modified version of routine IONOSU developed by Science Applications Incorporated for ROSCOE (Reference 6).

Inputs to the routine are the altitude of interest, time of day (day or night), and atmospheric properties (neutral species concentrations and gas temperature) at the altitude of interest. For altitudes below 90 km the only output quantity computed is the ambient ion-pair production rate (cm^{-3} sec^{-1}). For higher altitudes, the ambient electron density, atomic ion density, molecular ion density, and electron temperature are computed in addition to the ambient ion-pair production rate. The output quantities are determined by fits to nominal mid-latitude daytime and nighttime data and are not a function of geographic location, or date.

For use in WEDCOM the nighttime electron density profile has been modified to have a minimum value between the F region and the E region maximum similar to that in the nighttime profile adapted by the Naval Ocean Systems Center (Reference 4).

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WEDCOM IV. A FORTRAN CODE FOR THE CALCULATION OF ELF, VLF, AND --ETC(U)
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SUBROUTINE ISOREF

This routine computes coefficients for an exponential representation of the VLF reflection coefficient as a function of the angle of incidence and a phase reference altitude for a specified vertical ionization profile. A flowchart for the routine is shown in Figure 13.

A reference altitude is defined as the altitude where reflection maximizes. Starting with the lowest field-point altitude, computations are made of the real and imaginary parts of the square of the complex index of refraction (Section 3, Volume 3). An exponential interpolation at 1-km intervals is made between field-point altitudes. The reference altitude is defined as the altitude where the imaginary part of the square of the index of refraction is equal to 0.04. The highest and lowest altitudes on the ionization profile that must be considered are defined prior to the call to ISOREF.

After the reference altitude is determined, the reflection coefficient for two specified angles of incidence are found by a recursive relationship that proceeds downward from the highest altitude. "Slab" impedance values are computed for 1-km slabs by interpolating the index of refraction between field points. Depending on the value of KPOL, (an input option indicating polarization) the slab impedances are calculated for either horizontal or vertical polarization. Computations of the phase of the reflection coefficients are made at altitudes below the reference altitude.

The coefficients used in the exponential representation of the reflection coefficient as a function of the angle of incidence are then computed. Generally, reflection coefficient calculations are terminated below an altitude where significant absorption occurs. However, there is the possibility that the ionization below the reference altitude may decrease sufficiently to cause the slab calculation to be terminated and then increase enough (e.g., in a low-altitude debris region where the ionization does not cause reflection) to produce some absorption. To allow for this possibility, absorption occuring below the termination altitude is used to modify the reflection coefficient amplitude.

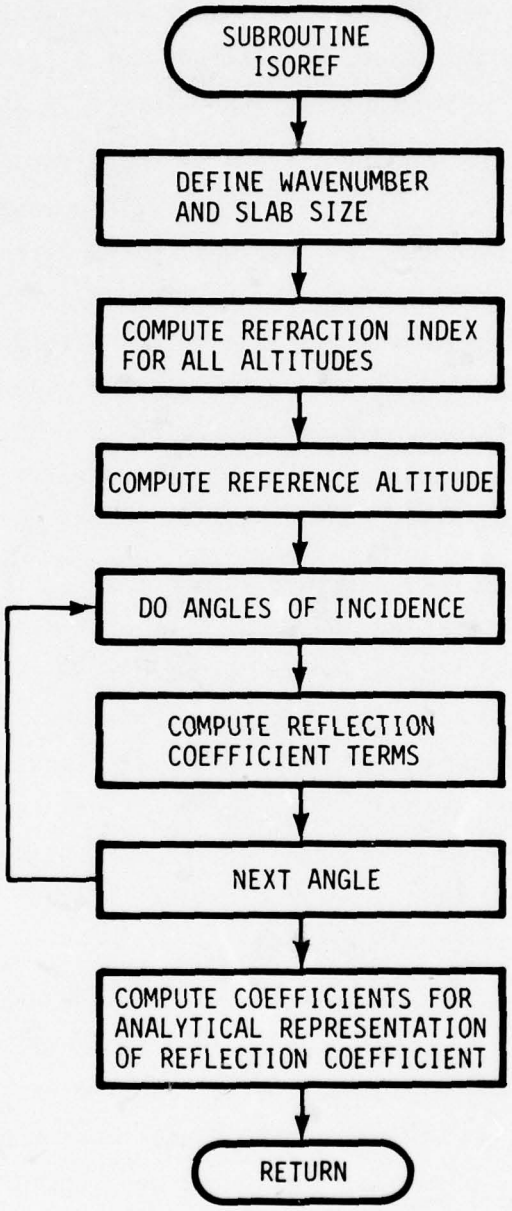

Figure 13. Flowchart for subroutine ISOREF.

SUBROUTINE ISORLF

This routine computes the amplitude and phase of the LF isotropic reflection coefficient and a phase reference altitude for a specified vertical ionization profile and angle of incidence.

Routine ISORLF is essentially the same as routine ISOREF except that calculations are made for a specified angle of incidence given as input and the reflection coefficient is given as output rather than the coefficients used in an analytical representation of the reflection coefficient.

SUBROUTINE LENTRP

This routine interpolates linearly between data stored for adjacent vertical paths to obtain electron and positive ion density values, ground electrical constants, and geometric parameters.

Values for ground conductivity, ground relative dielectric constant, propagation azimuth, magnetic field strength, magnetic field dip angle, ionospheric top and bottom altitudes, ionosphere scale height, and electron and positive ion density vertical profiles are stored for each vertical path. For a given position between two vertical paths, output quantities are found by linearly interpolating with distance.

SUBROUTINE LFHOP

This routine is the LF propagation driver routine and determines anisotropic reflection coefficients and ground wave and skywave field strengths. A simplified flowchart for the routine is shown in Figure 14.

First, propagation parameters and geometry are defined and nominal system quantities are written out. Then, for propagation paths less than 6000 km the groundwave field strength is determined by calling routine GNDWV.

A time loop over the calculation times is started and an ambient calculation flag (determine whether calculations will be made for ambient conditions) is set from input parameters. Next, a loop over the vertical paths between transmitter and receiver is started. For each path magnetic field quantities are established and the level of detailed output requested determined. The ionization and collision frequencies along the vertical path for disturbed conditions are obtained from the environment file. If detailed output concerning the index of refraction has been requested (IOUTPG = 2), routine OUTION is called.

After the ionospheric conditions for each vertical path have been obtained the skywave fields are determined for ambient (if requested) and disturbed conditions. First, routine BHRHS is called to obtain starting and stopping altitudes for reflection coefficient calculations and routine FINEGO is called to determine skywave geometry. Then, routine EHOP is called to determine the skywave field strengths. The total field (sum of groundwave field and skywave fields) is determined by calling routine TFIELD. The last step before starting calculations for the next calculation time is to prepare nominal output for disturbed and ambient field strengths.

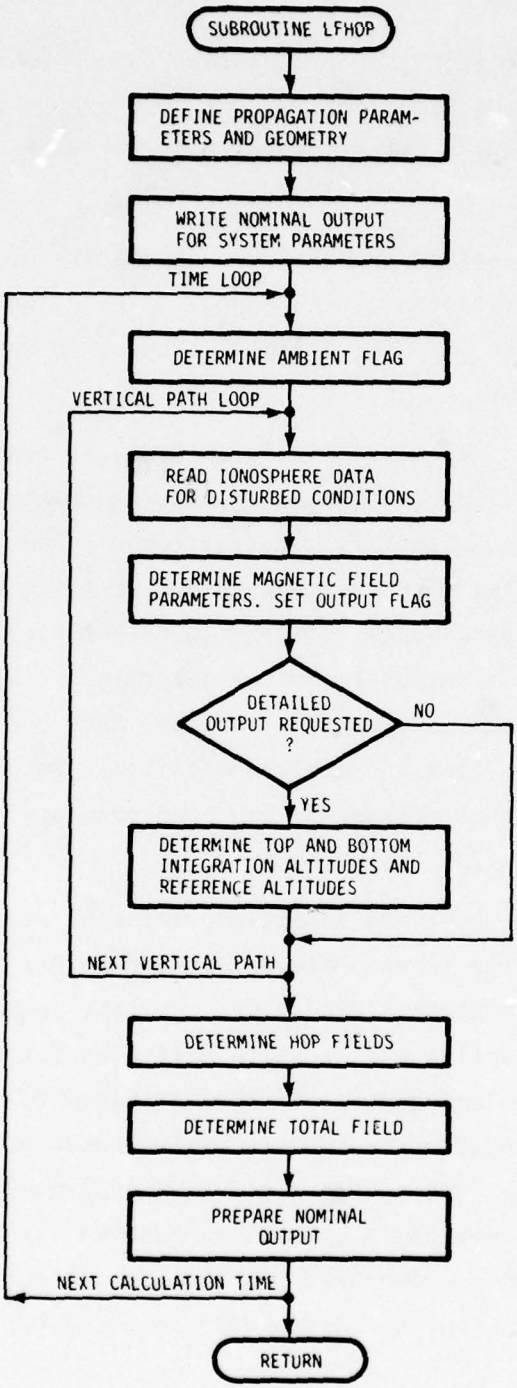

Figure 14. Flowchart for subroutine LFHOP.

SUBROUTINE LINKER

This routine is used when operating the WEDCOM IV code on a Honeywell computer system to provide overlaying. The LINKER routine is used rather than direct calls to LLINK (a Honeywell linking routine) in order to be able to test whether the overlay is already available.

SUBROUTINE MATINV

This routine solves a set of linear simultaneous equations

$$[A]\overline{X} = \overline{B}$$

where

[A] = a square matrix

$\overline{B}$ = force element vector

$\overline{X}$ = independent variable element vector to be solved.

Craut's L - U decomposition algorithm is used with partial pivoting (Reference 7).

SUBROUTINE MDHNKL

This routine computes the modified Hankel functions of order one-third and their derivatives for a specified complex argument. This is an NOSC routine adapted for WEDCOM (Reference 5).

SUBROUTINE MMATRX

This routine calculates the ionospheric susceptibility matrix including magnetic field effects and earth curvature.

The squared ratios of the electron, positive ion, and negative ion plasma frequencies to the signal frequency are defined. Next, the corresponding ratios of collision frequencies to the signal frequency are defined. The susceptibility matrix is initialized.

The susceptibility matrix is calculated by separately calculating and then summing the contributions due to electrons and positive and negative ions. If field effects are not important, only the diagonal terms are calculated. The effects of earth curvature are included by an artificial modification of the diagonal terms in the susceptibility matrix.

SUBROUTINE MODCON

This routine computes the VLF model mode conversion coefficients used to determine the received signal strengths from non-uniform waveguides.

A test is made to determine if the waveguide slab characteristics for the slab under consideration are identical to the prior slab. If so, a simple relationship exists between the coefficients of the new slab and the prior slab. For the first slab, or for the case where two adjacent slab characteristics differ, height-gain characteristics (in Volume 3 Equations 3-65 through 3-70) at the slab interface are computed using the eigenangles for the new slab. Slab interface height-gain characteristics are also computed for the prior slab for the same eigenangles. These characteristics are then used to formulate boundary condition relationships (Equation 3-64). The mode conversion coefficients are computed from the solution of a set of simultaneous equations (Equation 3-63). The height-gain characteristics computed above and mode conversion coefficients are saved for the next slab interface. Detailed output is printed if desired.

SUBROUTINE MODEZ

This routine computes solutions to the VLF mode equation for a given ionospheric profile and ground conductivity. Height gain and excitation factors are also calculated. A simplified flowchart for the routine is shown in Figure 14.

For ground ranges less than 4000 km and frequencies less than 15 kHz six modes are computed; otherwise four are computed. A flag is initialized at the start of the mode loop to direct calculations to the TM or TE mode branch. Half of the mode solutions result from TM calculations and the remaining half from TE calculations. An isotropic solution is found by calling routine GUESS and the attenuation rate is computed. If the attenuation rate is greater than 20 dB/Mm, a logical parameter, ISOANS, is set to 1 to indicate that the isotropic solution will be used.

Routine EIGENV is employed to calculate the value of the eigenvalue, including earth curvature and the earth's magnetic field effects, using the approximate isotropic ionosphere eigenvalue as a first estimate in the iteration process. If the iteration process does not converge, the isotropic value is saved for further calculations and a new mode is analyzed.

If the logical parameter ISOANS is equal to 1 (either because of the attenuation rate or because of being set in routine VLFMOD), the isotropic solution obtained from routine GUESS is used and only parameters related to mode conversion are obtained from routine EIGENV.

After the eigenvalue is calculated, the height gain and excitation factors are found by calling routines HTGAIN and EXCFAC. After all the modes are calculated the mode outputs are reordered so that the real part of the eigenangles decreases as the mode number increases.

If detailed output has been requested, the mode quantities, excitation factors and height-gain factors are written out.

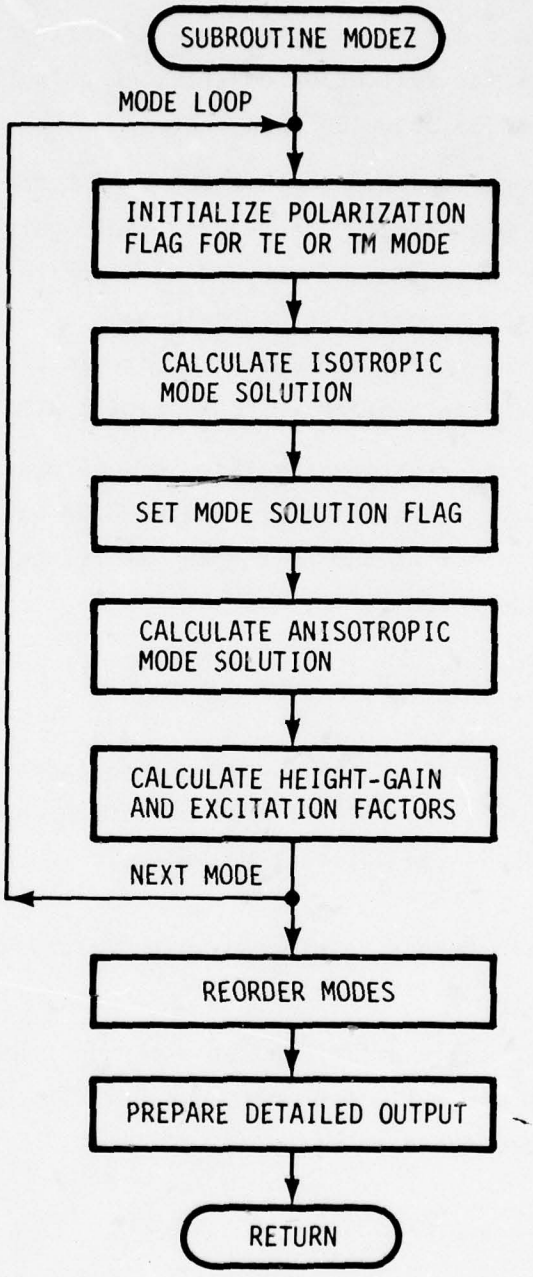

Figure 15. Flowchart for subroutine MODEZ.

SUBROUTINE OUTION

This routine computes the ionospheric index of refraction profile, the reference altitude for VLF and LF reflection, and the top and bottom altitudes for reflection coefficient calculations. A flowchart for the routine is shown in Figure 16.

The anisotropic and isotropic indexes of refraction are defined at each field point beginning at the lowest field point. The anisotropic index is used for detailed output and determining the top altitude for ELF reflection coefficient calculations. The isotropic index is used for approximating the VLF and LF reference altitudes and the top and bottom reflection coefficient calculation altitudes.

For ELF the top starting altitude is determined as the altitude where the one-way vertical absorption equals 30 dB and the bottom altitude is set to zero. For VL and LF the top starting altitude is determined as the altitude where

$$B < 2 \text{ maximum } (1, \frac{10}{\nu/w})$$

where

B = imaginary part of the square of the index of refraction.

The bottom altitude for VLF and reflection coefficient calculations is estimated as the altitude below where

$B < 0.0002$

and the reference altitude is estimated as the altitudes where

$B = 0.04$.

After completing the field-point altitude loop, refinement of the ionospheric top and reflection altitude definitions is made by interpolating between field points.

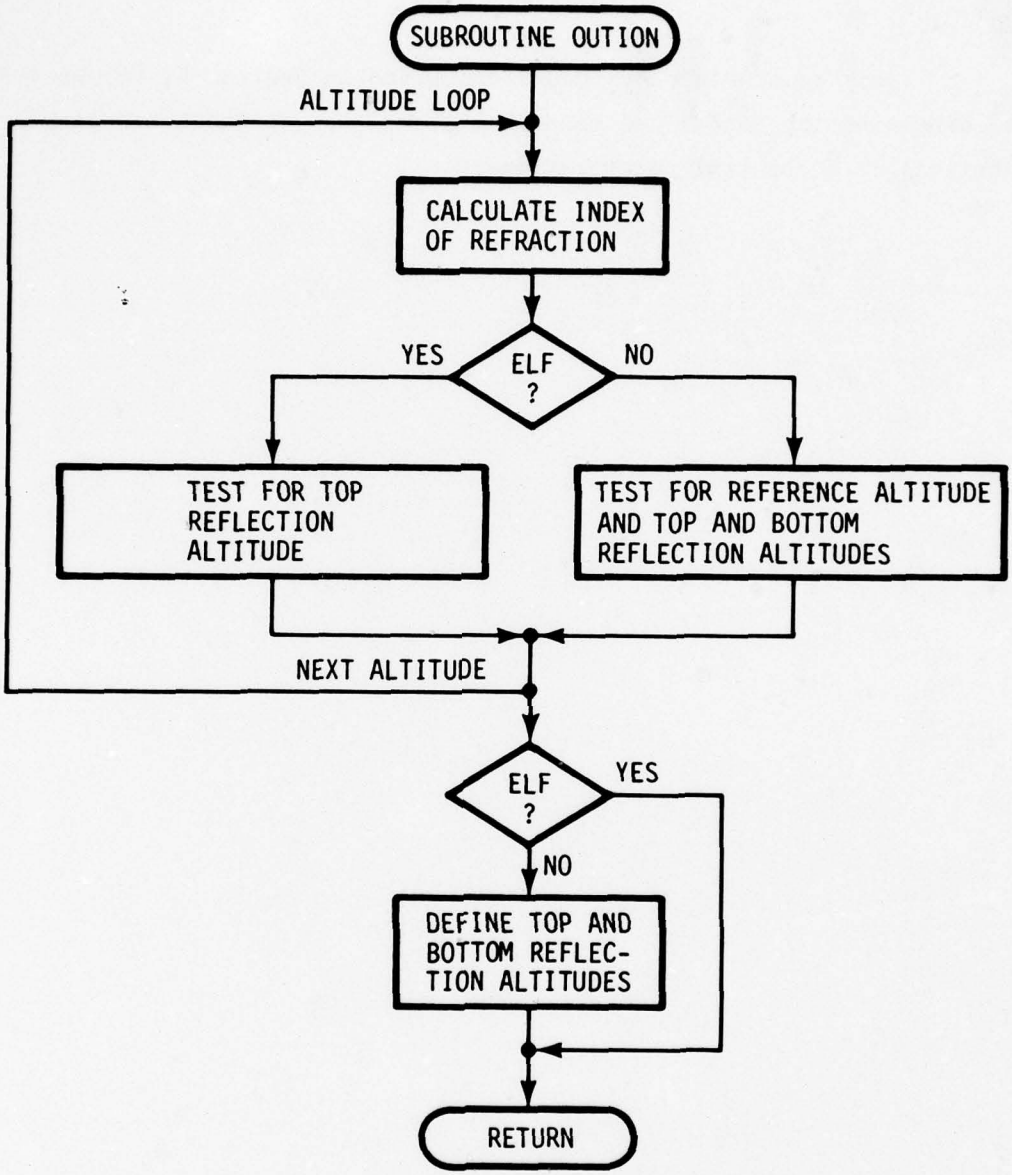

Figure 16. Flowchart for subroutine OUTION.

SUBROUTINE QSUBI

This routine computes the normalized ionospheric surface impedance.

This routine employs equations given in Section 3, Volume 4 to determine the normalized ionospheric surface impedance assuming vertical or horizontal polarization.

SUBROUTINE REFLCO

This routine computes complex values of reflection coefficients. A flowchart for the routine is shown in Figure 17.

Subroutine REFLCO is the driver routine for calculating ionospheric reflection coefficients. Magnetic field quantities, ionospheric incident angle values, and a starting altitude for the reflection coefficient integration are defined. Electron and ion densities, collision frequencies, and elements of the susceptibility matrix are defined at the starting altitude by calling routines ENNU and MMATRX. Starting values for the reflection coefficients are obtained from routine START, and the integration process is initiated by calling routine RINT.

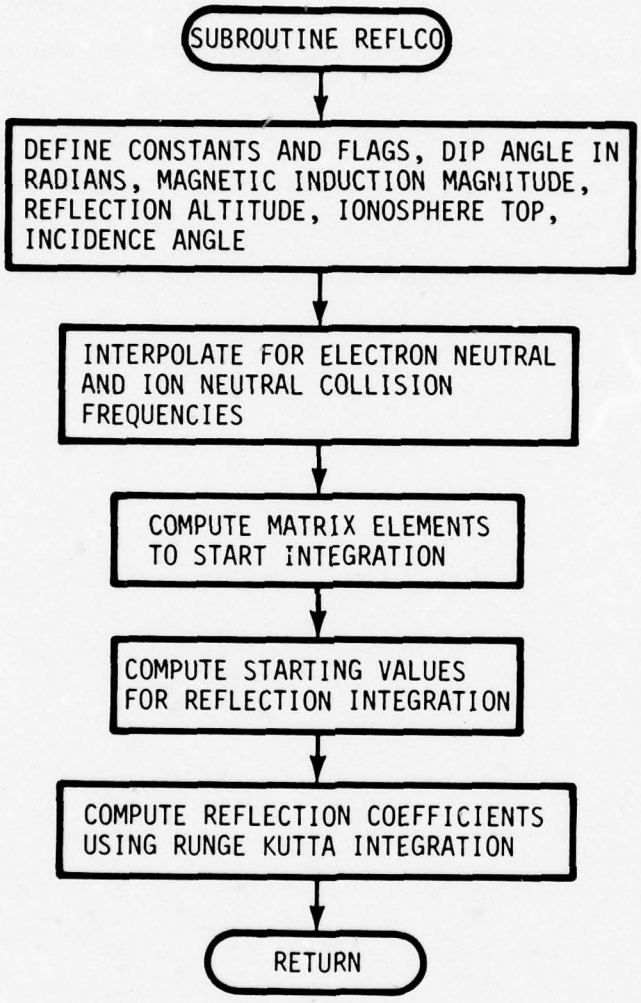

Figure 17. Flowchart for subroutine REFLCO.

SUBROUTINE REORDER

This routine reorders environmental data stored in a file for each vertical path for all calculation times so that they are stored for each calculation time for all vertical paths.

SUBROUTINE RGND

This routine calculates ELF and VLF ground reflection coefficients.

After initialization of several conductivity parameters, a test determines if this is a VLF or ELF case. For VLF the reflection coefficients are calculated using equations given in Appendix C, Volume 3. For ELF the Fresnel ground reflection coefficients are calculated.

SUBROUTINE RINT

This routine calculates reflection coefficients using the Runge-Kutta integration algorithms. A flowchart for the routine is shown in Figure 18.

To avoid the possibility of interpolation-induced numerical problems, the integration intervals always start and terminate at adjacent field-point altitudes.

The reflection coefficient starting values are defined followed by definition of the lower altitude of the first integration interval. The integration step size is defined as 0.5 km and the derivatives of the reflection coefficients are calculated.

Second- and fourth-order Runge-Kutta integrations are performed. A measure of the error is made through a root-mean square of the difference between the two integrations. This error is used to determine the step size for the next integration step, which is halved, held constant, or doubled depending on the magnitude of the error.

When the step size is to remain constant or be halved, a test is made to determine if the bottom of the integration interval has been reached. If it has, control is returned to the calling routine. Otherwise, if more field altitudes remain to be processed, Subroutine RINT does the next integration step.

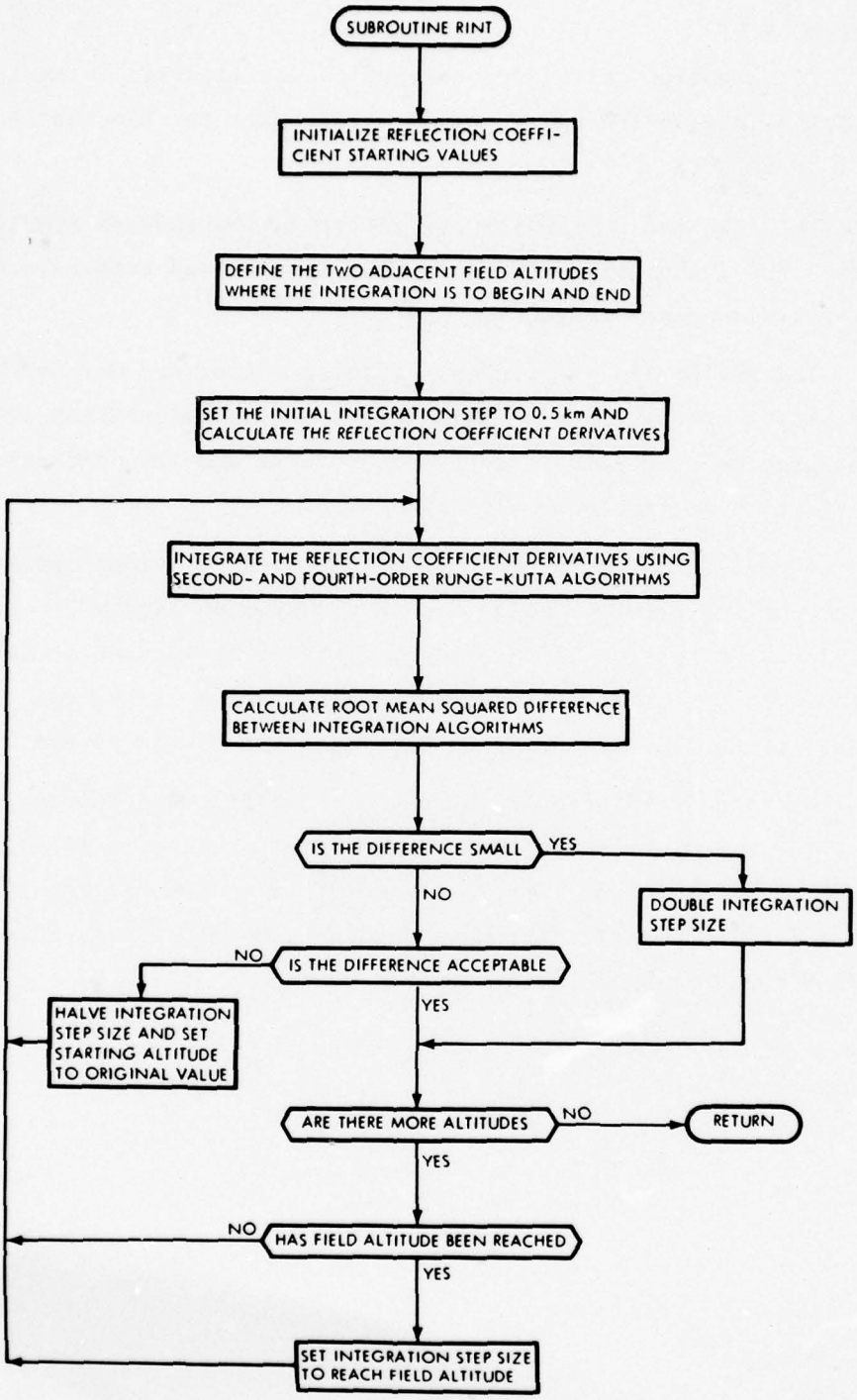

Figure 18. Flowchart for subroutine RINT.

SUBROUTINE ROOT

This routine employs Newton's procedure to compute the root of the VLF mode equation

Subroutine ROOT employs Newton's iteration method to calculate the solution to the isotropic mode equation from a given approximate solution. The parameter AMIN is defined as the absolute part of (1 - AB), where A and B are defined in Section 3, Volume 7. To obtain a good solution, AMIN must be smaller than 0.005, and the magnitude of the difference between successive calculations of the root must not be larger than 0.005. When these conditions are not satisfied after 20 iterations, a statement is written indicating the last value of AMIN. When the process diverges, the root is set to the original guess if it is a good approximation; otherwise a large attenuation is assigned.

SUBROUTINE RPRIME

This routine calculates the derivatives with respect to altitude of the anisotropic reflection coefficients.

The reflection coefficients are defined from a prior integration step. If the earth's magnetic field effects are to be ignored, simple relationships defining the derivatives are used. More complex definitions are used for the case where magnetic field effects are included (see Section 2, Volume 3).

SUBROUTINE RSTART

This routine calculates the starting values for reflection coefficient integration through anisotropic ionospheres.

The equations used to determine the initial reflection coefficient values are defined in Appendix B, Volume 3. For isotropic ionospheres the coupled terms ${}_{\perp}R_{\parallel}$ and ${}_{\parallel}R_{\perp}$ are zero, and ${}_{\parallel}R_{\parallel}$ and ${}_{\perp}R_{\perp}$ can be determined from simple expressions.

For the anisotropic case, the Booker quartic coefficients are calculated, followed by solving for the roots of the quartic. These solutions are then used as initial values for a Newton-Raphson iteration technique that refines the values. The two roots that correspond to the upgoing waves are selected and used to determine initial reflection coefficient matrix values.

SUBROUTINE RUNG

This routine performs a Runge-Kutta integration in the ground-wave calculations.

A standard fourth-order Runge-Kutta integration procedure is used. One of the following two equations is integrated over the inverval from 0 to Q_o:

$$\frac{dt}{dQ} = \frac{1}{t - Q^2} \quad \text{where } Q_o = Q_{mag} \text{ for } |Q_{mag}| < 1$$

or

$$\frac{dt}{dQ} = \frac{1}{1 - tQ^2} \quad \text{where } Q_o = \frac{1}{Q_{mag}} \text{ for } |Q_{mag}| > 1$$

SUBROUTINE SMAT

This routine calculates the S-matrix of the coefficients for the reflection coefficient differential equation.

The equations used for determining the S-matrix values are in Appendix A, Volume 3.

SUBROUTINE SURFQ

This routine determines the normalized surface impedance for horizontally or vertically polarized fields.

Subroutine SURFQ solves equations given in Section 3, Volume 3 to determine the normalized ground impedance for either the horizontally or vertically polarized fields, depending on the option selected at input.

SUBROUTINE TEM

This routine calculates TEM mode field values at the receiver for ELF propagation. A simplified flowchart for the routine is shown in Figure 19.

First, propagation parameters and geometry are defined and nominal system output quantities are written out. Then a time loop over the calculation times is started and eigenvalue-dependent data parameters defined in routine ELFMOD are read from a data file. If ambient calculations have been requested (input option) data for ambient conditions are read in first; otherwise, data for disturbed conditions are obtained. The short- and long-path height-gain factors for the transmitter and receiver locations are determined by calls to routine ETGAIN. The short path WKB approximation is always calculated and the long path calculation is made when requested (input option). Then, the short path (and the long path when requested) electromagnetic fields at the receiver location are determined and nominal output is written out. If the multiple receiver location option (input option) has been exercised, the electromagnetic fields at each vertical path location are computed. After calculations have been completed for disturbed conditions, calculations are started for the next calculation time.

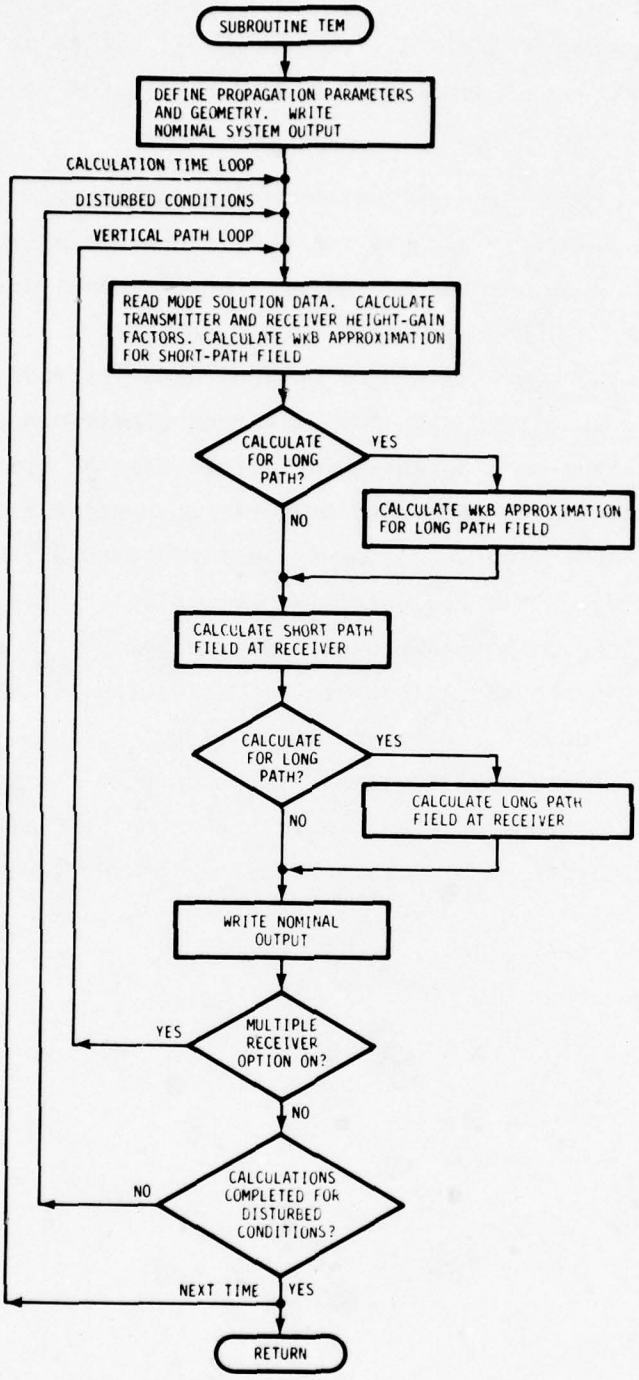

Figure 19. Flowchart for subroutine TEM.

SUBROUTINE TFIELD

This routine computes the total LF electric field strength by summing the fields of all the skywaves and the groundwave.

The electric field is first set equal to the groundwave value. Then, a vector or rms sum of the groundwave and skywave fields is computed. The vector sum is used when the multiple receiver location option (input option) is exercised and calculations of the electric field are made at each vertical path location. The rms sum is used when the multiple receiver location option is not exercised and calculations of the electric field are only made at one location. If detailed output has been requested (input option), the field strengths for vertical, normal, and parallel field polarizations at the transmitter and receiver locations are written out.

SUBROUTINE UANTD

This routine determines the orientation of the transmitter antenna as a function of time.

This is a dummy routine for illustration. The transmitter antenna zenith angle and azimuth angle are both set to zero (vertical dipole).

SUBROUTINE VLFMCV

This routine computes the VLF electric field strength in each mode at each vertical path location and the total field strength at receiver locations using mode conversion to account for effects of a variable height earth-ionosphere waveguide.

Parameters are first defined which relate the transmitter power to antenna orientation. Then cumulative mode conversion coefficients are computed for the region between the transmitter (first vertical path location) and the current vertical path location. The eigenangles, height-gain, and excitation factors for the first vertical path location are saved. Then, if the current vertical path location is a receiver location, the total field is computed from either a vector or rms sum of the mode fields. The vector sum is used when the multiple receiver location option is exercised (input option) and calculations of the electric field are made at each vertical path location. The rms sum is used when only one receiver location is specified.

SUBROUTINE VLFMOD

This routine is the VLF propagation driver routine and determines anisotropic reflection coefficients, mode solutions, and excitation factors. A simplified flowchart for the routine is shown in Figure 20.

First, propagation parameters and geometry are defined and nominal system output quantities are written out. Then, a time loop over the calculation times is started and an ambient calculation flag (determines whether calculations will be made for ambient conditions) is set from input parameters.

Next, a loop over the vertical paths between transmitter and receiver is started and calculations made for the disturbed environment. For each path the ionization and collision frequencies are obtained from the environment file. Magnetic field and ground conductivity quantities are established and the level of detailed output requested is determined. Then, routine OUTION is called to determine a reference altitude and the top and bottom altitudes to be used in computing reflection coefficients. If the reference altitude is less than 55 km, a logical parameter, ISOANS, is set to 1 to indicate that an isotropic mode solution is to be used.

If the input option to minimize the number of reflection coefficient calculations is exercised (MRCOEF = 1), tests are made to see how much the top altitude obtained from routine OUTION, the magnetic field properties, and the ground conductivity have changed from the values computed for the previous vertical path. If they have not changed by more than specified amounts, the mode characteristics previously determined are used for the current vertical path. Otherwise, either routine EIGSCH (reference altitudes greater than 70 km) or routine MODEZ (reference altitude less than 70 km) is called to determine the mode characteristics.

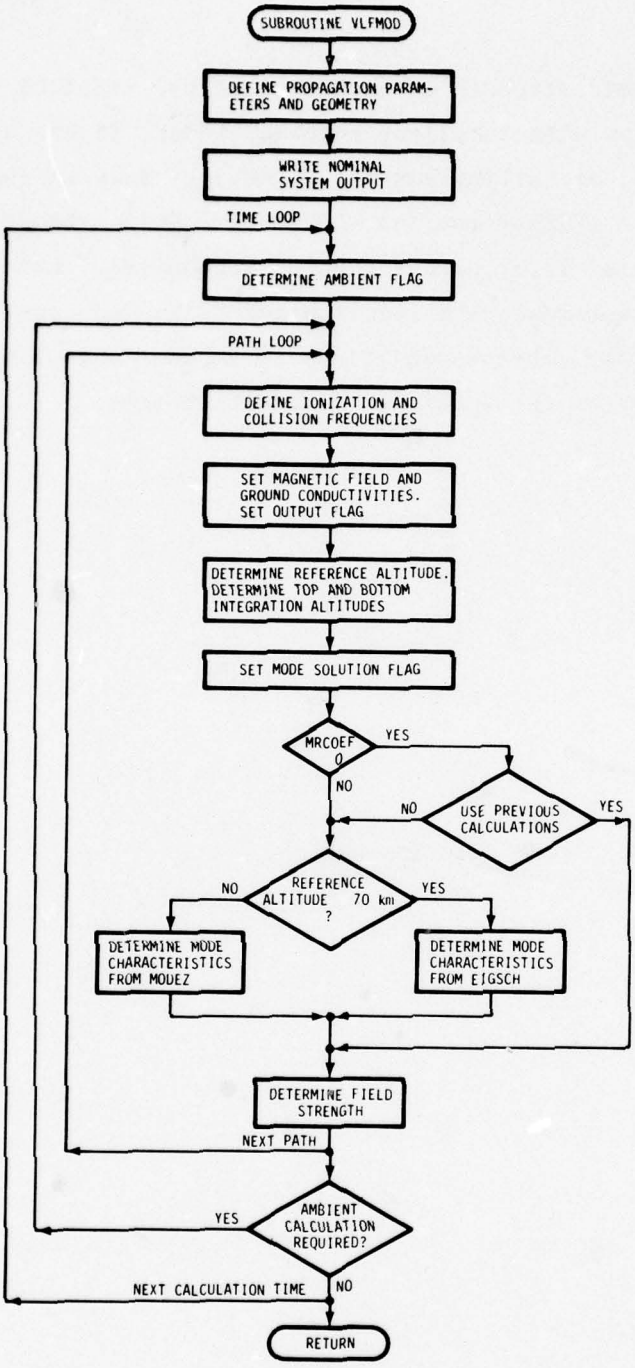

Figure 20. Flowchart for subroutine VLFMOD.

The field strength of each mode at the vertical path location is determined by either calling routine VLFWKB, if the WKB approximations are used, or calling routine VLFMCV, if mode conversion is to be determined. (Either routine VLFWKB or routine VLFMCV must be chosen as overlay [7,3] before running WEDCOM IV). Calculations are made for each vertical path location for disturbed conditions and then repeated for ambient conditions if ambient calculations have been requested for the specified calculation time.

SUBROUTINE VLFWKB

This routine computes the VLF electric field strength in each mode (WKB approximation) at each vertical path location and the total field strength at receiver locations.

First, the electric field strength in each mode at the current vertical path location is computed using a WKB approximation. Then, if the vertical path location is a receiver location, the total field is computed from either a vector or rms sum of the mode fields. The vector sum is used when the multiple receiver location option is exercised (input option) and calculations of the electric field are made at each vertical path location. The rms sum is used when only one receiver location is specified.

SUBROUTINE WFCTVL

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine computes F function values at mesh points.

SUBROUTINE WFINDF

This is a modified NOSC routine used in the mode search algorithm. It is used to compute the modified mode equation (Equation 3-8 in Volume 3) at a corner of a particular mesh.

SUBROUTINE WFDFDT

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine computes F function values and their derivatives with respect to θ at arbitrary values of θ.

SUBROUTINE WFSINT

This is a Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine performs an integration of the differential equations for the ionosphere reflection matrix through a free space region over a curved earth.

The routine has one additional entry point besides the main entry point. Entry point WINIFS is used for an integration that is independent of θ.

SUBROUTINE WFZERO

This is a modified Naval Ocean Systems Center routine used in mode search computations (Reference 5). The routine finds the zeros of a complex function, F, which are within a specified rectangular region of the complex (θ) plane, provided the function has no poles in the vicinity of the rectangle.

SUBROUTINE WLGRNG

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine performs Lagrange interpolation of reflection coefficients in the cos θ plane.

The routine has three additional entry points besides the main entry point. Entry point WINILG is used to initialize the Lagrange interpolation. Entry WLGDER is used to compute the derivatives of the interpolated values of cos θ. Entry WSETLG is used for further initialization of the Lagrange interpolation.

SUBROUTINE WNOMES

This is amodified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine finds exact (in the sense of no mesh approximations) locations of zeros of the function F for which a complete, but approximate, set was found in routine WFZERO.

SUBROUTINE WQUAD

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine finds the solution for the real roots of a quadratic equation of the form

$$ax^2 + 2bx + c = 0$$

SUBROUTINE WRBARS

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine computes values of variables used to form the elements of the reflection coefficient matrix of an ELM wave from the earth's surface.

The routine has one additional entry point besides the main entry point. Entry point WINFRB is used for computation that is independent of θ.

SUBROUTINE WSETRH

This is a modified Naval Ocean Systems Center routine used in mode search calculations (Reference 5). The routine selects given points in the Lagrange interpolation and selects the reference height.

SUBROUTINE XFER

This routine transfers one array into another.

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