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The RAIDER Program

Radio Algorithms for Integration and Design of Engineering Requirements

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PREFACE

Certain commercial equipment and programs are identified in this report to adequately explain the operation of the program. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the program or equipment identified is necessarily the best available for this application.

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THE RAIDER PROGRAM

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The Radio Algorithms for Integration and Design of Engineering Requirements (RAIDER) program consists of a set of modules which provide an easy to use and precise approach to the complete design and documentation of terrestrial radio links operating in the frequency range of 1 to 30 GHz. The program allows the engineer to design both analog and digital line-of-sight links and analog beyond line-of-sight links. Tabular and graphical outputs are developed which may be rendered to the screen or as hard copy at the request of the operator. The input variables can be easily changed and new outputs calculated to enable "what if" studies to be performed. The operator is prompted to input all required values so calculations can proceed and each user input is compared with a range of acceptable values to ensure accurate and complete calculations.

Key words: Automated calculations; Desk-top computer algorithms; Diffraction links; Input value range checking; Microwave links; Operator prompting; Radio link design; Tabular and graphical hard copy; Troposcatter links

1. INTRODUCTION

The use of terrestrial radio links to provide high-speed digital interconnections or multi-voice channel analog communications is important to support both civilian and military government activities as well as private sector functions. The military communication commands have supported development projects at the Institute for Telecommunication Sciences (ITS) for a number of years and in particular the U.S. Army Information Systems Engineering Command (ISEC) has supported the development of the Radio Algorithms for the Integration and Design of Engineering Requirements (RAIDER) program. This program is the most recent in a series of projects that ITS has undertaken to allow the use of desk-top computers to perform the calculations for terrestrial links that had heretofor required extensive hand calculations and the assistance of a large main-frame computer for their execution. The programs are designed to be used both in the field and in the office by personnel familiar with radio systems. The modularity of the design and the careful attention to good human interface practices make RAIDER of considerable value to any organization involved in the design, installation, upgrade, or maintenance of terrestrial radio systems.

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1.1 Algorithms Used for the Calculations

One of the basic philosophies that guided the development of the RAIDER program and its predecessors was that the algorithms used would be the most up-to-date available from accredited sources and no compromise of accuracy or completeness would be made. Many of the basic algorithms used for the Earth geometry calculations, enter path profile data, and draw the path profile and ray paths are based on the previously developed programs. These were updated and rewritten in the C language. The algorithms for line-of-sight (LOS)[1] link propagation reliability and rain attenuation are taken from the latest International Radio Consultative Committee (CCIR) reports and recommendations. The algorithm to determine the distortion fade margin for digital radios was provided by AT&T, as was the algorithm to use the CCIR technique of determining the expected rain rate distributions for various parts of the world.

1.2 Ease of Use

The RAIDER program was also designed to provide the ultimate in human interface usability and flexibility. Considerable attention has been given to making the RAIDER program available to non-engineer communication planners, particularly for tactical military users. Extensive use was made of menus for selecting functions and pop-up windows for information, help screens, and to indicate the allowed range of input variables. The calculation algorithms run quickly so studies of possible variations in equipment layout and physical parameters can be made and evaluated to arrive at a near-optimum design. To a large extent, the software uses curve fitting techniques to eliminate the need for reading graphical data. Tables of data are used to support the rain attenuation calculations to make them independent of rain rate maps. Waveguide loss charts and tables, and other information that might not be available in the field are incorporated into the program.

2. INITIAL SETUP

RAIDER has been designed so that it can run on many different types of hardware platforms which use the PC-DOS operating system. Although a hard disk drive is not essential to run the programs, it makes the modules respond much more quickly and makes the program easier to use. If a hard disk is used, 3.5 megabytes of disk storage must be available. Loading the software is easily accomplished as described below. Some knowledge of the peripheral devices is necessary for the user to set the variables to control the printer and plotter.

2.1 Equipment

The RAIDER program can be run on any personal computer using a PC-DOS 2.0 or later operating system. The system must be equipped with a floppy drive, either 5 1/4" 720 kbyte or 1.2 Mbyte, or a 3 1/2" disk drive to read the RAIDER files. The monitor may be monochrome or color and the graphic output will be adjusted to drive either a CGA, EGA, VGA, or an 8514-type high resolution monitor. The user is given the option of printing the input and output data displays on a laser printer. Those modules which produce graphic displays allow the user to view the plots on the screen, send the display to a plotter, or generate an HPGL (Hewlett-Packard Graphics Language) file for off-line plotting. Commercial programs such as Print-A-Plot are available which will allow an HPGL file to be printed on a laserjet printer. Any model of plotter which will respond to HPGL commands can be used for plotting RAIDER graphic displays. The RAIDER initialization program described in Section 2.3 allows the user to set up the plotter and the printer.

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[1] LOS is used interchangeably with line-of-sight in this report.

2.2 Loading Software

The RAIDER program set consists of thirteen modules that accept user inputs and produce graphical and tabular calculation outputs for point-to-point radio link performance predictions. The file RAIDER.BAT and the program WHAT.EXE are used to call the various modules in the RAIDER program set. Three bit-mapped fonts and two vector fonts used for the graphic plotting routines are included. The files "ne", "nw", "se", and "sw" are the RAIDER rain rate data files. The file called PALETTES.CFG sets the colors for the menu system incorporated in RAIDER and the file ANSI.SYS is used by the RAIDER modules to perform screen manipulations including cursor movement and color changes.

2.2.1 Software Installation

To prepare for the installation of RAIDER on a hard disk system, the user should create a directory called "RAIDER". The files on the floppy disk set should then be loaded into this directory using the DOS COPY command. Any RAIDER module that produces graphics should be run from this directory to provide access to the font files. The user should add an entry in the autoexec.bat file which states "SET FULLCOLOR=Y" if the monitor is color and "SET FULLCOLOR=N" if the monitor is monochrome. This will automatically let RAIDER determine the terminal type without asking the user for this information for each module. The RAIDER module to initialize the system is described in Section 4.1.1.

3. GENERAL OPERATION OF MODULES

The RAIDER program consists of thirteen modules that are individually started using the batch file shown as the main menu in Figure 1. The data used for the modules is stored in a link file system. A link file is a file which contains all of the information for a path which was entered by the user and all of the values which were calculated for the path. The creation and manipulation of link files are discussed in Section 4.1.2. Typically, the program would be run from within the RAIDER directory so the graphics programs can access the character font files. When the user types "RAIDER", the menu in Figure 1 appears. The modules listed may be run in any order, but if they are run in the order shown on the screen, many of the required inputs for the current module will already have been entered or calculated in the previous modules. The previously-entered or calculated values are used as defaults which can be changed by the user, although if calculated values are changed, the link file will contain invalid information until the module that calculated the changed value is rerun. For instance, if the antenna gain but not the antenna size is manually changed in the Link Design Summary module, the link file will be incorrect. A better technique is to return to the Gain module and change the antenna size and re-run the Gain calculations. Also, no note is made in the link file that one or more values have been changed from the calculated values, so the operator must be aware of the danger of corrupting a link file. In the main menu, all modules are started by entering the letter on the right-hand side of the screen.

```
                         RAIDER

      Radio Algorithms for Integration and Design

            of Engineering Requirements

    Initialize plotter................................i
    Select a link.....................................s
    Earth geometry....................................e
    Path profile data ................................d
    Plot profile .....................................p
    Climate ..........................................c
    Gain .............................................g
    Troposcatter .....................................t
    FM/FDM ...........................................f
    Variability ......................................v
    Median Diffraction Loss ..........................m
    Radios Dispersive Fade Margin Data ...............r
    Link Design Summary ..............................l
    eXit..............................................x

  Select Menu Item:
```

Figure 1. Raider main menu.

3.1 Module Design

All of the RAIDER modules were designed to provide a uniform appearance. Similar key strokes for control were selected so all modules would have a standard interface. When a module is started, a main menu is presented. While particular entries on the menu are different for each module, many of the functions are common to every program. For instance, every module has an input/edit option and an option to print the input screen. Each module has an output option which may be a plot on the screen, a table of inputs and calculated values, or both. The menu also allows the tabular output screens to be printed and the graphic displays sent to a plotter.

In contrast to the operation of the modules from the RAIDER main menu, the functions performed within the menus in the modules may be indicated in two possible ways. The first is to use the up and down arrow keys to move the emphasized bar to the desired function and pressing the enter key. The second way is to type the first letter of the desired function to activate it.

3.1.1 Input/Edit Screens

When the user chooses the Input/Edit option, a screen is displayed that lists the required inputs for the module and indicates a field for the user to make an entry for each input. The user can move around the screen using the arrow keys, the carriage return, the page up key, the page down key, and the home and end keys. The highlighted inputs are the ones for which values must be entered to allow the calculations to proceed. If the user does not know the appropriate range of values for any one of the inputs, the cursor may be moved to that line and '?' entered; the limits for that entry will be displayed on screen. If the user enters a value that is out of range or contains incorrect characters (letters or punctuation), a message will be displayed and the incorrect entry will be deleted. If the user requests that the calculations be performed without having entered all of the required inputs, a message will be shown on the screen indicating that the calculations will not be executed. This error-checking aids the user in entering valid inputs and ensures that the calculations will be executed without problems.

The RAIDER modules have been designed to use the function keys F1 through F8. In all modules where it is appropriate, the F1 function key is used to change between metric and English units for the values entered and displayed, although the default for the screen values is metric units. The F2 function key is used to redisplay the screen. Function keys F3 through F7 are specific to individual modules and will be described in the sections associated with the modules in which they are used. Function key F8 is used to exit the input/edit screen.

3.1.2 Text Output Screens

The output screens present a summary of the input values and a list of the calculated values. The user can scroll up and down the screen using the same keys that were used on the input screen. An option is presented to the user allowing the output display to be printed, and the output screen is exited by pressing the F8 function key or any key on the main keyboard.

3.1.3 Plots

The user has the option of plotting a graphic display on the screen or on a plotter, or saving the display in a plot file which can be sent off-line to a printer or plotter. If the graphic display is being viewed on the screen, the menu is accessible by pressing any key on the main keyboard. If the graphic display is sent to the plotter, a box is displayed on the screen which asks the user if the plotter is on-line. If the user answers Yes, the plotting begins; the user is automatically returned to the main menu when the plotting is completed. If the user answers No, the plot is aborted and the main menu is returned to the screen. If the user is plotting to a file, a prompt is displayed which asks the user for a file name. This file name can contain up to eight characters. The file will be saved in the directory in which the user is currently working with ".PLT" appended to the name. If a user does not enter a file name, the plot will be saved in the file PLOT.PLT. While a plot is being written to a file, a message is written to the screen stating that this is taking place and the user is returned to the main menu when it is completed. If the file being worked with is for a repeater link, the menu will allow the user to create a plot for either the main link or the repeater link. The colors of the plots can be chosen using the Initialize Plotter module described in Section 4.1.1. A number of software packages are available to rasterize the plot file to be output on a printer. The authors have had good results using a package called "Print-A-Plot".

3.1.4 Exiting the Modules

When a user has finished using a module, the Quit option in the menu should be chosen. When this choice is made, a box will be displayed asking if the new data is to be saved. If a Yes is selected, the data most recently entered or calculated in the current module will replace the old data in the link file. If No is chosen, the link file will not be updated with the new inputs and calculated outputs. If No is selected and the new values are needed to complete or update a link design, the current module must be rerun with the new inputs and the output values saved by selecting the Yes option.

4. MODULES

The RAIDER modules fall into three distinct groups: modules that are run for all paths, modules that are run only for line-of-sight paths, and modules that are run only for beyond-the-horizon paths. The modules that can be run for any type of path are: Initialize Plotter, Select a Link, Earth Geometry, Path Profile Data, Plot Profile, Gain, and FM/FDM. The Climate, Radio Dispersive Fade Margin Data, and Link Design Summary modules can be run for line-of-sight paths only. The Troposcatter, Variability and Median Diffraction Loss modules can be executed for only the appropriate beyond-the-horizon paths. A typical design would be started by establishing a link in the Select a Link module and then running the Earth Geometry and Path Profile Data modules. After the input to these modules has been completed and the calculations performed, the Plot Profile module will determine the type of path which has been entered. Only the subsequent modules appropriate to the type of path as determined in the Plot Profile module may be run for a link. The functions of each of the modules are briefly described below and in more detail in the following sections.

Initialize Plotter sets up the printer and plotter ports, plotter coordinates, and screen and plotter colors.

Select a Link creates and deletes link files and directories, and updates, transfers, and moves link files.

Earth Geometry calculates the path distance and beam azimuths at each end of a path, and calculates map crossings. The is the module where the user declares if the path is a single link or includes a repeater link.

Path Profile Data allows the user to enter and edit the path profile data points.

Plot Profile determines the type of path, and draws both line-of-sight and over-the-horizon path profiles. Ray path trajectories for average and extreme subrefractive Earth's radius factor are drawn for line-of-sight paths and the diffraction and scatter parameters for over-the-horizon paths are determined.

Gain allows user input of antenna size, transmission line type and length, and calculates net system gain.

FM/FDM calculates derived voice channel performance parameters (thermal and equipment intermodulation noise) in terms of received signal level.

Climate calculates rain rate distributions and the multipath occurrence factor, and draws multipath attenuation and rain attenuation distributions.

Radios Dispersive Fade Margin Data creates a database of radios and their corresponding dispersive fade margins, which can be entered directly or calculated by the program based on operator-entered data.

Link Design Summary requests the final design parameters and calculates a distribution of the fraction of time that signal losses exceed the performance threshold. From this distribution, it determines if the link performance is adequate.

Troposcatter Loss calculates the median basic transmission loss for an over-the-horizon path.

Median Variability calculates the long term variability of hourly median basic transmission loss.

Median Diffraction Loss calculates single diffraction or double diffraction obstacle median basic transmission loss.

4.1 Modules for All Path Types

This section will deal with those modules that can be run for all types of point-to-point radio paths. These are Initialize Plotter, Select a Link, Earth Geometry, Path Profile Data, Plot Profile, Gain, and FM/FDM and are described in the paragraphs below.

4.1.1 Initialize Plotter

Although the program will now be ready for use, the Initialize Plotter module, the first one listed in the RAIDER main menu, should be run to allow the user to customize RAIDER and set the printer and plotter constants. The menu shown in Figure 2 is displayed when the letter "I" is entered, followed by a carriage return.

```
Setup Module

  Setup Input/Edit
  Print Setup
  Quit

Press ESC to cancel.
```

Figure 2. Initialize plotter main menu.

4.1.1.1 Setup Input/Edit

The Input/Edit screen is shown in Figure 3 with the original default values. The user must enter the printer and plotter ports for the individual system to ensure that the outputs will be routed to the correct device if the ports are different from the default values. The default plotter coordinate values are appropriate for an HP7475A plotter; for other plotters, consult your manual for the plotting range for the desired paper size (usually 8.5 x 11 inches). If the correct values have not been set for the plotter used, the plots may not be drawn correctly or the program may unexpectedly halt. If this happens, it will be necessary to re-boot the computer and rerun the setup program to allow the correct values to be entered.

This program also allows the user to choose six colors which will be used in the plotting programs for the plot title and labels and the lines in the displays. The colors can be changed as often as the user desires and different colors can be chosen before running different plots. An information box on the right-hand side of the screen as shown below relates the colors to the corresponding numbers. The color numbers for the plotter also designate the plotter pen numbers. The user must load the plotter pens to match the colors with the pen numbers.

```
INPUT / EDIT
Printer Port                            1
Plotter Port                            2
Screen Title Color                     13        Colors
Screen Axis Label Color                 9        0-black
Screen Axis Color                      15        1-blue
Screen Primary Line Color              14        2-green
Screen Secondary Line Color            11        3-cyan
Screen Tertiary Line Color             12        4-red
Plotter Plot Title Color                5        5-magenta
Plotter Axis Label Color                1        6-brown
Plotter Axis Color                      1        7-white
Plotter Primary Line Color              2        8-gray
Plotter Secondary Line Color            4        9-light blue
Plotter Tertiary Line Color             5        10-light green
Plotter X-Axis Min                      0        11-light cyan
Plotter X-Axis Max                  10365        12-light red
Plotter Y-Axis Min                      0        13-light magen
Plotter Y-Axis Max                   7962        14-yellow
                                                 15-bright whit

                                                 TYPE
                                                 F2 for refresh
                                                 F8 to exit
```

Figure 3. Initialize plotter input/edit screen.

4.1.1.2 Print Setup

This option shown in Figure 2 allows the user to print the data in the input/edit screen shown in Figure 3.

4.1.2 Select A Link

The Select a Link module is the basic file manager for RAIDER. It is the module that allows the user to create, organize, destroy, rename, and move the link files. The Select a Link menu presents the user with eleven options as shown in Figure 4.

```
PROGRAM SELECT A LINK

 Path Directories List
 List Links in Current Directory
 Create a Directory
 Establish a Link
 Reverse a Link
 Update Link File Header
 Delete a Link
 Make a Duplicate File
 Transfer a File
 Kill a Directory
 Quit

Press ESC to cancel.
```

Figure 4. Select A Link main menu.

4.1.2.1 Path Directories List

This option gives the user a list of the directories that have been created for RAIDER link files. When the bright bar has been arrowed to one of the directories and the user presses enter, that directory has been selected. The display will then revert to the main menu shown in Figure 4.

4.1.2.2 List Links in Current Directories

This option lists the links that are currently available in a directory chosen by the user as described in the preceeding paragraph. If no directory has been chosen, the user will be prompted to choose one from the list of available directories. When the user presses the arrow keys to move the bright bar to one of the link names and enters a carriage return, the link has been chosen. The display reverts to that shown in Figure 4 but the link that was selected is the current link and will be used when running the other RAIDER modules until the user chooses another link. To reiterate, a user must choose both a directory name and a link name to select the current link for further design.

4.1.2.3 Create a Directory

As a user or group of users begins work with RAIDER, it may be convenient to decide on a number of categories for the links to be designed. The user may choose to create several directories to make finding a particular link file easier. If the Create a Directory option is selected as described earlier, the user is prompted to enter a directory name of up to seven characters. The new directory is then created and added to the list of available directories.

4.1.2.4 Establish a Link

When a user begins to work with a new pair of locations to design a new link, a new link file must be opened. This is done using the Establish a Link option. The link name will be placed in the currently chosen directory. If a directory has not been chosen, the user will be given a list of directory names into which the new link may be placed. The screen shown in Figure 5 is displayed first. The user must enter a three or four letter code for both the transmitter site and the receiver site. The first three characters can be letters or numbers, but the last character must be a number. This allows several files with different link and equipment parameters to be maintained for the same physical locations. All of the other screen inputs are optional, but since the transmitter and receiver site names as entered here appear as headers and titles for output screens for the other RAIDER modules, it is advisable to enter an appropriate name. Otherwise the words "transmitter" and "receiver" will be used in headings and titles in the other modules. The four-character site codes are combined into an eight-character link file identifier. Since the link identifier is the DOS file name, identical link identifiers are not allowed in a directory but may exist in different directories.

```
CREATE A LINK FOR DIRECTORY moon

Initials                                ___
Project Number                          _________
3 or 4 Letter Transmitter Site Code     ____
Transmitter Site Name                   ____________________
3 or 4 Letter Receiver Site Code        ____
Receiver Site Name                      ____________________


Type F8 to exit
```

Figure 5. Create a link input/edit screen.

4.1.2.5 Reverse a Link

The Reverse a Link option allows a user to reverse a transmitter and receiver site. The user is first prompted for the directory in which the link to be swapped exists. The user is then prompted for the link name. If a reversal of the link name will create a duplicate link in the directory, an error message is displayed and the link is not reversed. Otherwise the site latitudes and longitudes and profile data are reversed. The antenna heights, azimuths, and elevation angles are also reversed. The remaining values for the link are deleted since they should be recalculated to obtain correct values.

4.1.2.6 Update Link File Header

This function allows the user to change the information that was entered when the link file was established. The user is first prompted to select a directory and then a link name. The screen used to create a link is displayed as shown in Figure 5 except that the current information is displayed. The user is free to make any changes, which are saved when the user exits the screen. To exit this function without making changes, press the F8 key.

4.1.2.7 Delete a Link

This modules allows the user to delete a link from a directory. The user is prompted for a directory name from a list of directories and is then presented with a list of links in that directory. After a user has chosen the link, a screen is presented which asks if the link should be deleted. This is done to ensure that the user does not inadvertently delete a link that should have been saved. If the user presses the enter key with the Yes button emphasized, the link is deleted.

4.1.2.8 Make A Duplicate File

The user is able to duplicate a link file using this option. The user is first prompted to choose a directory in which the link to be duplicated exists, and then the name of the link to be duplicated. The user is then presented with the input/edit screen as shown in Figure 5 which contains the information for the chosen link. The user must change at least one character in one of the site codes so that the link identifier (which is the two site codes concatenated) is not the same as any other link in the directory in which it is to be saved. The user is then presented with a list of directories and asked to choose the directory for the new link. If a link file with the same two site codes does not currently exist in the new directory, the file is duplicated. Otherwise, an error message is displayed which states that a link file with the same link identifier already exists.

4.1.2.9 Transfer a Link

This function assists a user in transferring a link file to another directory. The user is given a list of directories and asked to choose the source directory in which the link to be transferred exists. A list of the links in that directory is then displayed and the user must choose the link to be moved. A list of directories is displayed again so that the user can pick the target directory for the link. The transfer is completed if a link file with an identical link identifier does not currently exist in the target directory. If such a link file does exist, an error message is displayed and the transfer is denied.

4.1.2.10 Kill a Directory

The Kill a Directory function deletes all of the link files in the selected directory and removes the directory from the DOS operating system file structure. The user is first presented with a list of directories, then asked if the directory should be deleted. This is done to make sure that the user definitely wants the directory to be deleted. If the response is Yes the directory and all files it contains will be deleted, but if the response is No the delete operation will be aborted. If a directory is inadvertently deleted, a commercial DOS file recovery program may be used to reconstruct the lost information.

4.1.3 Earth Geometry

The Earth Geometry module allows the user to enter geographical site information and calculates path distance, path azimuths, and map crossings. It is during the use of this module that the user must decide whether to enter a single link or a repeater link. A repeater link is simply one that might have a passive repeater location between two sites with active RF equipment. The profile information for both parts of such a configuration is entered in the same link file and carried together as a single entity. After the type of link decided upon is entered in this module, it cannot be changed in subsequent modules. If the user wishes to change the type of link, the Earth Geometry module must be rerun and the link file saved with the new link type. The main menu for this module is shown in Figure 6.

```
Earth Geometry - feldberg to schwarzenborn

  Single Link Input/Edit
  Passive Repeater Link Input/Edit
  Calculate
  Map Crossings - Transmitter - Receiver
  Transmitter - Repeater Map Crossings
  Repeater - Receiver Map Crossings
  Input/Edit Print Listing
  Output Print Listing
  List Map Crossings to Printer
  Quit

Press ESC to cancel.
```

Figure 6. Earth geometry main menu.

4.1.3.1 Single Link Input/Edit

The inputs required for this module are the latitudes and longitudes for the transmitter and receiver, their respective tower base elevations, and the Earth spheroid option. Inputs for the magnetic declination from true North are optional. Latitudes of 0 to 90 degrees north or south and longitudes of 0 to 180 degrees east or west are legal inputs. The degrees and minutes are whole numbers from 1 to 59 and the seconds can be numbers from 0.01 to 59.99. The default latitudes and longitudes are north and east. These can be changed by entering an 's' or a 'w'. The tower base elevations must be values between 0 and 10,000 m. The selection of an Earth spheroid will depend on the location on the Earth of the path, but the error in using the International spheroid, number 1, for all paths will be quite small. For further information on the appropriate spheroid to be used in various areas of the world, Department of the Army, (1967) may be consulted. If the coordinate locations entered result in a path length greater than 500 km, a warning will be shown on the screen that the sites are too far apart, and the latitudes and longitudes will be deleted if the user exits without entering new coordinates that result in a shorter path. The input/edit screen is shown in Figure 7.

4.1.3.2 Passive Repeater Link Input/Edit

The inputs required for this module are the same as for the Single Link but the same values are also needed for the repeater link. The passive repeater input/edit screen is shown in Figure 8.

```
INPUT / EDIT                                  Feldberg      Schwarzenborn
Antenna latitude                      50° 14' 34.00" N    50° 55'  2.00" N
Antenna longitude                      8° 29' 49.00" E     9° 25' 24.00" E
Magnetic declination from true N     ___° __' _____" _   ___° __' _____" _
Tower base elevation above msl         684.00 m           634.00 m
Earth spheroid options                 International
International...................1
Clark 1866......................2
Clark 1880......................3
Everest.........................4
Bessel..........................5
Australian National.............6
Airy............................7
Fisher..........................8
Malayan.........................9

Type F8 to eXit
```

Figure 7. Earth geometry single link input/edit screen.

```
INPUT / EDIT                              Feldberg          Giessen
Antenna latitude                        50° 14' 34.00" N   50° 27' 32.00" N
Antenna longitude                        8° 29' 49.00" E    9°  1' 13.00" E
Magnetic declination from true N         2° 12'  0.00" E    2°  1'  0.00" W
Tower base elevation above msl           684.00 m           587.00 m

INPUT / EDIT                             Giessen           Schwarzenborn
Repeater Site Name                      Giessen
Repeater Site Code                      Gsn
Antenna latitude                        50° 27' 32.00" N   50° 55'  2.00" N
Antenna longitude                        9°  1' 13.00" E    9° 25' 24.00" E
Magnetic declination from true N         2°  1' 00.00" E    1° 45'  0.00" E
Tower base elevation above msl           587.00 m           634.00 m
Earth spheroid options                  International
    International...................1
    Clark 1866......................2
    Clark 1880......................3
    Everest.........................4
    Bessel..........................5
    Australian National.............6
    Airy............................7
    Fisher..........................8
    Malayan.........................9
 Type F8 to eXit
```

Figure 8. Earth geometry repeater link input/edit screen.

4.1.3.3 Calculate

The model that we use to compute Earth geometry uses standard spherical geometrical equations and should be satisfactory for the engineering of all terrestrial radio links. Table 1 lists the equatorial and polar radii of spheroids in use today. The accuracy criteria for this model is a maximum error of 1 m in position or geodetic length and latitude, longitude, and azimuth within .035 second over the longest possible hemispheroidal geodesics (Thomas, 1970, pp. 7 and 19).

Table 1. Earth Spheroid Constants

Spheroid	Equatorial Radius (km)	Polar Radius (km)
International	6378.388	6356.912
Clark 1866	6378.2064	6356.5838
Clark 1880	6378.249145	6356.514869
Everest	6377.276345	6356.075415
Bessel	6377.397155	6356.078963
Australian Nat'l	6378.160	6356.7745
Airy	6377.563396	6356.256910
Fisher	6378.155	6356.77332
Malayan	6377.304063	6356.103039

The constants in Table 1 are the semimajor and semiminor axes (in kilometers) of the appropriate spheroid. A chart showing which areas of the world are mapped based on the various spheroids is contained in Department of the Army TM 5-241-1 (1967). For greatest accuracy, the spheroid constants that are entered should be the ones used in preparing the maps from which profile values are selected.

The algorithms used in this module are based on standard spherical trigonometric formulae and use an inverse path calculation. The code was prepared for the U.S. Navy Oceanographic Office described in a report by Thomas (1970). The initial point latitude, λ_1, and longitude, ϕ_1, as well as the terminal point latitude, λ_2, and longitude, ϕ_2, are entered. The algorithm assumes positive values are north or east and negative values are south or west. The great circle path length and the azimuth from the initial point, α_{1-2}, and azimuth from the terminal point, α_{2-1}, are returned. The azimuth values are returned in degrees east of north. If the magnetic declination from true north has been entered, the forward magnetic azimuth will also be calculated, otherwise the magnetic azimuth is equal to the true azimuth and is not listed in the output screen. These values are calculated for both the primary and the repeater link if a passive repeater link has been chosen. The output screen for a single link is shown in Figure 9 and the calculations for a passive repeater link are displayed in Figure 10.

INPUT SUMMARY	feldberg	schwarzenborn
Antenna latitude	50° 14′ 34.00" N	50° 55′ 2.00" N
Antenna longitude	8° 29′ 49.00" E	9° 25′ 24.00" E
Tower base elevation above msl	684.00 m	634.00 m
Earth spheroid options	International	
OUTPUT SUMMARY		
Equatorial radius	6356.9120 km	
Polar radius	6378.3880 km	
Link distance	99.6730 km	
Forward azimuth	40° 48′ 56.06"	221° 31′ 52.45"

Figure 9. Earth geometry calculation screen for single link.

INPUT SUMMARY	Feldberg	Giessen
Antenna latitude	50° 14′ 34.00" N	50° 27′ 32.00"N
Antenna longitude	8° 29′ 49.00" E	9° 1′ 13.00"E
Magnetic declination from true N	2° 12′ 0.00" E	2° 1′ 0.00"E
Tower base elevation above msl	684.00 m	587.00 m
Earth spheroid options	International	
OUTPUT SUMMARY		
Equatorial radius	6356.9120 km	
Polar radius	6378.3880 km	
Link distance	44.3327 km	
Forward azimuth	54° 57′ 38.73"	237° 21′ 49.35"
Forward magnetic azimuth	54° 45′ 38.73"	235° 20′ 49.35"
INPUT SUMMARY	Giessen	Schwarzenborn
Antenna latitude	50° 27′ 32.00" N	50° 55′ 2.00"
Antenna longitude	9° 1′ 13.00" E	9° 25′ 24.00"
Magnetic declination from true N	2° 1′ 0.00" E	1° 45′ 0.00"
Tower base elevation above msl	587.00 m	634.00 m
Earth spheroid options	International	
OUTPUT SUMMARY		
Equatorial radius	6356.9120 km	
Polar radius	6378.3880 km	
Link distance	58.4046 km	
Forward azimuth	29° 2′ 2.40"	209 20′ 45.06"
Forward magnetic azimuth	27° 1′ 2.40"	207 35′ 45.06"

Figure 10. Earth geometry calculation screen for repeater link.

4.1.3.4 Map Crossings - Transmitter - Receiver

The Map Crossings option allows the user to determine the point at which the path crosses a given latitude or longitude with the length of the path. This feature is most useful when a path profile must be developed from maps and the path extends over more than one map sheet. This will frequently be the case because the most detailed maps available should be used, and even a fairly short path may lie on more than one sheet. After the user has entered data for a link, the map crossings for that link may be determined. The user is presented with a screen that lists the latitudes and longitudes of the two sites at the top of the screen as shown in Figure 11. Beneath these coordinates are fields for the user to enter latitudes and longitudes. If a user enters a latitude, a longitude and a distance will be calculated at the location where the map crossing exists when the user moves the cursor to the left or right off of the last field in the entry; that is the N, S, E, or W, or if the up-arrow or down-arrow key is pressed. If a longitude is entered, a latitude and a distance where the crossing occurs will be calculated when the user moved from the last entry field. The user may enter as many latitude and longitude values as the display allows. When this is full, the user may overwrite the values if the values to be overwritten are not required to be saved. If the user wishes to save a listing of the values, the screen should be exited and the List Map Crossings to Printer option should be selected. Every time the user reenters the map crossings screen, the values that had been previously input will be deleted.

```
MAP CROSSINGS     Feldberg to Schwarzenborn
Limits     Latitude 50° 14' 34.50"N - 50° 55'  1.50"N
Longitude    8° 29' 49.50"E -    9° 25' 23.50"E
Distance from
Latitude                    Longitude                 Transmitter (km)
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
   __° __' _____" _            __° __' _____" _
```

Figure 11. Map crossings input/edit screen.

Map crossings are calculated by successive approximations in which forward azimuth values (computed using the Thomas model, 1970) are compared with the path forward azimuth to provide error values to measure convergence. If values of (λ_1, ϕ_1), (λ_2, ϕ_2) and λ_3 or ϕ_3 are given, the program calculates ϕ_3 or λ_3, respectively (Figures 12 and 13). In Figures 12 and 13, the symbols have the following definitions:

x =	the distance east from the Prime Meridian to the point (x,y)
y =	the distance north from the equator to (x,y)
ϕ =	the longitude of (x,y)
λ =	the latitude of (x,y)
α =	the azimuth from Point 1 to (x,y) (from the Thomas model)
r =	the distance from (x_1, y_1) to (x,y) (from the Thomas model)
e =	α_{12} - α (azimuth error)
Δs =	the arc length
a =	Earth radius (6370 km)
$\Delta\phi$ =	the magnitude of the longitude error
$\Delta\lambda$ =	the magnitude of the latitude error.

The equations that apply to Figure 12 are:

$$\Delta\lambda = \frac{180\ \Delta y}{\pi a} \tag{1}$$

$$\Delta y \approx \frac{\Delta s}{\sin\alpha_{12}} \tag{2}$$

$$\Delta s \approx r_1 e_1 \frac{\pi}{180}. \tag{3}$$

Combining these three equations,

$$\Delta\lambda \approx \frac{r_1 e_1}{a \sin \alpha_{12}}. \tag{4}$$

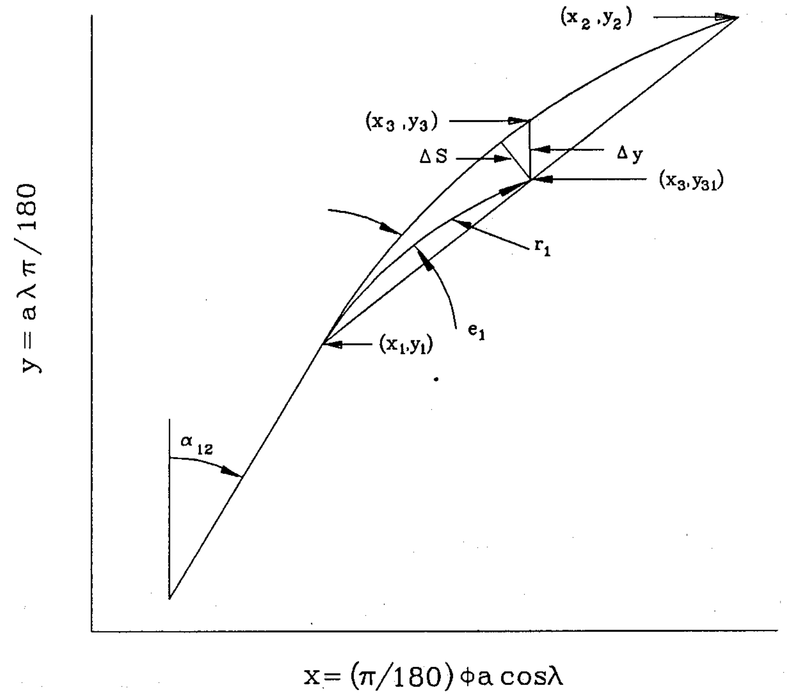

Figure 12. Geometry for calculating latitude for a given longitude.

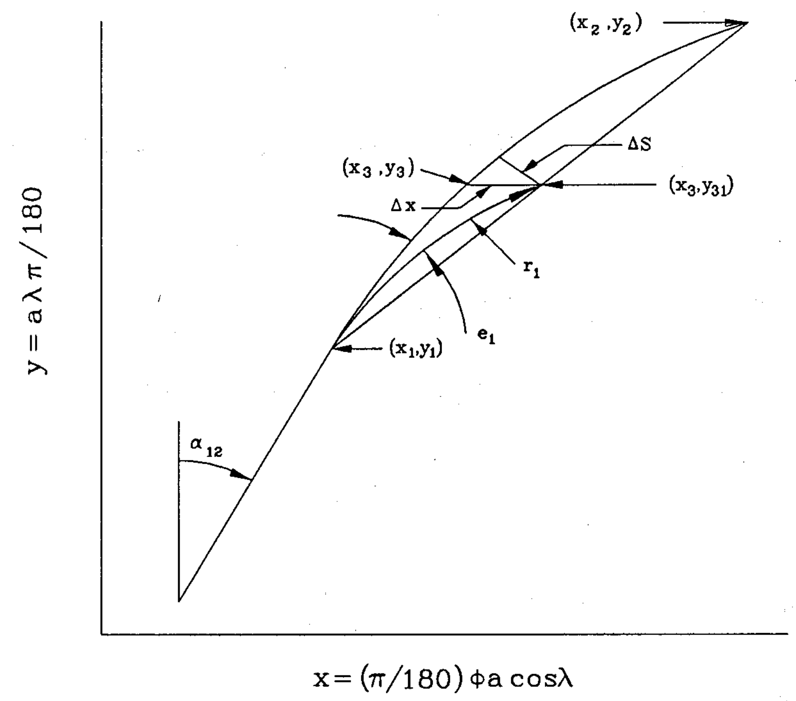

Figure 13. Geometry for calculating longitude for a given latitude.

The equations that apply to Figure 13 are:

$$\Delta\phi = \frac{180\ \Delta x}{\pi\ a \cos \lambda_1} \tag{5}$$

$$\Delta x \approx \frac{\Delta s}{\cos\alpha_{12}} \tag{6}$$

Combining these two equations,

$$\Delta\phi \approx \frac{r_1 e_1}{a \cos \lambda_1 \cos\alpha_{12}}. \tag{7}$$

The algorithm for computing the map crossings is as follows:

1) Using the algorithm by Thomas (1970), calculate the azimuth, $\alpha_{1\text{-}2}$, from (λ_1, ϕ_1) along the great circle path to (λ_2, ϕ_2).
2) Calculate the first estimate of λ_3 or ϕ_3, called λ_{31} and ϕ_{31} respectively, by linear interpolation:

$$\lambda_{31} = \lambda_1 + \frac{\phi_3 - \phi_1}{\phi_2 - \phi_1}(\lambda_2 - \lambda_1) \tag{8}$$

$$\phi_{31} = \phi_1 + \frac{\lambda_3 - \lambda_1}{\lambda_2 - \lambda_1}(\phi_2 - \phi_1) \tag{9}$$

3) Using the Thomas algorithm, calculate azimuth, $\alpha_{1\text{-}31}$ from (λ_1, ϕ_1) to (λ_3, ϕ_{31}) or to (λ_{31}, ϕ_3), whichever is applicable.

4) Calculate the azimuth error, e_1:

$$e_1 = \alpha_{1\text{-}31} - \alpha_{1\text{-}2}; \quad (e_n = \alpha_{1\text{-}3n} - \alpha_{1\text{-}2}) \tag{10}$$

5) Calculate the second estimate of ϕ_3 or λ_3 called $\phi_{3(n+1)}$ or $\lambda_{3(n+1)}$, respectively:

$$\phi_{3(n+1)} = \phi_{3n} - k_\phi e_n \quad \text{where } k_\phi = \frac{r_n}{a \cos \lambda_1 \cos\alpha_{1\text{-}n}} \tag{11}$$

$$\lambda_{3(n+1)} = \lambda_{3n} - k_\lambda e_n \quad \text{where } k_\lambda = \frac{r_n}{a \sin \alpha_{1\text{-}n}} \tag{12}$$

6) Calculate the azimuth, $\alpha_{1\text{-}32}$; $\alpha_{1\text{-}3(n+1)}$.

7) Calculate the azimuth error e_2; e_{n+1}:
$e_2 = \alpha_{1-2} - \alpha_{1-32}$; $e_{n+1} = \alpha_{1-2} - \alpha_{1-3(n+1)}$

8) Is $|e_1| > |e_2|$?; Is $|e_n| > |e_{n+1}|$?;

9a) If yes, repeat the steps from Number 5 using the appropriate subscripts for each new step until $|e_n| < 0.01$ seconds

9b) If no, repeat the steps from Number 5, having changed the sign of k_ϕ or k_λ.

4.1.3.5 Transmitter - Repeater Map Crossings

This selection allows the user to calculate the map crossings for a main link in a passive repeater link. The geographic coordinates for the main link are displayed at the top of the screen. This option displays a screen as shown in Figure 11 and operates in the same manner as described in the previous section.

4.1.3.6 Repeater - Receiver Map Crossings

Choosing this option will allow the user to calculate the map crossings for the repeater link. The geographic coordinates for the repeater link are displayed at the top of the screen. The screen display is the same as shown in Figure 11, and the calculations are executed as described in Section 4.1.3.4.

4.1.3.7 Input/Edit Print Listing

This option sends the input/edit screen to the printer. Depending on the type of link, either the single link or the repeater link input/edit screen will be printed. The printout is identical to the input/edit screen which is displayed on the terminal shown in Figures 7 and 8 in Sections 4.1.2.1 and 4.1.2.2 respectively.

4.1.3.8 Output Print Listing

This option prints the calculation screen. The screen is printed as it appears to the terminal. This is shown in Figures 9 and 10 in Section 4.1.3.3.

4.1.3.9 List Map Crossings to Printer

This option prints that last set of map crossings that has been entered. Each time the user enters an input/edit map crossing screen, the previous inputs will be deleted. If a user wants to keep a record of the map crossings which have been calculated, this option must be executed after exiting a map crossing input/edit screen or before reentering a map crossing input/edit screen. The map crossing screen which is printed is the same as the one which is displayed to the screen. This is shown in Figure 11 in Section 4.1.3.4.

4.1.4 Path Profile Data

The Path Profile Data module allows the user to enter the terrain elevation versus distance data for the path. This can be done for a single link or a repeater link. The main menu for this module is shown in Figure 14.

```
Terrain Profile

 Single Link Profile Input/Edit
 Transmitter/Repeater Profile Input/Edit
 Repeater/Receiver Profile Input/Edit
 List to Printer Single Link Profile Data
 Print Transmitter/Repeater Profile Data
 Output Repeater/Receiver Profile Data to Printer
 Quit

Press ESC to cancel.
```

Figure 14. Path profile main menu.

4.1.4.1 Single Link Profile Input/Edit

This menu selection allows the user to enter the profile data for a single link. The profile input screen is displayed in Figure 15. The top of the screen has column headers for the distance from the transmitter, the elevation, the obstacle type, and the obstacle height. The first distance on the screen is the default distance. This is the location of the transmitter site and the distance is displayed as 0. The elevation is the transmitter height. The user may enter as many distances as desired between the transmitter and receiver sites.

```
Terrain Profile - Feldberg to Schwarzenborn            Obstacle Types
Dist From       Elevation     Obstacle     Obstacle    t=tree
Xmtr (km)          (m)          Type       Height (m)  o=other
                                                       s=water starts
  0.000         684.000                                e=water ends
  0.233         684.000                                *=delete
  1.233         670.000                                  obstacle
  1.993         620.000
  3.213         500.000
  5.033         400.000                                TYPE
  6.113         340.000                                F1 for units
  9.493         324.000                                F3 for # points
 10.923         370.000                                F4 to find poin
 12.463         300.000                                F5 to print
 14.023         350.000                                F8 to eXit
 16.593         310.000
 18.873         210.000                                # points 60
 21.153         180.000
 23.143         200.000                                link distance
 23.483         190.000                                    99.673 km
 26.773         140.000
 28.613         160.000
```

Figure 15. Path profile input/edit screen.

The user may enter a new point by typing the new point values on a blank line on the screen. A blank line may be obtained by pressing the enter key when the cursor is on the last line of the input or by pressing the insert key at any point in the list. The user may enter the distances in any order, but a distance-elevation pair must always be entered. The distance values entered must be between 0 and the path length. The elevation must be between -500 and 10,000 m. The user also has the option of entering an obstacle type and its height. If an obstacle type is entered, its height must also be entered. Exceptions to this are the water starts and water ends, which do not have a height associated with them. The obstacle types are listed at the right of the screen. The user may enter a "t" for a tree, a "b" for a building, an "o" for any other type of object, an "s" to denote where water starts and an "e" to denote where water ends. If the user enters an "*" the object that is currently associated with the line to which the cursor points will be deleted. The obstacle elevations must be between -500 and 10,000 m. When the user finishes an entry and moves to a new line, the input will be checked to determine that all of the required inputs have been obtained. If the entry is valid, the entry will be sorted by distance order and it will be placed in the correct location on the screen. Otherwise, an error message will be printed to the screen. The user may delete a line by placing the cursor on the line and entering the delete key. A line may also be changed by entering new values on that line. When the user exits the input/edit screen, a final entry containing the path length and receiver site elevation will be added to the list of profile data.

If a user enters a point and designates it as a water starts, a prompt will be displayed for the distance for the water ends point. Similarly, if a user first enters a water ends, a prompt will appear for the water starts. The user may not insert points between the water starts and ends. If a point is entered between the water starts point and the water end point, the user will have the option of choosing a new distance for the water starts or ends points, or will be able to delete the intermediate points. If the user rejects these options, the water start and end points will be deleted.

The function keys F1, F2, and F8 act as described in Section 3.3.1. The profile data module also uses the function keys F3, F4 and F5. Function key F3 displays the number of profile points to the right of the input screen. The number of points is only updated on the screen when this key is entered.

Function key F4 allows the user to perform data searches. When this key is pressed, the user is presented with a box with the options to search by distance, elevation, point number, obstacle height, or obstacle type. If the user enters distance, a prompt will be displayed to enter the distance. The program will then search for the point that is closest to this distance and the cursor will be moved to this point. If a user chooses elevation or an obstacle height, the program will operate in the same manner as it did when it searched for a distance. If the user enters obstacle type, a prompt will be give to enter the obstacle type and a search will be done for this type. The program will always find the next elevation, obstacle height, or obstacle type in the list and will then start searching at the top of the list if an element at a greater distance than the current point cannot be found. If a user searches for a point number, the user will be prompted for the number and the cursor will find that element number in the list. If the data search cannot be completed, an error message will be displayed.

Function key F5 allows the user to print the path profile data. The printout will display the heading data and the profile data as it appears in Figure 15.

4.1.4.2 Transmitter/Repeater Profile Input/Edit

This option allows the user to enter the profile data for the primary link of a repeater link. The operation and screen displayed for this option are the same as described in Section 4.1.4.1.

4.1.4.3 Repeater/Receiver Profile Input/Edit

This menu option allows the user to enter data for the second link in a repeater link. The operation and screen for this option is also the same as that described in Section 4.1.4.1.

4.1.4.4 List to Printer Single Link Profile Data

This menu option prints the profile data for a single link. The output includes the header data and the profile data as shown in Figure 15.

4.1.4.5 Print Transmitter/Repeater Profile Data

This menu option prints the profile data for the primary link in a repeater link. The output includes the header data and the profile data as shown in Figure 15.

4.1.4.6 Output Repeater/Receiver Profile Data

This menu option prints the profile data for the second link in a repeater link. The output includes the header data and the profile data as shown in Figure 15.

4.1.5 Plot Profile

The Plot Profile module requests that the user supply antenna and climatological information which is used with the profile data to determine the type of path. The six path types recognized by the program are clear line-of-sight, marginal line-of-sight, difficult line-of-sight, single diffraction, double diffraction, and troposcatter. The module determines the type of path based on the terrain clearance (or terrain obstruction) and performs calculations appropriate for either the within line-of-sight or over-the-horizon paths and prepares graphic displays which correspond to the path type. The main menu for the plot profile module is shown in Figure 16.

```
Plot Module - Feldberg to Schwarzenborn

   Link Input/Edit
   Results of Calculations to Screen
   Input/Edit Print Listing
   Calculations Print Listing
   View Path on Screen
   Draw Path on Plotter
   Keep Path in File
   Quit

Press ESC to cancel.
```

Figure 16. Plot profile main menu.

4.1.5.1 Link Input/Edit

Figure 17 shows the screen which is displayed when this menu item is selected and the user has entered a single link. The input screen for a repeater link is the same as the screen shown in Figure 17 except that the fields are listed twice, once for the main link and once for the repeater link.

INPUT / EDIT Feldberg	Schwarzenborn		
Transmitter antenna height	50.20 m		
Transmit antenna diameter	45.72 m	150.00 ft	
Receiver antenna height	1.00 m		
Receiver antenna diameter	45.00 m	147.64 ft	
Normalized surface refractivity	301.00		
Average earth radius factor	1.33		
Extreme earth radius factor	0.67		
Frequency	20.00 GHz		
Average July temperature	20.00 °C		TYPE
Absolute humidity	15.00 g/m3		
Diversity Type Option	Space diversity		F1 for units
Nondiversity................N			F2 for refresh
Space Diversity.............S			F8 to eXit
Frequency Diversity.........F			
Antenna spacing (vertical)	30.00 m		
Diversity antenna diameter	______ m	______ ft	
Frequency spacing	N/A		
Combiner hysteresis	1.00 dB		

Figure 17. Single link input/edit screen for plot profile.

Some of the user input values must be entered for the particular path and other required inputs have default values that are used if the user chooses not to change them. The user is required to make an entry for the transmitter and receiver antenna diameters that is between 1 and 45.72 m. A default value of 1 will be used if the user does not input a value. A frequency between .1 and 30 GHz must also be entered, and a diversity type must be chosen. If the user chooses space diversity, an entry between 1 and 100 m must be made for the antenna spacing and a combiner hysteresis with a value between 0 and 10 must be entered. If frequency diversity has been selected, the frequency spacing between 1 and 100 Mhz and combiner hysteresis between 0 and 10 must be entered. The surface refractivity varies with climate and region of the Earth as shown in Figure 18, from Bean et. al., (1960). The surface value must be corrected for the height of the path above sea level by the equation:

$$\overline{N_s} = \frac{\overline{N_0}\left[e^{(-0.1057\, H_{LA})} + e^{(-0.1057\, H_{RA})} \right]}{2} \qquad (13)$$

where:

H_{LA} = the elevation of the transmitter antenna site in km

H_{RA} = the elevation of the receiver antenna site in km

$\bar{N}_o$ = surface refractivity normalized to mean sea level.

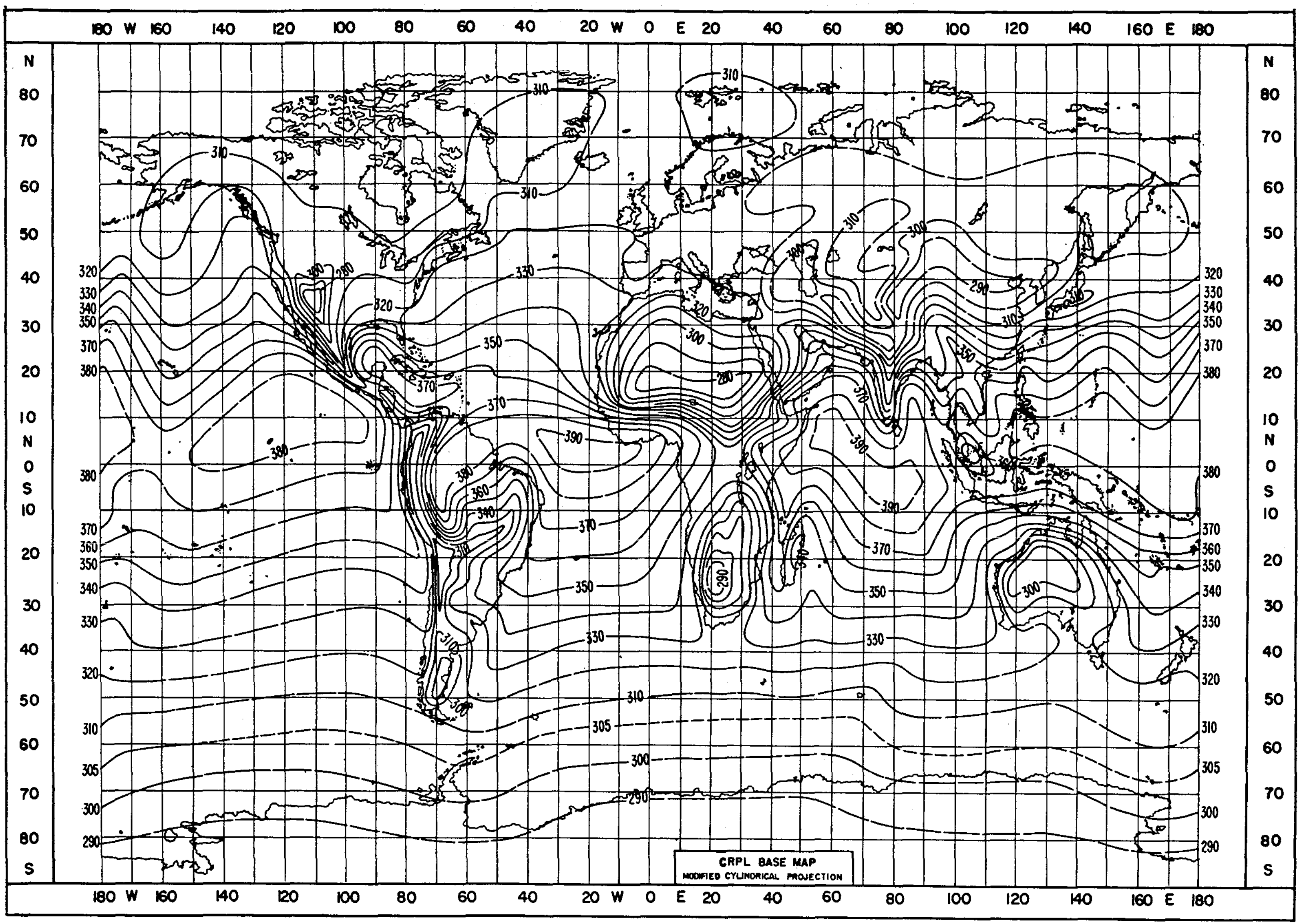

Figure 18. Global map of surface refractivity (from Bean, Horn, and Ozanick, 1960).

The program has a default value of 301 (changeable by the user) for normalized surface refractivity, which is related to the Earth radius factor by the equation:

$$k = \frac{1}{\left[\, 1 - 0.04665\, e^{\left(0.00557\, N_s\right)} \,\right]} \qquad (14)$$

The default k is 1.33 and the default extreme Earth radius factor is 0.67. The average July temperature has a default value of 20°C and average humidity defaults to 15 g/m³.

4.1.5.2 Results of Calculations to Screen

The Plot Profile module performs calculations to determine if the path is line-of-sight, single diffraction, double diffraction, or scatter. If a profile shows that a path is not clear line of sight, that is, it has an obstruction between the transmitting antenna and the receiving antenna for the extreme value of Earth's radius, a prompt to the screen indicates where the obstruction lies on the path and asks if the user wishes to recalculate antenna heights to create a line-of-sight path. If the user answers Yes, calculations are done to determine the antenna heights necessary to allow an unobstructed line-of-sight path to exist. If the antenna heights that are calculated exceed 500 m, the user will not be able to keep this antenna height when the module is exited, even though the screen graphic display may show antenna heights exceeding this value. If the user answers No and the link is a single link, calculations are done for the over-the-horizon path. If the link is a repeater link and the user does not wish to recalculate the antenna heights, an error message will be displayed because both sections of a repeater link must be line-of-sight paths.

4.1.5.2.1 Line-of-Sight Path Calculations

Figure 19 shows a calculation screen that was created for a single-link line-of-sight path. The output for a repeater link is the same as for a single link, but values for both the primary and repeater link have been calculated.

To calculate ray path trajectory and Fresnel zone clearance values, two expressions are required. They are the expression for the ray path height, h_r, in meters above mean sea level (msl),

$$h_r = \frac{d^2}{12.75k} + \frac{d\left(h_{a2} - h_{a1}\right)}{D} - \frac{D\, d}{12.75k} + h_{a1} \qquad (15)$$

where:

h_{a1} = the first antenna height in m above msl at d = 0,
h_{a2} = the second antenna height in m above msl at d = D,
d = the distance along the path in km,
D = the length of the path in km, and
k = the Earth's radius factor

INPUT SUMMARY Feldberg Schwarzenborn			
Path Length	99.67	km	
Frequency	20.00	GHz	
Average July Temperature	20.00	°C	
Absolute Humidity	15.00	g/m3	
Transmitter Antenna Height Above Ground	50.20	m	
Transmitter Antenna Diameter	45.72	m	150.00 ft
Receiver Antenna Height Above Ground	1.00	m	
Receiver Antenna Diameter	45.00	m	147.64 ft
Normalized Surface Refractivity	301.00		
Diversity Type Option	Space Diversity		
Antenna Spacing (Vertical)	30.00	m	
Antenna Diameter	N/A		
Combiner Hysteresis	1.00		
OUTPUT SUMMARY Feldberg Schwarzenborn			
Mean Terrain Elevation	296.45	m	
Standard Deviation of Elevations	100.56	m	
Effective Path Length	99.67	km	
PRIMARY ANTENNA VALUES FOR AVERAGE EARTH'S RADIUS FACTOR			
Average Earth's Radius Factor	1.33		
Minimum Ray Path Absolute Clearance Distance	98.22	km	
Minimum Ray Path Absolute Clearance	20.04	m	
Minimum Ray Path 1st Fresnel Zone Clearance Distance	98.22	km	
Minimum Ray Path 1st Fresnel Zone Clearance	4.33	1st Rad	
Transmitting Antenna Elevation Angle	-0 23′ 37.66"		
OUTPUT SUMMARY Feldberg Schwarzenborn			
Mean Terrain Elevation	296.45	m	
Standard Deviation of Elevations	100.56	m	
Effective Path Length	99.67	km	
PRIMARY ANTENNA VALUES FOR AVERAGE EARTH'S RADIUS FACTOR			
Average Earth's Radius Factor	1.33		
Minimum Ray Path Absolute Clearance Distance	98.22	km	
Minimum Ray Path Absolute Clearance	20.04	m	
Minimum Ray Path 1st Fresnel Zone Clearance Distance	98.22	km	
Minimum Ray Path 1st Fresnel Zone Clearance	4.33	1st Rad	
Transmitting Antenna Elevation Angle	-0 23′ 37.66"		
Receiving Antenna Elevation Angle	-0 16′ 47.09"		
Mean Atmospheric Pressure on the Ray Path	94.33	kPa	
Mean Ray Path Height Above Ground	289.61	m	
PRIMARY ANTENNA VALUES FOR EXTREME SUBREFRACTIVE EARTH'S RADIUS FACTOR			
Extreme Subrefractive Earth's Radius Factor	0.67		
Minimum Ray Path Absolute Clearance Distance	98.22	km	
Minimum Ray Path Absolute Clearance	11.77	m	
Minimum Ray Path 1st Fresnel Zone Clearance Distance	98.22	km	
Minimum Ray Path 1st Fresnel Zone Clearance	2.55	1st Rad	
Terrain Slope RMS Value	44.00	mrad	
Path Type	Clear LOS		
Oxygen Absorption	0.94		
Water Absorption	19.46		
Atmospheric Absorption	20.40		

Figure 19. Line-of-sight calculation screen.

and the expression for first Fresnel zone radius

$$R_f = 17.3\sqrt{\frac{(dD-d^2)}{fD}} \tag{16}$$

where f is the carrier frequency in GHz.

Antenna beam elevation angle, E_{11}, which is often called the takeoff angle, is the angle between the horizontal plane and the tangent to the ray path at the antenna. At the first antenna (the end of the path where d = 0), the value of E_{11} is obtained using the expression:

$$E_{11} = \arctan\left[\frac{(h_{a2} - h_{a1})}{1000\ D} - \frac{D}{12750k}\right] \tag{17}$$

This equation and the following one were obtained by deriving the slope from equation (15), the ray path trajectory, and the same variable definitions are applicable. At the second antenna (where d = D), the value of E_{12} is obtained using the following expression:

$$E_{12} = -\arctan\left[\frac{(h_{a2} - h_{a1})}{1000\ D} + \frac{D}{12750k}\right]. \tag{18}$$

The concept of effective path length, D_e, is used in the multipath fading calculations. D_e is a function of penetration angle of the beam center line and atmospheric layers, which results in a function in terms of antenna heights above msl and the total path length. The expression for D_e is based upon one year of measurements made by Hause (1986) on five long paths in Italy (unpublished data). The value of the effective path length is obtained from the following expressions:

$$\begin{aligned} &\text{let } d_o = 0.5D - 8.49\,\frac{|h_{a2} - h_{a1}|}{D} + 163, \text{ so} \\ &\text{if } d_o > D, \quad \text{then } D_e = D, \text{ or} \\ &\text{if } 0 \le d_o \le D, \text{ then } D_e = d_o, \text{ or} \\ &\text{if } d_o < 0, \quad \text{then } D_e = 0, \text{ or} \\ &\text{if } d_o > 326, \quad \text{then } D_e = 326. \end{aligned} \tag{19}$$

The minimum ray path terrain clearance is the minimum distance between the center line of the beam and the bare terrain or the obstacles directly beneath the beam. This distance can be measured in terms of absolute clearance in meters, or in units of first Fresnel zone radii, R_F. Since R_F varies as a function of distance along the path, the absolute clearance minimum will sometimes not occur at the same distance from the first antenna as the Fresnel clearance, C_f, minimum. Fresnel clearance minimums are not meaningful at distances near the antennas. For this reason, Fresnel clearance values within 1 km of an antenna are not considered in calculating the first Fresnel zone clearance minimum.

meaningful at distances near the antennas. For this reason, Fresnel clearance values within 1 km of an antenna are not considered in calculating the first Fresnel zone clearance minimum.

The absolute minimum antenna height (for a path to qualify as line of sight) of an antenna above ground is determined by two conditions:

1) Minimum antenna heights for a path are the values that tend to minimize tower heights and at the same time provide six tenths first Fresnel zone clearance when the ray path is calculated using the extreme subrefractive Earth-radius factor, k_e.
2) The absolute clearance within 1 km of each antenna is greater than 3 meters plus one-half of the local antenna's vertical dimension plus the ray path clearance.

The algorithm for calculating optimum antenna heights proceeds in the following way. If the absolute clearance criteria are not met within the 1 km distance from the antennas, increase the height of the local antenna by the amount of the negative clearance (blockage, B_t, in meters). If the absolute clearance criteria within 1 km of the antennas are met, then increase the height of the antennas by the amount indicated in the following expressions:

$$I_{a1} = B_t \left(2\frac{d_b}{D} + 1\right)\left(1 - \frac{d_b}{D}\right)$$
$$I_{a2} = B_t \left(\frac{d_b}{D}\right)\left(3 - 2\frac{d_b}{D}\right) \qquad (20)$$

where:

B_t = the negative of the minimum Fresnel zone clearance in meters,
d_b = the distance from the first antenna to the point of minimum Fresnel zone clearance in km,
D = the length of the path in km, and
I_{a1} and I_{a2} = the increases in tower heights.

These increases are calculated to maintain the required fractional Fresnel zone clearance while minimizing tower costs.

To calculate the mean atmospheric pressure along the path, we use the expression for pressure, P_a, as a function of altitude above mean sea level (msl) provided in List (1951, p.266);

$$P_a = 101.3\left(1 - 2.26 h_r \times 10^{-5}\right)^{5.2553} \qquad (21)$$

where:

P_a = the atmospheric pressure in kiloPascals (kPa).
h_r = the height of the ray path above msl in m where $-100 < h_r < 10^5$.

The mean atmospheric pressure, P_{am}, is obtained by averaging ten values of P_a calculated for ten approximately equidistant points along the path calculated using the average value of Earth-radius factor, k.

The mean ray path height above ground, h_{rg}, in meters, is given by the expression:

$$h_{rg} = \frac{1}{D} \sum_{n=1}^{n=p} \frac{(h_r - h_e)\,(d_{n+1} - d_{n-1})}{2} \qquad (22)$$

where:

h_r = ray path height above msl (m)
h_e = terrain height above msl plus obstacle height (m)
D = path length (km)
d = distance from the first antenna to a point (km)
n = the number of the profile point
p = the number of profile points.

Mean terrain elevation, h_{me}, in meters, is given by the expression:

$$h_{me} = \frac{\sum_{n=1}^{n=p} (d_{n+1} - d_n) \frac{h_n + h_{n+1}}{2}}{\sum_{n=1}^{n=p} (d_{n+1} - d_n)} \qquad (23)$$

where:

h_n = the height of the terrain above msl at point "n".

The standard deviation of terrain elevations, S_1, in meters, is given by the expression:

$$S_1 = \sqrt{\frac{\sum_{n=1}^{n=p} (d_{n+1} - d_n) \left[h_{me} - \left(\frac{h_{n+1} + h_n}{2}\right)\right]^2}{\sum_{n=1}^{n=p} (d_{n+1} - d_n)}} \qquad (24)$$

Antenna sites are excluded from the profile points when calculating S_1.

4.1.5.2.2 Over-the-horizon Path Calculations

For the purposes of the RAIDER modules, over-the-horizon paths are those which have zero or negative terrain clearance for both normal and extreme gradient conditions. The profile geometry notation has been generalized so that values derived from it can be applied to both tropospheric scatter and diffraction models. To mathematically describe the main profile features, a number of functions and constants are needed. Refer to Figure 20 for a graphic description of these values.

The following height functions of distance, d (km), along the path from the left terminal are defined (all heights, h, are in m):

h_m = the height of the terrain above msl along the great circle path. Values of h_m should be entered for values of d no greater than 5 km apart and no greater than 1 km apart between the antennas and horizons. In the vicinity of the horizon locations ($\pm$5 km from the horizon), values of h_m should be entered no greater than 1 km apart and even more frequently in most circumstances.

h_c = the distance between the msl circle and the chord which intersects the msl circle at the ends of the path.

h_p = $h_m + h_c$ which is the terrain profile height.

h_T = the heights above ground of obstacles on the path (trees, building, etc.).

h_E = $h_m + h_c + h_T$ is the envelope profile height.

The following functions are defined:

H_m(min) = the minimum value of h_m.
H_m(ref) = [h_m(min)-100] rounded to the nearest 100 m.
D = the total path length.
H_{LA} = the left antenna height above msl.
H_{RA} = the right antenna height above msl.
$h_c = (1 / 12.75\ k)(Dd - d^2)$,

where k is the effective Earth's radius factor. From these functions and constants, other functions and constants are derived which are used to obtain the constant values used to predict path loss and performance. These functions include equations for the desired ray path center lines and the pseudo-inter-horizon line, h_I. The slope intercept expression for a straight line is used. For example, $h_I = S_I d + b_I$ where S_I is the slope of the h_I and b_I is the intersection of h_I with the h axis.

The left ray path height, h_L, is found by using the maximum slope, S_L, from the left antenna to h_E. This coordinate of h_E giving maximum slope is (d_1, h_{E1}). A similar expression is written for the right ray path height, h_R. The slope of this line is the minimum value of slope, S_R, from the right antenna to points on h_E. The coordinates of h_E giving S_R is (d_5, h_{E5}).

The pseudo-inter-horizon, h_I, is defined as the line between two points on h_E. The left-most of these two points is the highest point on h_E within 5 km to the right of d_1. The right-most point is the highest point within 5 km to the left of d_5. The coordinates of these two points are defined as (d_2, h_{E2}) and (d_4, h_{E4}), respectively.

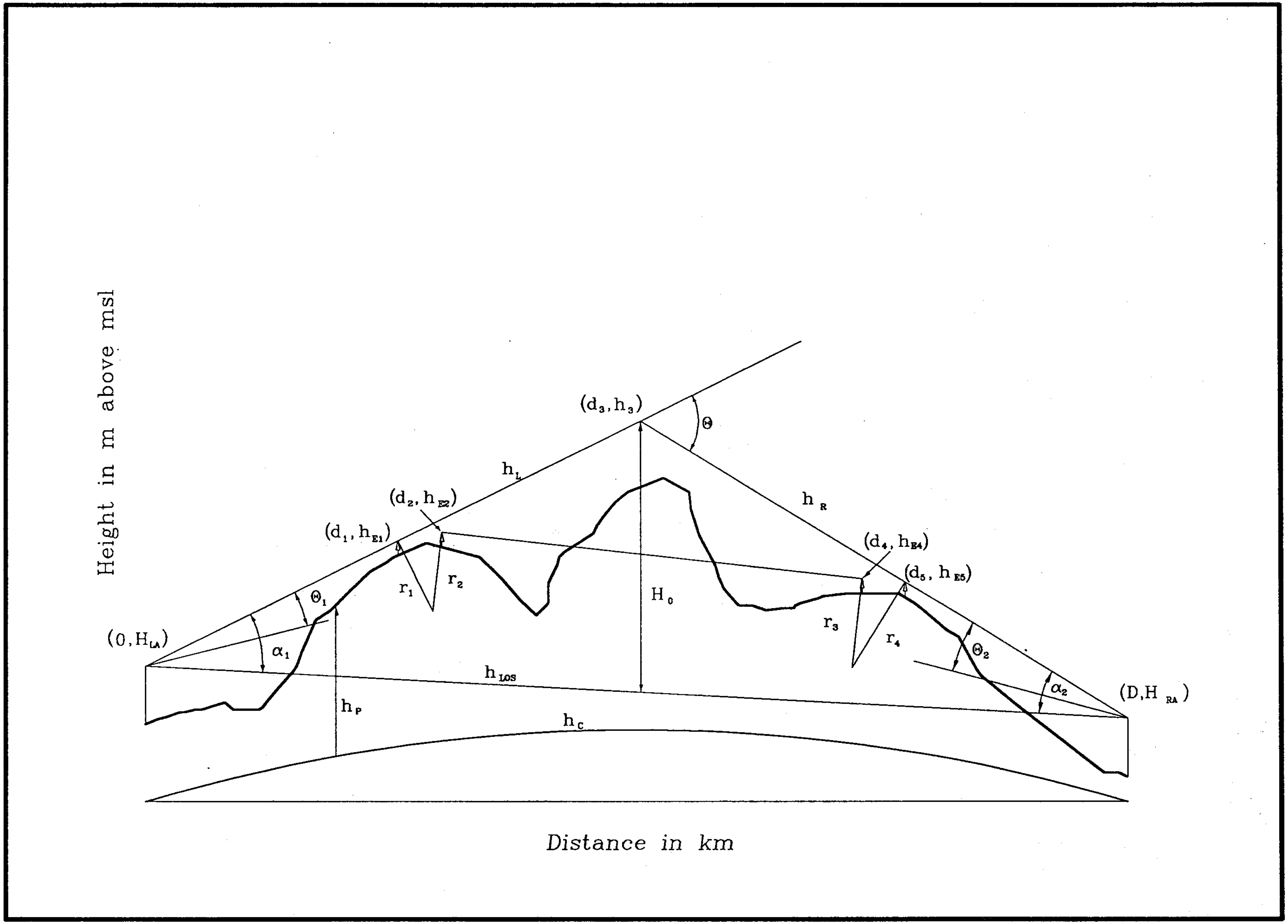

Figure 20. Over-the-horizon path geometry.

The line between the antennas, h_{LOS}, is used in several of the prediction models. Profile coordinates of the left and right antennas are (0, H_{LA}) and (D, H_{RA}), respectively.

The coordinate of the center of curvatures for the first rounded obstacle is (d_{c1}, h_{c1}) and for the second obstacle it is (d_{c2}, h_{c2}). The radii that are averaged to obtain the radius of curvature, R_1, for the first obstacle are r_1 and r_2. The radius for the second obstacle, R_2, is obtained in the same way from r_4 and r_5.

θ is the acute angle between the ray path center lines. θ_1 and θ_2 are the elevation angles of h_L and h_R at the left and right antennas, respectively. α_1 and α_2 are the acute angles between h_L and h_R and the line between the antennas, respectively.

$$S_L = \frac{h_{E1} - H_{LA}}{d_1 \, (1000)} \tag{25}$$

$$S_R = \frac{H_{RA} - h_{E5}}{(D - d_5) \, (1000)} \tag{26}$$

$$S_I = \frac{h_{E4} - h_{E2}}{(d_4 - d_2) \, (1000)} \tag{27}$$

$$S_{LOS} = \frac{H_{RA} - H_{LA}}{D \, (1000)} \tag{28}$$

$$b_L = H_{LA} \tag{29}$$

$$b_R = H_{RA} - D \, S_R \, (1000) \tag{30}$$

$$b_I = h_{E4} - d_4 S_I \, (1000) \tag{31}$$

$$b_{LOS} = H_{LA} \tag{32}$$

$$\theta = \tan^{-1} S_L - \tan^{-1} S_R \tag{33}$$

$$\theta_1 = \tan^{-1} S_L - \tan^{-1} \frac{D}{12.75\ k} \tag{34}$$

$$\theta_2 = -\tan^{-1} S_R + \tan^{-1} \frac{D}{12.75\ k} \tag{35}$$

$$\alpha_1 = \tan^{-1} S_L - \tan^{-1} S_{LOS} \tag{36}$$

$$\alpha_2 = -\tan^{-1} S_R + \tan^{-1} S_{LOS} \tag{37}$$

$$d_3 = \left(\frac{H_{RA} - H_{LA} - DS_R\,(1000)}{S_L - S_R}\right) x\ 10^{-3} \tag{38}$$

$$h_3 = S_L\ 1000\ d_3 + H_{LA} \tag{39}$$

$$d_{c1} = \frac{S_L\ S_I}{S_L - S_I}\left(h_{E2} - h_{E1} + \frac{1000\ d_2}{S_I} - \frac{1000\ d_1}{S_L}\right) \tag{40}$$

$$h_{c1} = \frac{S_I}{S_I - S_L}\left(h_{E2} - h_{E1} + \frac{1000\ d_2}{S_I} - \frac{1000\ d_1}{S_L}\right) + h_{E1} + \frac{1000\ d_1}{S_L} \tag{41}$$

$$r_1 = \sqrt{\left[(d_{c1} - 1000\ d_1)^2 + (h_{c1} - h_1)^2\right]} \tag{42}$$

$$r_2 = \sqrt{\left[(d_{c1} - 1000\ d_2)^2 + (h_{c1} - h_2)^2\right]} \tag{43}$$

$$R_1 = \frac{r_1 + r_2}{2000} \tag{44}$$

$$d_{c2} = \frac{S_R\, S_I}{S_I - S_R}\left(h_{E5} - h_{E4} + \frac{1000\, d_5}{S_R} - \frac{1000\, d_4}{S_I}\right) \tag{45}$$

$$h_{c2} = \frac{S_R}{S_R - S_I}\left(h_{E5} - h_{E4} + \frac{1000\, d_5}{S_R} - \frac{1000\, d_4}{S_I}\right) + h_{E4} + \frac{1000\, d_4}{S_I} \tag{46}$$

$$r_4 = \sqrt{\left[(d_{c2} - 1000\, d_4)^2 + (h_{c2} - h_4)^2\right]} \tag{47}$$

$$r_5 = \sqrt{\left[(d_{c2} - 1000\, d_5)^2 + (h_{c2} - h_5)^2\right]} \tag{48}$$

$$R_2 = \frac{r_4 + r_5}{2000} \tag{49}$$

$$H_o = h_3 - h_{LOSS} \tag{50}$$

$$\overline{h_{LA}} = H_{LA} - \overline{h_{lg}} - \Delta h_l \tag{51}$$

$$\overline{h_{RA}} = H_{RA} - \overline{h_{rg}} - \Delta h_r \tag{52}$$

4.1.5.2.2 Single Obstacle Diffraction Path Calculations

A single-obstacle diffraction path is one for which a single terrain feature is the horizon point for both ends of the path. A generic terrain profile for an example beyond-the-horizon path is shown in Figure 21; this would correspond to a single-obstacle path if one terrain point determined the horizon for both ends of the path. The various ray paths, elevations, and distances relevant to the calculations are shown. The elevations have been adjusted for the curvature of the Earth's surface so that all ray paths can be approximated as straight lines. The straight-line ray path segments shown on the figure are expressed in slope-intercept (y = m[x] + b) form. All geometric values such as take-off angles, scatter angles, and diffraction angles are calculated on this basis using formulae from analytic geometry. In Figure 21, the distances are symbolized by "d" with various subscripts as shown. The envelope heights (terrain elevation plus obstacle height) are symbolized by "h_E" with a subscript number as shown, H_{LA} is the left hand antenna height, H_{RA} is the right hand antenna elevation, h_L is the left antenna horizon ray, h_R is the right antenna horizon ray, h_I is the inter-horizon ray path, and h_C is sea level height above a chord joining the terminal locations at sea level. For this configuration, the horizon ray clearance, reflection plane elevation, effective antenna heights and horizon ray takeoff and absolute angles are calculated for both the transmitter and receiver antennas. The diffraction parameters, which include diffraction angle and diffraction obstacle radius and diffraction distance and elevation, are then presented on the output screen. This is followed by the ray start and end points, ray slope and intercept, ray minimum clearance, ray mean height and ray mean atmospheric pressure which are calculated for the transmitter horizon, line-of-sight and receiver horizon. This output is displayed in Figure 21.

4.1.5.2.3 Double-Obstacle Diffraction Path Calculations

A double-obstacle diffraction path is one for which separate terrain features form the horizons for each end of the path, but for which the inter-horizon path is line-of-sight for normal refractive conditions. Referring to Figure 20, the profile would correspond to a double-obstacle diffraction path if the ray h_I were line-of-sight. The technique and variables are the same as described for single-obstacle diffraction described in paragraph 4.1.5.2.2 above. The output screen for the double diffraction path is shown in Figure 22. First the double diffraction path calculations output screen presents a list of the horizon distance and elevation, ray clearance, ray takeoff and absolute angles, obstacle radius, reflection plane elevation, and effective antenna heights for the transmitter and receiver sites. The diffraction angles for the transmitter and receiver are also calculated. The ray start point, ray end point, ray slope and intercept, ray minimum clearance, ray mean path height and ray mean atmospheric pressure is then displayed for the transmitter-to-horizon path, the inter-horizon line-of-sight path, and receiver horizon-to-receiver path. The next information on the output screen displays the distance of certain elements on the path profile as shown in Figure 27.

4.1.5.2.4 Tropospheric Scatter Path Calculations

A tropospheric scatter path is one for which separate terrain features form the horizons for each end of the path, and for which the inter-horizon path is not line-of-sight for normal refractive conditions. Referring to Figure 28, the profile shown corresponds to a troposcatter path since the ray h_I is not line-of-sight. The first output on the scatter path calculations is a list of the horizon distance and elevation, ray clearance, ray takeoff and absolute angles, obstacle radius, reflection plane elevation and effective antenna heights for the transmitter and receiver sites. This is followed by the scatter volume height, scatter volume distance, scatter volume normalized height, and scatter angle. The ray start point, ray end point, ray slope and intercept, ray minimum clearance, ray mean path height and ray mean atmospheric pressure are then displayed for the transmitter horizon, inter horizon, line-of-sight and receiver horizon. The next information on the output screen displays the distance of certain elements on the path profile as shown in Figure 23.

Propagation Parameters - Tosa to Weisshorn	
Path Length	403.40 km
Surface Refractivity	250.00
k-factor	1.33
Transmitting Site Elevation	1062.50
Transmitter Primary Antenna Height	1.00 m
Receiving Site Elevation	1483.00 m
Receiver Antenna Primary Antenna Height	1.00 m
Diversity Branches	N/A
Diversity Antenna Configuration	N/A
Diversity Separation	N/A
Transmitter Diversity Antenna Height	N/A
Receiver Diversity Antenna Height	N/A
Transmitter Horizon Ray Clearance	256.96 m
Transmitter Reflection Plane Elevation	550.50 m
Transmitter Effective Antenna Height	513.00 m
Transmitter Horizon Ray Takeoff Angle	- 0° 6′ 28.14″
Transmitter Horizon Ray Absolute Angle	20.8 mr
Receiver Horizon Ray Clearance	111.16 m
Receiver Reflection Plane Elevation	1125.00 m
Receiver Effective Antenna Height	359.00 m
Receiver Horizon Ray Takeoff Angle	0° 19′ 52.61″
Receiver Horizon Ray Absolute Angle	30.6 mr
Diffraction Angle	51.4 mr
Diffraction Obstacle Radius	0.00 km
Diffraction Obstacle Distance	240.00 km
Diffraction Obstacle Elevation	6306.87 m
Transmitter Horizon Ray Start Point Elevation	1063.50 m
Transmitter Horizon Ray Start Point Distance	0.00 km
Transmitter Horizon Ray End Point Elevation	6306.87 m
Transmitter Horizon Ray End Point Distance	240.00 km
Transmitter Horizon Ray Slope	0.0218
Transmitter Horizon Ray Intercept	1063.50
Transmitter Horizon Ray Minimum Clearance Distance	36.00 km
Transmitter Horizon Ray Minimum Clearance	256.96 m
Transmitter Horizon Ray Path Mean Height	840.80 m
Transmitter Horizon Ray Path Mean Atmospheric Pressure	91.58 kPa
Line of Sight Ray Start Point Elevation	1063.50 m
Line of Sight Ray Start Point Distance	0.00 km
Line of Sight Ray End Point Elevation	1484.00 m
Line of Sight Ray End Point Distance	403.40 km
Line of Sight Ray Slope	0.0010
Line of Sight Ray Intercept	1063.50
Line of Sight Ray Minimum Clearance Distance	240.00 km
Line of Sight Ray Minimum Clearance	-4993.20 m
Line of Sight Ray Path Mean Height	992.40 m
Line of Sight Ray Path Mean Atmospheric Pressure	89.92 kPa
Receiver Horizon Ray Start Point Elevation	6306.87 m
Receiver Horizon Ray Start Point Distance	240.00 km
Receiver Horizon Ray End Point Elevation	1484.00 m
Receiver Horizon Ray End Point Distance	403.40 km
Receiver Horizon Ray Slope	-0.0295
Receiver Horizon Ray Intercept	13390.76
Receiver Horizon Ray Minimum Clearance Distance	277.00 km
Receiver Horizon Ray Minimum Clearance	111.16 m
Receiver Horizon Ray Path Mean Height	1312.98 m
Receiver Horizon Ray Path Mean Atmospheric Pressure	86.47 kPa

Figure 21. Calculation screen for single diffraction path.

Propagation Parameters - Tosa to Weisshorn	
Path Length	403.40 km
Surface Refractivity	250.00
k-factor	1.33
Transmitting Site Elevation	1062.50
Transmitter Primary Antenna Height	1.00 m
Receiving Site Elevation	1483.00 m
Receiver Antenna Primary Antenna Height	1.00 m
Diversity Branches	N/A
Diversity Antenna Configuration	N/A
Diversity Separation	N/A
Transmitter Diversity Antenna Height	N/A
Receiver Diversity Antenna Height	N/A
Transmitter Horizon Distance	189.00 km
Transmitter Horizon Elevation	4923.68 m
Transmitter Obstacle Radius	0.00 km
Transmitter Horizon Ray Clearance	98.13 m
Transmitter Reflection Plane Elevation	550.50 m
Transmitter Effective Antenna Height	513.00 m
Transmitter Horizon Ray Takeoff Angle	- 0° 11' 21.56"
Transmitter Horizon Ray Absolute Angle	19.4 mr
Receiver Horizon Distance	277.00 km
Receiver Horizon Elevation	5103.61 m
Receiver Obstacle Radius	32.47 km
Receiver Horizon Ray Clearance	154.18 m
Receiver Reflection Plane Elevation	1125.00 m
Receiver Effective Antenna Height	359.00 m
Receiver Horizon Ray Takeoff Angle	0° 16' 51.36"
Receiver Horizon Ray Absolute Angle	29.7 mr
Transmitter Diffraction Angle	18.3 mr
Receiver Diffraction Angle	30.8 mr
Transmitter Horizon Ray Start Point Elevation	1063.50 m
Transmitter Horizon Ray Start Point Distance	0.00 km
Transmitter Horizon Ray End Point Elevation	4923.68 m
Transmitter Horizon Ray End Point Distance	189.00 km
Transmitter Horizon Ray Slope	0.0204
Transmitter Horizon Ray Intercept	1063.50
Transmitter Horizon Ray Minimum Clearance Distance	188.00 km
Transmitter Horizon Ray Minimum Clearance	98.13 m
Transmitter Horizon Ray Path Mean Height	521.91 m
Transmitter Horizon Ray Path Mean Atmospheric Pressure	95.18 kPa

Figure 22a. Calculation screen for double diffraction path.

Inter Horizon Ray Start Point Elevation	4923.68 m
Inter Horizon Ray Start Point Distance	189.00 km
Inter Horizon Ray End Point Elevation	5112.41 m
Inter Horizon Ray End Point Distance	276.00 km
Inter Horizon Ray Slope	0.0022
Inter Horizon Ray Intercept	4513.69
Inter Horizon Ray Minimum Clearance Distance	275.00 km
Inter Horizon Ray Minimum Clearance	43.15 m
Inter Horizon Ray Path Mean Height	2085.57 m
Inter Horizon Ray Path Mean Atmospheric Pressure	78.60 kPa
Line of Sight Ray Start Point Elevation	1063.50 m
Line of Sight Ray Start Point Distance	0.00 km
Line of Sight Ray End Point Elevation	1484.00 m
Line of Sight Ray End Point Distance	403.40 km
Line of Sight Ray Slope	0.0010
Line of Sight Ray Intercept	1063.50
Line of Sight Ray Minimum Clearance Distance	276.00 km
Line of Sight Ray Minimum Clearance	-3761.21 m
Line of Sight Ray Path Mean Height	981.24 m
Line of Sight Ray Path Mean Atmospheric Pressure	90.04 kPa
Receiver Horizon Ray Start Point Elevation	5103.61 m
Receiver Horizon Ray Start Point Distance	277.00 km
Receiver Horizon Ray End Point Elevation	1484.00 m
Receiver Horizon Ray End Point Distance	403.40 km
Receiver Horizon Ray Slope	-0.0286
Receiver Horizon Ray Intercept	13035.99
Receiver Horizon Ray Minimum Clearance Distance	344.00 km
Receiver Horizon Ray Minimum Clearance	154.18 m
Receiver Horizon Ray Path Mean Height	935.82 m
Receiver Horizon Ray Path Mean Atmospheric Pressure	90.54 kPa
D - d5	126.40 km
d5 - d4	1.00 km
d4 - d2	87.00 km
d2 - d1	0.00 km

Figure 22b. Calculation screen for double diffraction path (continued).

Propagation Parameters - Tosa to Weisshorn

Path Length	403.40 km
Surface Refractivity	250.00
k-factor	1.33
Transmitting Site Elevation	1062.50
Transmitter Primary Antenna Height	1.00 m
Receiving Site Elevation	1483.00 m
Receiver Antenna Primary Antenna Height	1.00 m
Diversity Branches	N/A
Diversity Antenna Configuration	N/A
Diversity Separation	N/A
Transmitter Diversity Antenna Height	N/A
Receiver Diversity Antenna Height	N/A
Transmitter Horizon Distance	188.00 km
Transmitter Horizon Elevation	4805.13 m
Transmitter Obstacle Radius	0.00 km
Transmitter Horizon Ray Clearance	186.94 m
Transmitter Reflection Plane Elevation	550.50 m
Transmitter Effective Antenna Height	513.00 m
Transmitter Horizon Ray Takeoff Angle	- 0° 13′ 9.17″
Transmitter Horizon Ray Absolute Angle	18.9 mr
Receiver Horizon Distance	277.00 km
Receiver Horizon Elevation	5103.61 m
Receiver Obstacle Radius	30.78 km
Receiver Horizon Ray Clearance	154.18 m
Receiver Reflection Plane Elevation	1125.00 m
Receiver Effective Antenna Height	359.00 m
Receiver Horizon Ray Takeoff Angle	0° 16′ 51.36″
Receiver Horizon Ray Absolute Angle	29.7 mr
Scatter Volume Height	5972.54 m
Scatter Volume Distance	246.66 km
Scatter Volume Normalized Height	6926.19 m
Scatter Angle	48.5 mr
Transmitter Horizon Ray Start Point Elevation	1063.50 m
Transmitter Horizon Ray Start Point Distance	0.00 km
Transmitter Horizon Ray End Point Elevation	4805.13 m
Transmitter Horizon Ray End Point Distance	188.00 km
Transmitter Horizon Ray Slope	0.0199
Transmitter Horizon Ray Intercept	1063.50
Transmitter Horizon Ray Minimum Clearance Distance	36.00 km
Transmitter Horizon Ray Minimum Clearance	186.94 m
Transmitter Horizon Ray Path Mean Height	511.17 m
Transmitter Horizon Ray Path Mean Atmospheric Pressure	95.30 kPa

Figure 23a. Calculation screen for scatter path.

Inter Horizon Ray Start Point Elevation	4805.13 m
Inter Horizon Ray Start Point Distance	188.00 km
Inter Horizon Ray End Point Elevation	5112.41 m
Inter Horizon Ray End Point Distance	276.00 km
Inter Horizon Ray Slope	0.0039
Inter Horizon Ray Intercept	4045.25
Inter Horizon Ray Minimum Clearance Distance	212.00 km
Inter Horizon Ray Minimum Clearance	-8.99 m
Inter Horizon Ray Path Mean Height	2072.36 m
Inter Horizon Ray Path Mean Atmospheric Pressure	78.73 kPa
Line of Sight Ray Start Point Elevation	1063.50 m
Line of Sight Ray Start Point Distance	0.00 km
Line of Sight Ray End Point Elevation	1484.00 m
Line of Sight Ray End Point Distance	403.40 km
Line of Sight Ray Slope	0.0010
Line of Sight Ray Intercept	1063.50
Line of Sight Ray Minimum Clearance Distance	276.00 km
Line of Sight Ray Minimum Clearance	-3761.21 m
Line of Sight Ray Path Mean Height	977.52 m
Line of Sight Ray Path Mean Atmospheric Pressure	90.08 kPa
Receiver Horizon Ray Start Point Elevation	5103.61 m
Receiver Horizon Ray Start Point Distance	277.00 km
Receiver Horizon Ray End Point Elevation	1484.00 m
Receiver Horizon Ray End Point Distance	403.40 km
Receiver Horizon Ray Slope	-0.0286
Receiver Horizon Ray Intercept	13035.99
Receiver Horizon Ray Minimum Clearance Distance	344.00 km
Receiver Horizon Ray Minimum Clearance	154.18 m
Receiver Horizon Ray Path Mean Height	935.82 m
Receiver Horizon Ray Path Mean Atmospheric Pressure	90.54 kPa
D - d5	126.40 km
d5 - d4	1.00 km
d4 - d2	88.00 km
d2 - d1	0.00 km

Figure 23b. Calculation screen for scatter path (continued).

4.1.5.3 Input/Edit Print Listing

This menu selection prints the headers and input data as it appears on the input/edit screen. A sample input screen is shown in Figure 17 in Section 4.1.5.1.

4.1.5.4 Calculations Print Listing

The Calculations Print Listing option calculates and prints the output screen. The output that is printed is determined by the type of path. The output screens that are printed are identical to the ones displayed on the screen. These are described in Section 4.1.5.2.1 through 4.1.5.2.4. The sample outputs are shown in Figures 17 through 19.

4.1.5.5 View Path on Screen

The two general categories of path considered in RAIDER, namely within and beyond line-of-sight have traditionally been presented in different formats. For within line-of-sight paths, the terrain profile has been drawn as though the Earth's surface were flat and the ray paths then were parabolic curves whose curvature corresponded to values of atmospheric refractive index gradient and hence effective Earth's radius. On the other hand, beyond line-of-sight path terrain profiles were drawn with equal elevations above or below sea level represented by parabolic curves whose curvature corresponded to a standard vertical refractivity profile giving an effective Earth's radius (5280 miles or 9000 kilometers) factor of about 1.33. The vertical scale was linear so that ray paths could be approximated as straight lines. This practice was continued for the RAIDER displays and the type of path determines the style of plot which is displayed on the screen. If an obstruction to a line-of-sight path is found while the plot calculations are taking place, the user will be presented with a box that explains where the obstruction is located on the path and is asked whether to recalculate the antenna heights. If the user chooses to recalculate the antenna heights, a line-of-sight path will be drawn, occasionally with extremely large tower heights. If the user does not choose to recalculate the antenna heights, a beyond-the-horizon plot will be drawn.

4.1.5.5.1 Line-of-Sight Path Profile

The line-of-sight path profile displays the path profile and three ray paths from the transmitter to the receiver. The calculations done for this plot are described in Section 4.1.5.2.1. If the path is a repeater path, the primary link is shown at the left and the repeater link is to the right. The ray paths are for the average Earth's radius factor, the extreme Earth's radius factor and the 0.6 Fresnel zone. An example of a line-of-sight plot for a single link is shown in Figure 24 and a plot for a repeater link is shown in Figure 25.

4.1.5.5.2 Single Diffraction Plot

The profile plot for a single diffraction path shows the rays between the transmitter and receiver and the common horizon. A single diffraction path plot is shown in Figure 26.

4.1.5.5.3 Double Diffraction Plot

The double diffraction plot shows the rays between the transmitter and receiver and the common horizon. It also shows the location of the line-of-sight path between the transmitter and receiver. Figure 27 shows a double diffraction plot.

4.1.5.5.4 Scatter Plot

A scatter plot shows a ray from the transmitter and a ray from the receiver which meet at the scatter point for the path. This is shown in Figure 28.

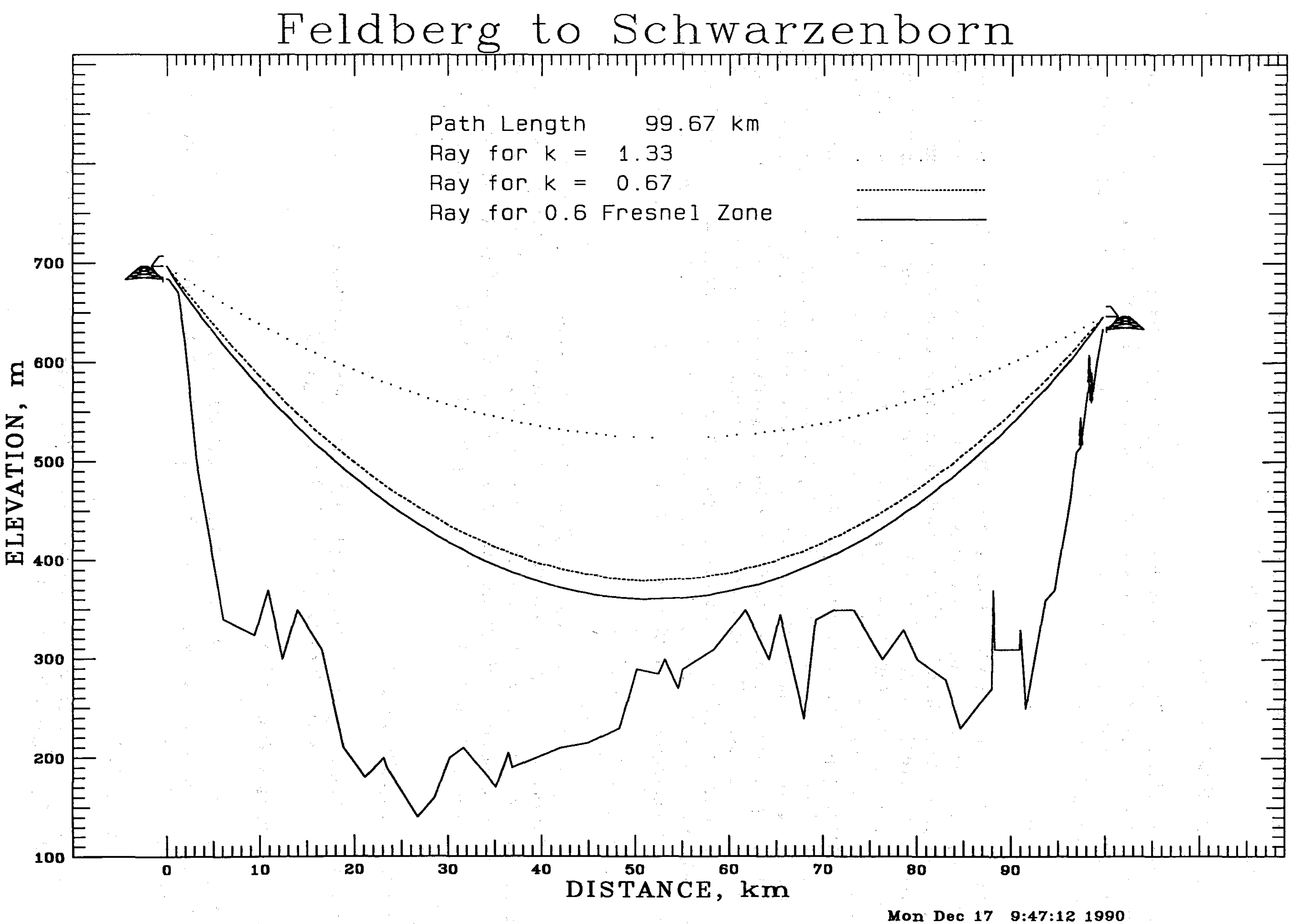

Figure 24. Line-of-sight path for a single link.

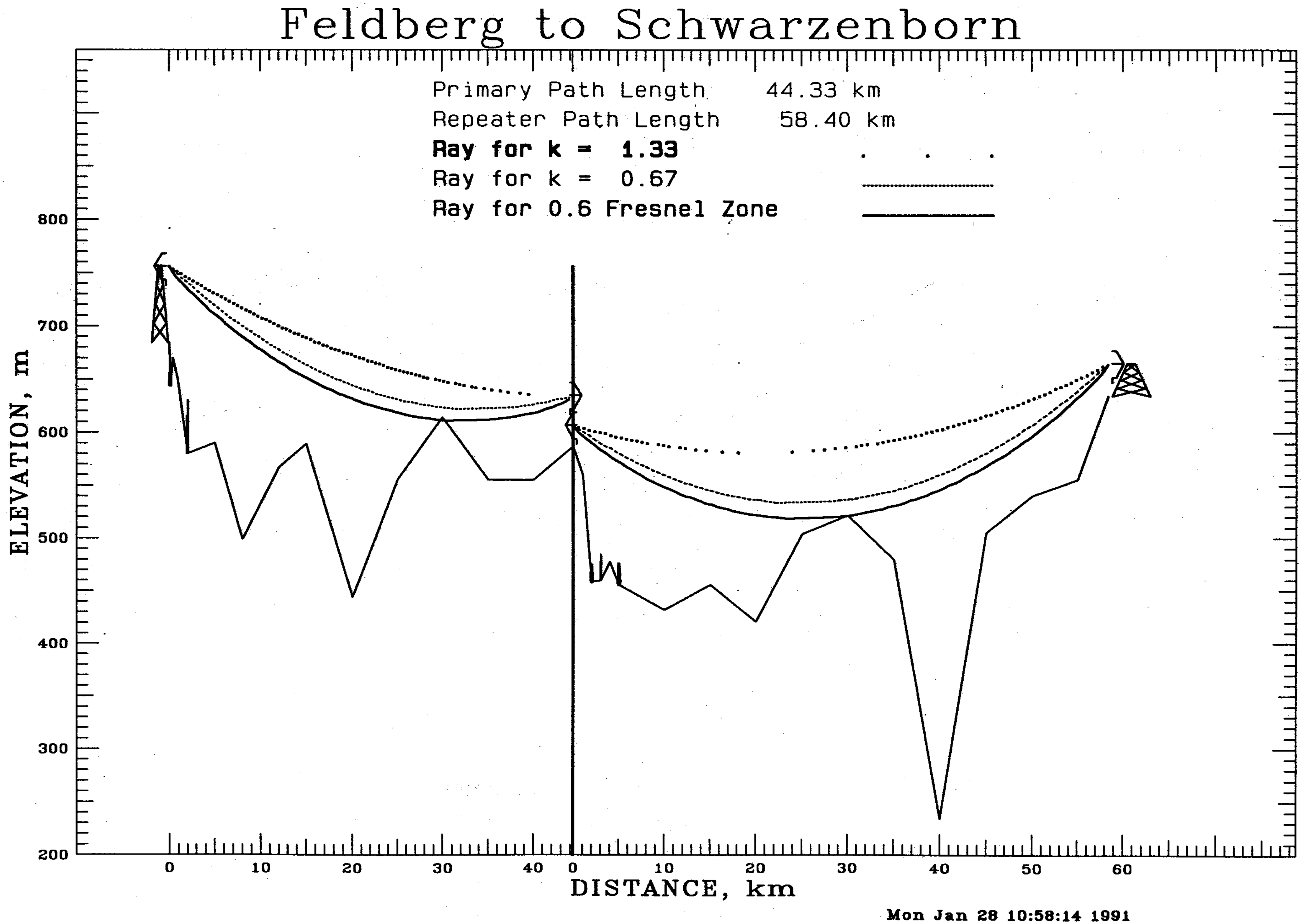

Figure 25. Line-of-sight path for a repeater link.

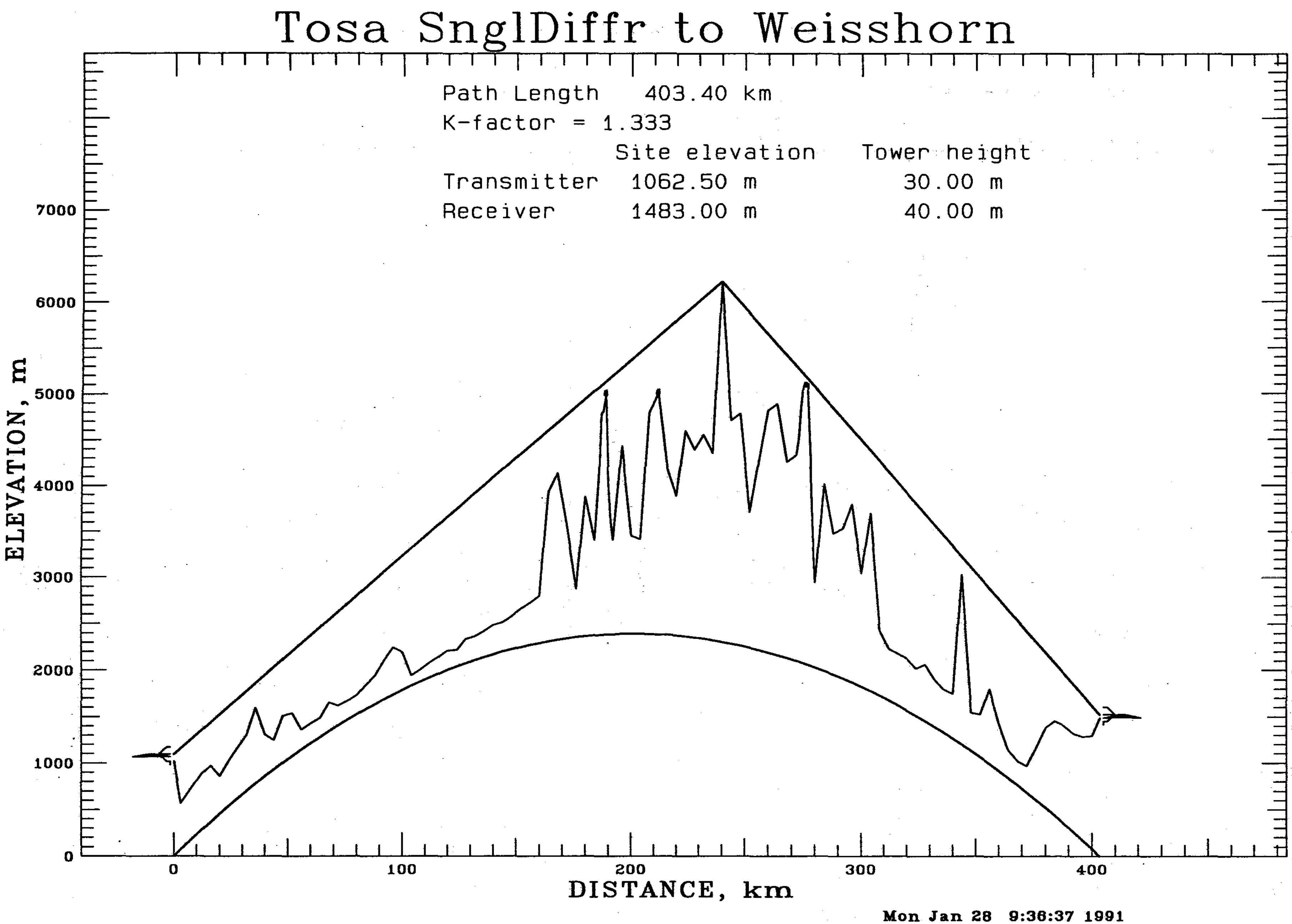

Figure 26. Single diffraction path.

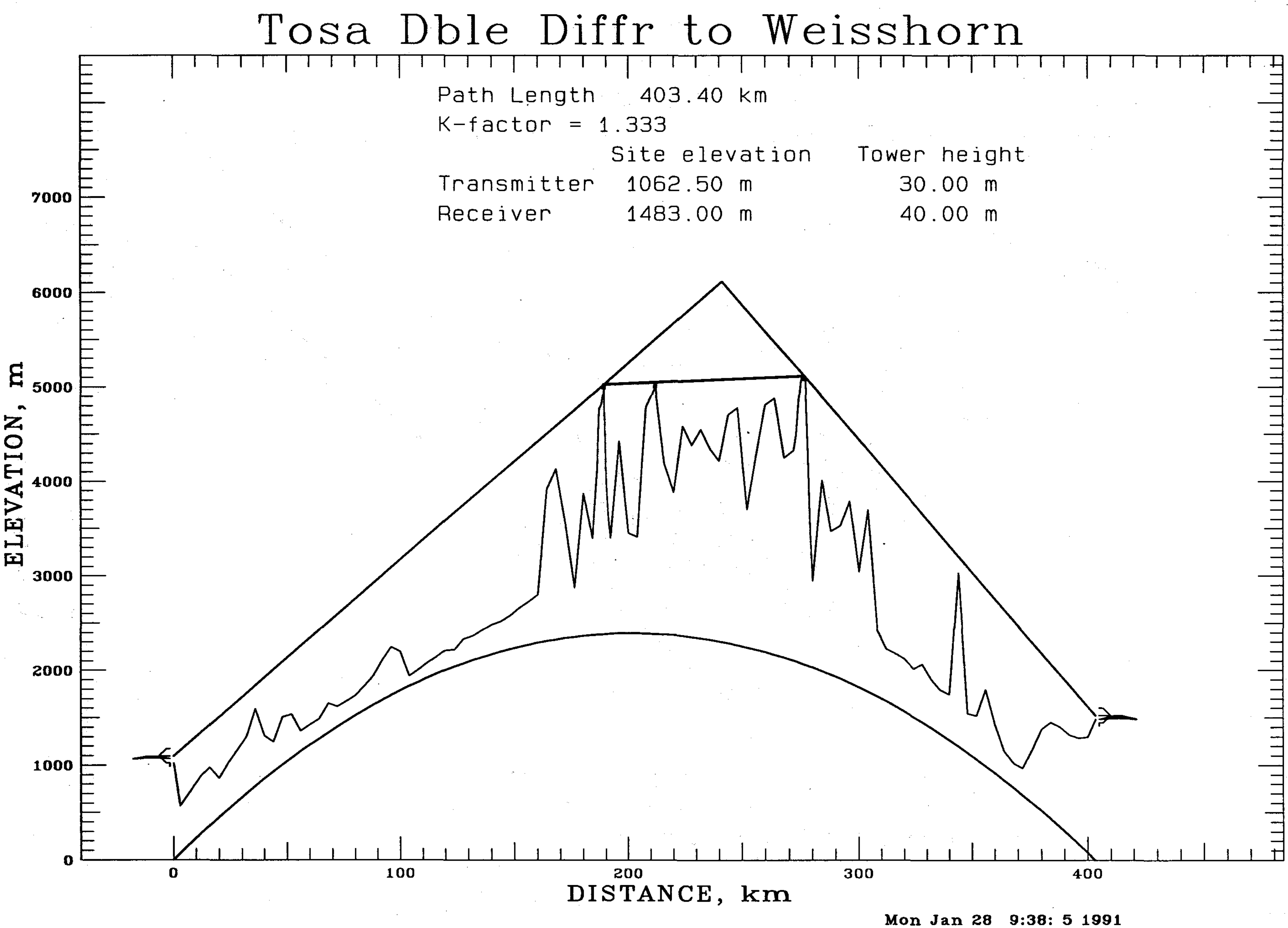

Figure 27. Double diffraction path.

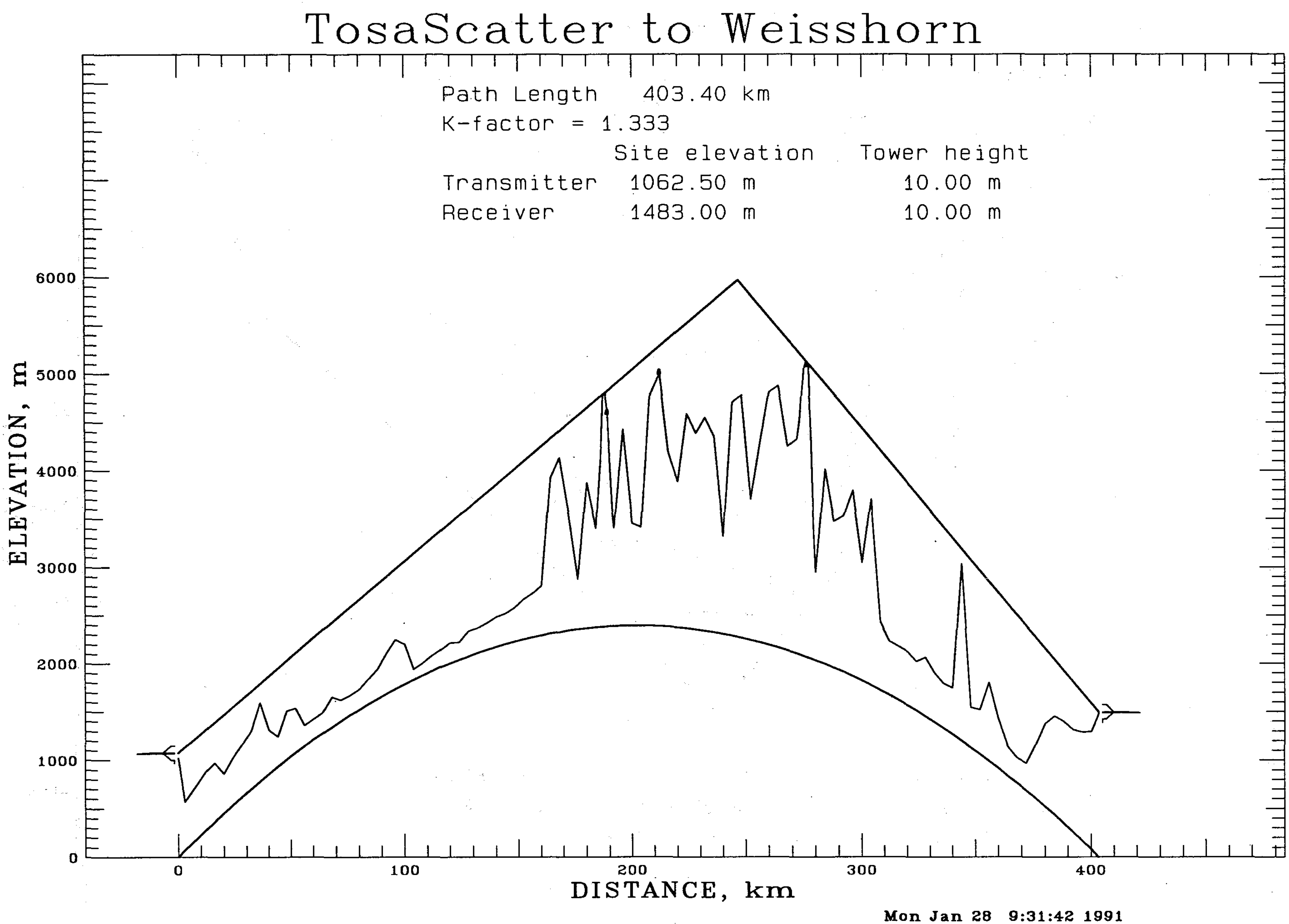

Figure 28. Scatter path.

4.1.5.6 Draw Path on Plotter

Choosing this menu item will cause the plot calculations to be performed in the same manner as described in Section 4.1.5.5. The plots drawn are the same plots as those described in Sections 4.1.5.5.1 through 4.1.5.5.4.

4.1.5.7 Keep Path in File

The plot calculations are performed as described in Section 4.1.5.5. The plots produced are the same as the ones discussed in sections 4.1.5.5.1 through 4.1.5.5.4. The plot is written to a file which can be sent to a laserjet printer.

4.1.6 Gain

The Gain module allows the user to enter appropriate values for the various components of fixed gain and loss appropriate to the link under design. These include the transmission line type, the antenna size, and the transmitter power. Calculations are then performed to determine system gain, which allows a determination of received signal level for the link. Initially, the user is presented with a menu that has the options to input data or to perform calculations as shown in Figure 29.

```
SYSTEM GAIN  - Tosa to Weisshorn

          Link Input/Edit
          Calculate
          Quit

Press ESC to cancel.
```

Figure 29. Gain main menu.

4.1.6.1 Link Input/Edit

Choosing this menu option will invoke another menu that allows the user to choose either to continue with the Link Input/Edit option or print the input values using the Input/Edit Print Listing option from the menu shown in Figure 30. If the user chooses the Link Input/Edit option, the screen in Figure 31, which is the input screen for a single link, will be displayed. The screen to allow the user to perform this function for a repeater link has two sets of the same entries as those for a single link.

The default values for the required values of frequency and antenna height above ground will be the values that were entered in the plot modules. If the user wishes to change these values, the frequency value must be between 1 and 30 GHz and the antenna heights must be between 1 and 45.72 m. If the user changes the frequency, the program determines if the line loss and line type are compatible with the new frequency. If they are not, the user will receive a prompt for each incompatible line loss and be asked if the line loss should be changed. If the user answers Yes it will be changed, otherwise it is left as it currently exists. The user is also required to input values for transmitter output power, horizontal

```
Input/Edit Options

 Link Input/Edit
 Input/Edit Print Listing
 Quit

Press ESC to cancel.
```

Figure 30. Menu for gain input/edit.

```
ANTENNA GAIN
Double Diffraction Path

INPUT / EDIT                       Tosa         Weisshorn
Frequency                         8.00 GHz
Transmitter power output          9.000 W       39.542 dBm
Antenna Data                     Transmitter     Receiver
Antenna Height Above Ground       1.00 m         1.00 m       TYPE
Vertical Line Type                EW-77          EW-77
Vertical Line Loss per 100 m      5.75 dB        5.75 dB      F1 for units
Horizontal Line Length            5.00 m         6.00 m       F2 for refresh
Horizontal Line Type              EW-77          EW-77        F6 for line typ
Horizontal Line Loss per 100 m    5.75 dB        5.75 dB      F8 to eXit
Miscellaneous Line Losses         0.40 dB        0.40 dB
Branching Loss                    0.30 dB        0.30 dB
Antenna Diameter                  1.20 m        10.00 m
Diversity Order (2, 4, 8, 16)     16
```

Figure 31. Input/edit screen for gain.

and vertical line losses per 100 m, horizontal line length, miscellaneous losses, branching losses, antenna diameters, and diversity order. The transmitter output power must be between .001 and 100,000 W.

The vertical line losses per 100 m values can be between .1 and 50 dB and the horizontal line losses per 100 m can be between .1 and 10 dB. The horizontal line length may be between 1 and 100 m. Miscellaneous losses and branching loss may have values between .1 and 5. The antenna diameters can be between .3 and 45.72 m. Legal entries for diversity order are 2, 4, 8, or 16. Any characters may be entered for line type.

The program uses the F1, F2 and F8 function keys as they are described in Section 3.1.1. This module uses a file of line types that are suitable for particular frequency ranges. When function key F6 is pressed, the user is prompted for a frequency. The user is then given a list of line types that may be used at this frequency with their associated losses per 100 m length. This allows the user to see the frequency range and nominal loss for several line types. The line type display is shown in Figure 32.

```
NAME        FREQ RANGE (GHz)  LOSS for  7.00 GHz
EW-64        5.30 -  7.80            4.95
EW-63        5.80 -  7.10            4.39
EW-77        7.00 -  8.50            6.40

          Press any key to continue ...
```

Figure 32. List of line types for a frequency of 7.0 GHz.

The Input/Edit Print Listing option allows the user to print the input screen. The output will have the same heading information and input data as shown in Figure 31.

4.1.6.2 Calculate

Choosing this option from the menu causes the program to display a new menu as shown in Figure 33. If the user chooses the Calculate option, the screen in Figure 34 is displayed. This example shows a single link. The output for a repeater link is the same except that the data is repeated for the repeater site.

Antenna gains are calculated from

$$G = 10 \log \frac{\eta \pi^2 D_a^2}{\lambda^2} \; dBi \tag{53}$$

where:

η = aperature efficiency (usually 0.55),
D_a = diameter,
λ = wavelength (in the same units).

Equation 53 may be rewritten for η = 0.55, f in GHz and D_a in meters to give:

$$G = 20 \log 7.772 \, D_a f \; dB. \tag{54}$$

For troposcatter paths, the gain of the antenna is degraded by the incoherence of the received signal. The model for L_{mc} in dB is obtained from the curve from CCIR (1978, p. 213). The expression for L_{mc} is:

$$L_{mc} = 10 \ln (\exp[0.079(G_T + G_R) - 6.48] + 1) \tag{55}$$

where G_T and G_R are the transmitting and receiving antenna gains in dB.

These values are stored in the link file for use by subsequent modules such as the FM/FDM module.

```
Calculation Options

 Calculate
 Print Calculations
 Quit

Press ESC to cancel.
```

Figure 33. Gain calculations menu.

INPUT	Tosa	Weisshorn
Frequency	8.00 GHz	
Transmitter Power Output	9.000 W	39.542 dBm
Antenna Data	Transmitter	Receiver
Antenna Height	1.00 m	1.00 m
Vertical Line Type	EW-77	EW-77
Vertical Line Loss per 100 m	5.75 dB	5.75 dB
Horizontal Line Length	5.00 m	6.00 m
Horizontal Line Type	EW-77	EW-77
Horizontal Line Loss per 100 m	5.75 dB	5.75 dB
Miscellaneous Losses	0.40 dB	0.40 dB
Branching Loss	0.30 dB	0.30 dB
Antenna Diameter	1.20 m	10.00 m
Diversity Order	16	
OUTPUT	Tosa	Weisshorn
Vertical Line Loss	0.06 dB	0.06 dB
Horizontal Line Loss	0.29 dB	0.35 dB
Antenna Gain	37.46 dBi	55.87 dBi
Aperature-to-Medium Coupling Loss	11.87 dB	
System Gain	118.86 dB	

Figure 34. Single link gain calculations output screen.

If the user chooses the Print Calculations option the output will be printed. It will appear as it does in Figure 34, with a second set of figures for a repeater path.

4.1.7 FM/FDM Module

This module allows the user to complete the design of a link, either within or beyond line-of-sight, that will employ frequency division multiplexing and frequency modulation (FDM/FM) transmission technologies. The user is prompted to input the variables such as the number of FDM voice channels, the baseband frequency limits, the IF bandwidth to be used, equipment parameters, and various transmission line constants as shown in Figure 37. The transmission line is referred to as a "feeder" as was done in Medhurst (1959). The user is presented with the menu shown in Figure 35 when this module is chosen.

```
FM/FDM  - Tosa to Weisshorn

      Link Input/Edit
      Calculate
      Plot
      Quit

Press ESC to cancel.
```

Figure 35. FM/FDM main menu.

4.1.7.1 Link Input/Edit

The menu associated with the Link Input/Edit option has two choices as shown in Figure 36. The first option is Link Input/Edit. When this is chosen, a screen as shown is Figure 37 is displayed. This screen is for a single link. For a repeater link, the inputs are displayed twice, once for the primary link and once for the repeater link. All of the fields on the screen are required inputs. Default values derived from the values calculated in Gain are used for the total transmission line length and the total line loss. If the user wishes to change these values, the total transmission line length must be between 1 and 500 m and the total line loss must be between .1 and 50 dB. The voltage standing wave ratio (VSWR) at the antenna and radio must also be entered. These values must be greater than 1 and less than or equal to 2. The user must enter a receiver noise figure between .1 and 10 dB and a receiver IF bandwidth between .1 and 20 dB. The emphasis improvement can be either 0 or 4 dB. There may be between 12 and 240 voice channels and the voice channel bandwidth can be between 2 and 25 kHz. The equipment noise-power ratio (NPR) can be between 30 and 60 dB. The root mean square (RMS) per channel deviation can take values between 10 and 500 kHz. The user must select whether or not threshold extension will be considered. The baseband signal peak factor must be between 5 and 20. The highest modulating frequency must be between 100 and 6000 kHz and the lowest modulating frequency must be between 1 and 500 kHz.

The input/edit screen will be printed if the the Input/Edit Print Listing option is chosen from the Link Input/Edit menu and will appear with the same headings and input data as shown in Figure 37.

```
Input/Edit Options

 Link Input/Edit
 Input/Edit Print Listing
 Quit

Press ESC to cancel.
```

Figure 36. FM/FDM input/edit menu.

```
ANALOG RADIO SYSTEM SINGLE RECEIVER
      TRANSFER CHARACTERISTIC

INPUT / EDIT                          feldberg    schwarzenborn
                                     TRANSMITTER   RECEIVER
Total Transmission Line Length        147.13 m     100.97 m
Total Line Loss                         3.13 dB      2.15 d
Feeder Velocity Ratio                  65.00 %      65.00       TYPE
VSWR at Antenna                         1.06         1.06
VSWR at Radio                           1.06         1.06       F1 for units
Receiver Noise Figure                   3.00 dB                 F2 for refresh
Receiver IF Bandwidth                  15.18 MHz                F8 to exit
Emphasis Improvement (0 or 4)           4.00 dB
Number of Voice Channels              600.00
Voice Channel Bandwidth                 3.10 kHz
Equipment NPR                          55.00 dB
RMS per Channel Deviation             140.00 kHz
Threshold Extension                   no
  Y - Yes
  N - No
Baseband Signal Peak Factor            13.50
Highest Modulating Frequency in BB 2460.00 kHz
Lowest Modulating Frequency in BB    60.00 kHz
```

Figure 37. Single link FM/FDM input/edit screen.

4.1.7.2 Calculate

When the Calculate option is chosen, a new menu is presented as shown in Figure 38 that has the options for Link Calculations and Calculation Print Listing. Figure 39 shows the screen which is displayed when Link Calculations is chosen. This screen is for a single link; for a repeater link, data for both the primary link and the repeater link would be shown.

```
Calculation Options

 Link Calculations
 Calculations Print Listing
 Quit

Press ESC to cancel.
```

Figure 38. FM/FDM calculation menu.

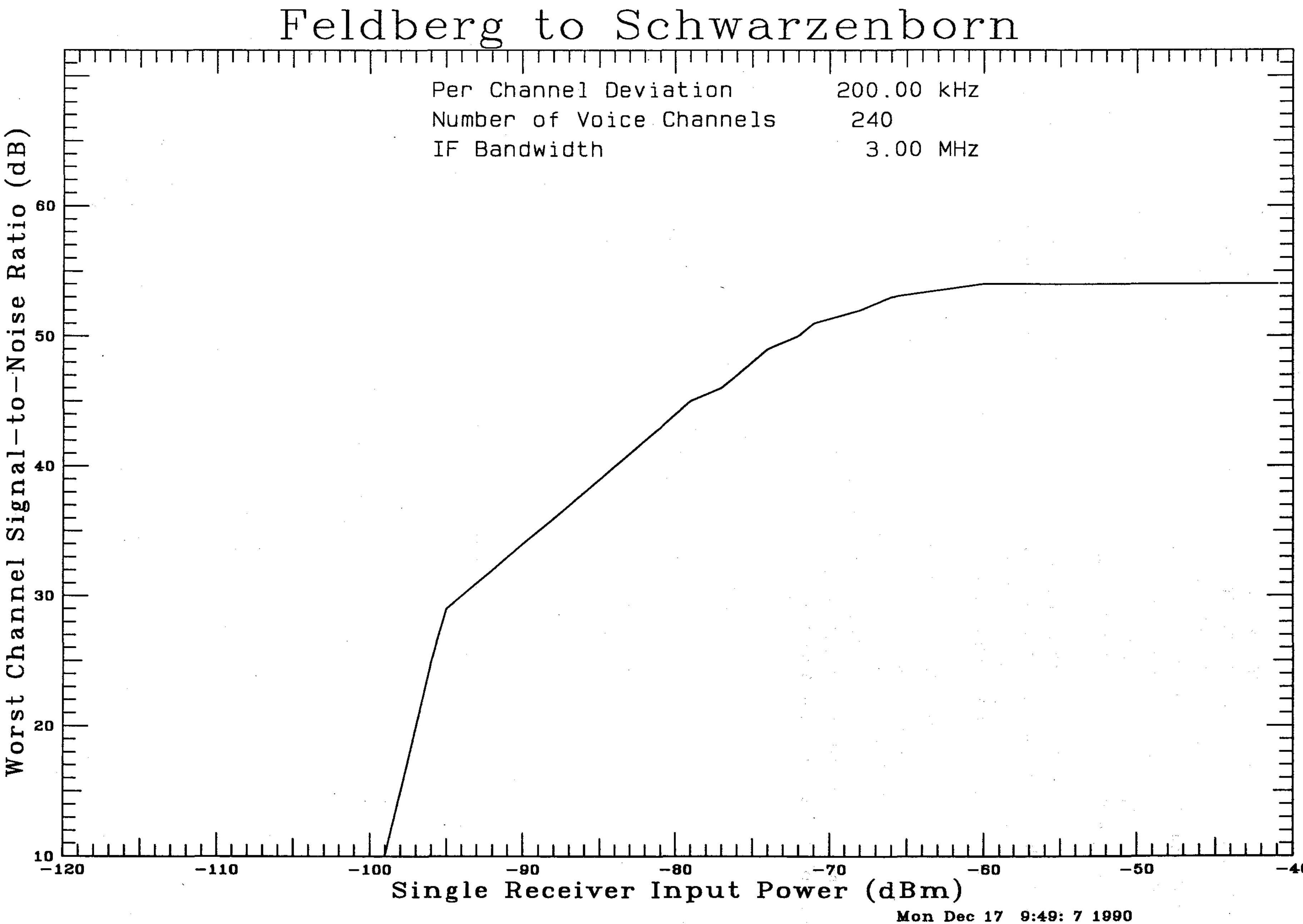

Figure 41. FM/FDM plot.