

User-Friendly Software for the Design of Digital Line-of-Sight Radio Links

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USER-FRIENDLY SOFTWARE FOR THE DESIGN OF DIGITAL LINE-OF-SIGHT RADIO LINKS

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This report provides a description of and operating instructions for Digital Line-of-Sight (DLOS) programs. These programs, which run on a desk-top computer, automate the calculations involved in design of line-of-sight microwave radio relay paths. The programs manipulate information about Earth geometry, terrain profiles, ray paths, median basic transmission loss, variability of loss, equipment effects, and path performance. The computer hardware and software configurations are designed to be convenient to operate and to give the design engineer immediate access to calculated results corresponding to changes in design parameters. The programs are intended to be used interactively by persons having no experience in programming. The algorithms may be applied over a wide range of path parameters. The frequency range is from 1 GHz to 10 GHz; the path length may be up to 200 km; and the path must have adequate terrain clearance. The results of the calculations are given in terms of the requirements of MIL-STD-188-323.

Key words: computer software; digital radio; microwave radio; MIL-STD-188-323 requirements; radio path performance; radio relay

1. INTRODUCTION

The Digital Line-of-Sight (DLOS) programs were developed to give microwave link design engineers and technicians a set of tools to design such links and systems to meet the requirements of MIL-STD-188-323. The algorithms on which the programs are based were drawn from a number of sources such as the ARROWS programs (Hause, 1986), which provided the Earth geometry and antenna height algorithms, and recent CCIR documents (CCIR, 1986), which provided the multipath occurrence factor algorithm. The Defense Communication Agency (DCA), through the Defense Communication Engineering Center (DCEC), determines the standards for military communication system design. In pursuit of this task, DCEC issued Engineering Publication EP 15-87 (Smith and Smullen, 1987), which discusses the

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rationale for the DCEC technique of microwave path analysis and provides a discussion of the algorithm used to determine the performance of particular digital modulation schemes as a function of typical path parameters. An appendix of DCEC EP 15-87 describes the operation of the DCEC version of this program set. This report will assist an operator in using the DLOS programs, although each module has an operating menu. A brief discussion of the underlying algorithms is provided to assist the operator in making the required entries but a complete discussion of microwave propagation is not included. The interested user is referred to the Defense Communication Engineering Center EP 15-87 on which the DLOS programs are based. Programming the algorithms was sponsored by U.S. Army Information Systems Engineering Command, Ft. Huachuca, AZ. The primary use of the program set is the analysis of line-of-sight (LOS) paths, although the Earth geometry and profile entry modules are applicable to any type of path. These programs calculate the optimum antenna height values from the Earth and terrain geometry parameter values. They also calculate the expected performance of a communication link operating over the path based on the selected antenna size, antenna gains, other equipment parameters, and the given atmospheric and terrain parameters.

2. SCOPE

The idea behind the DLOS programs represents a radical departure from previous link prediction programs such as ARROWS or WORLD prepared by the Institute for Telecommunication Sciences (ITS). These earlier programs were intended to provide not only link design assistance to an engineer but to provide a complete documentation package for the design, including extensive hard copy curves, graphics, and tables. In contrast, DLOS provides graphic output of the path profile, text output for the profile data points and, for other modules, text output is available through the print-screen function. DLOS is intended simply as a design tool that will provide a series of link design modules for running in sequence to provide a complete link prediction or running singly to investigate some aspects of expected link performance.

2.1 Input/Edit Operation

Since one of the motivations for developing DLOS was to provide a friendly user interface, free use was made of as much screen control as was available.

Color, inverse video, highlighting, and error messages and advisories are all used to separate various fields on the displays and to help the operator make the necessary entries. For instance, certain inputs must be available to the algorithm before calculations can be performed. For modules A, E, F, G, H, and T, these values are highlighted. If a user tries to perform the calculations with some of these inputs missing, the input/edit menu will be returned to the screen. If the operator types a "?" in the first place of the entry field for a parameter, the permissible limits of the parameter will be called up to a display at the bottom of the screen. If a user enters a value outside of these limits or an illegal character, an error message will be displayed at the bottom of the screen. Any module may be exited by typing an upper or lower case "x".

2.2 Description

Determining the expected performance of a microwave communication link requires knowledge of such things as the geographic location of the path, the physical configuration of the future sites, the general area in which the path is located, and an indication of the climate and terrain of the area. The structure of the programs assumes that this information is available to the operator but the individual modules can be run separately so that hypothetical situations can be conveniently investigated. The menus provided for data entry include suggested choices by names of areas in which paths are located. For example, "Pacific" includes Japan, Korea, and the Philippines; "Continental US" includes only the contiguous United States. Each of the modules has a single function or related set of functions as set forth below.

- "A" uses the coordinates of the antennas to calculate the path distance and beam azimuths at each end of a transmission path. A map-crossing algorithm helps in the preparation of terrain profiles.
- "B" provides a convenient means of entering, editing, and manipulating path profile data. It is also used to calculate the effective-Earth-radius factor corresponding to atmospheric conditions.
- "C" is used to calculate recommended minimum antenna height values.
- "D" examines ray-path clearance and calculates fundamental atmospheric and geometric statistics about the propagation path. This module allows the operator to request a plot of the path profile on the terminal or on a plotter, including the location of the ray paths.
- "E" calculates the component of path loss due to atmospheric absorption.
- "F" calculates the multipath occurrence factor based on geographic area and terrain and climatic parameters.

- "G" calculates the performance threshold level of a selected digital modulation scheme in terms of the received signal level.
- "H" allows the input of equipment parameters such as antenna size and transmitter power and calculates the path performance in terms of the fraction of the worst month that the signal remains above the defined minimum acceptable quality.

As stated, any of these modules can be run independently and in any order. This means that an operator can get a quick answer to a question about the suitability of a link for digital operation if, for instance, the path distance were known approximately. This convenience does allow incorrect data to exist in the link file. This would happen if, for example, a set of coordinates were entered in module A and a path distance calculated. If the operator then went to module H and entered a different link distance, this incorrect new distance would be retained in the link file until module A was run again and the distance recalculated. This is true of most other values that are calculated and passed from one module to another. A convenient way to ensure that a file has only the information appropriate for a certain link is to run through the modules from A to H in sequence without altering any of the variables that are passed from one module to another. Each calculated value would then be consistent with the input data. These calculated values are listed for each module in the section covering that module.

2.3 Hardware Required to Operate DLOS

These programs are written to operate on a PC-AT or clone with a hard disk drive and one floppy drive. The operating system must be DOS 2.0 or later. Text output is available through the PRINT SCREEN command, so a printer may be attached to COM1. The program allows the operator to plot a hard copy of the path profile. This output is also on COM1, so some sort of a switch is needed to change the output device from printer to plotter. The program runs with either a monochrome or color monitor and with an EGA or a VGA monitor board; however, a color monitor is advised since color is used to assist and guide operator input. If a monochrome monitor is used, messages to the operator will be displayed using either intense or highlighted text.

3. ORGANIZATION OF THE MODULES

One of the most important features of the DLOS programs is the highly interactive format that allows a user quickly to try a number of different

combinations of parameters to select those that would meet the communication quality performance requirements of the link at the least cost. Since the user need not wait for hard-copy output to see the result of a change in a parameter and since the calculation time for these modules is so short, it is possible to change parameters repeatedly and see the effect of these changes immediately. This feature should make the DLOS a welcome addition to the communication engineer's automated design tool kit.

The DLOS program set operates as a set of relatively independent modules all of which intercommunicate through a common data file. As each module is activated, it reads information from this common file, requests additional information from the operator as needed, and calculates its parameters. When the operator leaves the module, it writes all of the data it drew from the common file and all of the parameters it calculated back to the common file. As the operator goes through the set of modules, more and more of the common file is filled out until the last module completes the link design. At any point, the currently operating module can be left and another module started to change or add to any of the previously entered values. For instance, only a few path profile points may be entered to start with, but at any time, more points can be entered or previously entered values can be edited or deleted. As this is done, the common file is updated each time the operator exits one of the modules.

Since there is only one common file, as more links are entered into the data base, a set of link files is developed. The basic link file set consists of 26 files, each containing the same data as the common file in a similar layout. As the DLOS program set is exited by the operator in normal operation, the common file is written out to one of the 26 link files. These link files are stored either with the DLOS programs or on an archive disk. That is why the operator must indicate how he wishes his filing system set up when DLOS is started.

Each set of 26 link files includes files named XXXXXA, XXXXXB, and so on through XXXXXZ. This can be seen if the DOS command DIR is entered from the DLOS directory. In addition to the executable code files and various system files, there is a COMMON.FIL, a LINKNAME file, and the XXXXX_ files. For reasons involving the operation of the computer, the XXXXX_ files do not get a new name when they contain link information. Instead the LINKNAME file

associates each link identifier with a particular XXXXX_ file. This link name file is read to let the operator know which link files are available in a particular directory.

The common file and the link data files have similar structures and contain the same information. The link data file does not contain the four character strings at the beginning of the COMMON.FIL file, but contains information that follows. Each file is a fixed size laid out as described in Table 1 below.

Table 1. Common File Layout

<u>Type of Data Storage</u>	<u>Information Stored</u>
6-character string	file name
18-character string	date
9-character string	project number
3-character string	user's initials
400 4-byte single-precision numbers	link profile distances (km)
400 4-byte single-precision numbers	link profile elevations (m)
400 4-byte single-precision numbers	link profile obstacle types and heights (m) (B=building, T=tree, O=generic obstacle, S=water starts, E=water end)
20 50-character strings	calculation program strings such as link name, site designator, site names, transmission line types, and modulation type
500 8-byte double-precision numbers	numeric variables for programs A through H

Note that the storage allotment is the same for all links and allows for a maximum number of data points. For instance, only 400 profile points (each of which includes distance, elevation, obstacle type and height, and water crossings if applicable) can be stored, but that memory space is always allocated for this many regardless of the actual number of profile points (if any) entered in the link data file. These files are stored in binary format so

the only way to tell what is in them is to run DLOS, call up a file, and view the contents.

The SAVEFILE program writes the information from the common file to a link file when the DLOS program is exited. It is guided to the correct link file by reading the link name which is stored as the first element in the common file. As new links are entered, the LINKNAME file, which keeps track of which link is contained in each XXXXX_ file, saves the filename of the new XXXXX_ file.

4. INDIVIDUAL MODULE DESCRIPTIONS

Each of these modules allows some part of the total data entry and performs part of the calculations necessary to complete the link design. Although the division of the tasks among the modules is somewhat arbitrary, the need to keep the size of the modules reasonably small militated against having only a single program. The use of menus allows the operator to change quickly and easily from one function to another without requiring performance of laborious file-handling functions. The structure of the DLOS software set is based on a batch file from which all of the other modules are called and to which program control returns when each module is exited normally.

The process is started when the command "DLOS" is entered from DOS in the appropriate directory. This will bring the main menu shown in Figure 1 to the screen. The program will run from the default directory (that is, the directory from which DLOS was called) and it will store the link files in that directory. If you invoke DLOS from a directory that has not previously been used, it will automatically create the files necessary to run DLOS. However, only 26 link files are available, so when these are full, they must be stored in another directory or, alternately, on a floppy disk. It is convenient to operate on a link file from a hard disk, but it may be better to store these link files on floppies if others use the computer also. For this reason, the operator is allowed to set up files before starting the program. When storing files, remember that all 26 must be stored at the same time and that the LINKNAME file and the COMMON.FIL file must accompany the link data files. The LINKNAME file is the directory for the link XXXXX-files and if it is not kept with the link files, the data on the link files will not be available to the operator until a new LINKNAME file is made.

WELCOME TO DLOS

LOS Link Design Menu

```
Select a link.....s
Earth geometry.....a
Path profile data and effective earth radius.....b
Primary antenna height recommendations.....c
Path profile and ray traces.....d
Atmospheric absorption.....e
Multipath fading.....f
Minimum received signal level (ber threshold)....g
Digital link design summary.....h
Transfer files between hard & floppy disk.....t
eXit.....x
```

Figure 1. The DLOS main menu.

Creating a new LINKNAME file by hand is a very laborious process, but could be done using a line editor such as DOS' EDLIN to rebuild the file. The user would have to determine which filename was associated with each XXXXX_ file and put the filenames into the LINKNAME file in the correct order. It is not recommended that the user attempt to recreate a LINKNAME file. The transfer files or "T" program was prepared to copy a set of link files with its associated LINKNAME and COMMON.FIL files to and from a floppy or another directory using the menus provided to assist the operator in the task. Alternately, the operator can use the DOS commands to do the file transfers, but the precaution of writing the file to the destination disk or directory before deleting the files in the source directory must be observed.

As soon as the letter corresponding to the selected module is entered, that module is started and its own menu appears. No ENTER key press is needed. As soon as the menu for each separate module is presented, the choice may be made but must be followed by an ENTER key press.

4.1 The "SELECT A LINK" Module

The programs may be run in any order but to start the process, some link information must be available to the program or must be entered to start with. The program called "Select a Link" makes this possible by allowing the operator

to either choose from among the existing links or to establish a new one. The initial menu for this module is shown in Figure 2 for the condition that one or more link files are present in the current directory. If no links are in the current directory, the link files are all blank; there is no link to select. In this case, the only choices presented are "Create a Link" or "Exit". If the Create option is selected, the display shown as Figure 3 (section 4.1.1) will appear.

```
Current links are:

FELASBNA DONBHDGA BLNATPFA

Select one of these options:

Create a link.....1
Select an existing link.....2
Reverse a link.....3
Change a linkname.....4
Delete a link.....5
Update user initials and project number..6
Duplicate linkfile.....7
    Note: This is automatic when
           creating a link
Return to main menu.....x
Enter option:__
```

Figure 2. The "Select a link" main menu.

The program will assist the operator through the execution of any function selected.

4.1.1 Create a Link

If number 1 is selected, the display shown in Figure 3 will appear one line at a time. At the option of the operator, a return will be accepted for the first four of these fields leaving the entry blank in the link file, but the transmitter and receiver site designators must be entered. The operator can abort the process of link creation at any time by typing "exit". If you enter a link identification that you find is in error, finish up and delete the link or change the link name as described below. When a link is created, the time and date are placed in the file along with the operator's initials, project

Enter initials (up to 3 characters)
Enter project number (up to 9 characters)
Enter transmitter site name:
Enter receiver site name:
Enter transmitter site 4 letter site designator:
Enter receiver site 4 letter designator:

Figure 3. The "Create a link" menu.

number, and transmitter and receiver site names if these latter are entered. If you have a file to which you would like to add a set of operator initials and site names, use the "Change a link name" command discussed in section 4.1.4 below.

A word about the site designator is in order. The DCA has selected a unique three-letter site code for each site in the Defense Communication System and these codes are the ones to use for the first three characters in the designator. The fourth character location was added so that more than one design for a link could be retained. This fourth character, which may be an underline or a number from 0 to 9, will allow the operator to differentiate between various design options that have been investigated. If a fourth character is not wanted or needed, enter only three characters and press ENTER. An underline character will be inserted automatically.

When the receiver site designator is entered, the select menu returns to the screen. To proceed with the link design, type "x" to return to the main menu and then enter the letter of the module you wish to run.

4.1.2 Select an Existing Link

If option 2 is selected and the ENTER key pressed, the display shown in Figure 4 will appear. The display will list as many links as are available in the currently selected directory up to a maximum of 26. If the link you are looking for is not listed, you may exit from this function by typing "exit", exit from the Select menu by entering "x", and exit from the DLOS program by again


```
TO RETURN TO MENU TYPE "EXIT"

SELECT A LINK BY TYPING THE 8-LETTER LINK NAME:

Current links are:

FEL1SBN2      ABC4DEF6      DON1HDG_      BLNOBBG3

Enter the link name:
```

Figure 4. The "Select an existing link" screen.

entering "x". At this point, you must review your LINKNAME files in all of your different DLOS directories to determine to which set of links the one you are searching for belongs. This can be done by using an editor on the LINKNAME files or by running program S from each different directory to get a list of the links in each directory.

When the link name (all eight characters) is typed and the ENTER key is pressed, the select menu appears although no confirmation is given that the link was selected. To check that the correct link was picked up, exit from the select menu by typing "x", upper- or lowercase, and enter "a". The data and site names for the link selected will appear in the prediction programs.

4.1.3 Reverse a Link

This option will allow you to interchange the transmitter (left hand) and receiver (right hand) sites of a link. You may wish to do this to see that the diversity antennas have sufficient clearance in both path directions since DLOS always assigns the left-hand site as the transmitter. The display shown in Figure 4 is presented and the operator selects the link to be reversed. When the eight-character link identifier is entered and ENTER pressed, the reversing is accomplished. The main menu is again presented. If you wish to assure yourself that the link reversal was done, press the "s" key for select and note that the link identifier has the site codes interchanged.

4.1.4 Change a Link Name

This option will allow a link name to be corrected by changing any part of the site names or link identifier characters. The first screen shown is the one in Figure 4. After you select a link by link identifier, the sequence indicated in Figure 3 is shown one line at a time. Again, the first four fields can be left blank by pressing the ENTER key when the line appears (although leaving these fields blank will eliminate this information from the existing link file) but the full four-character site identifiers must be entered for both the transmitter and the receiver.

4.1.5 Delete a Link

This option allows the operator to remove all link information from a link file, leaving it ready for use for another link. This would make room on a full hard disk file for another link if old or unneeded information exists in a file. The first screen appears as shown in Figure 4. When the eight-character link identifier is entered, the file is totally cleared of entered data and calculated values. There is no way to "undelete" a link, and no request for confirmation of your desire to delete the link, so care should be exercised in the use of this command. After the deletion is finished, the main menu is again presented.

4.1.6 Duplicate Link File

This option allows an operator to make a copy of the current link file. This would be used if the operator wants to keep a set of link parameters and calculated values and then make another set of input parameter choices on the same path. This might occur when the operator wished to see the difference between the choice of frequency diversity versus space diversity on the performance of a microwave link. The initial screen presented is shown in Figure 4.

When the identifier of the link you wish to be copied is entered, the sequence shown in Figure 3 appears one line at a time. As with creating a link, the first four fields may be left blank by pressing ENTER when the line appears but the full link identifier is required. Note that the new identifier must differ in at least one character from the name of any other file in the current set of 26 link files. This is the only restriction.

4.2 The "TRANSFER FILES" Module

This module permits an operator to move a set of 26 link files, the common file, and the link name file from the current operating directory to another directory either on the hard disk or on an archive floppy disk. The display to do this is shown in Figure 5.

```
FILE TRANSFER

Transfer files
Save files to a floppy disk.....S
Retrieve files from a floppy disk.....R
```

Figure 5. Transferring files to and from the hard disk.

The cursor stops at the point above and to the right of the "S" and if "S", either upper- or lowercase, is entered, the display changes to that shown in Figure 6.

```
FILE TRANSFER

Transfer files                               S
Save files to a floppy disk.....S
Retrieve files from a floppy disk.....R

Transfer files to drive                      _
Transfer files to directory                  _
```

Figure 6. Transferring files to a floppy disk.

The operator must enter the drive letter as shown in Figure 7 and then press ENTER. If the files are to be stored in a particular directory, that directory must exist. The directory is optional, and if nothing is entered, the files will be written to the current directory. To specify the directory, the standard DOS format is used; that is, the HOLLAND directory would be specified as HOLLAND. Similarly, if the files are to be stored in the LINKS directory, the COLORADO subdirectory, this would be entered as LINKS\COLORADO on the directory line.

```

FILE TRANSFER

Transfer files                               S
Save files to a floppy disk.....S
Retrieve files from a floppy disk.....R

Transfer files to drive                       A
Transfer files to directory                   _____

Type X to continue

```

Figure 7. Transferring files to a floppy disk after S has been chosen.

If you have made an entry in the "Transfer files to directory..." blank and wish to eliminate it, just type a back slash, "\", at the start of the wrong entry. The program will transfer the files and list them on the screen in the DOS format when the ENTER key is pressed. If for some reason the transfer was not successful, the screen will carry an announcement to that effect from the DOS system. Such errors as no disk in the target drive, no directory or subdirectory on the target drive will cause transfer failure. If this should happen,

DO NOT ANSWER "YES" WHEN YOU ARE ASKED IF THE HARD DISK FILES SHOULD BE PURGED. IF YOU PURGE THESE FILES BEFORE A SUCCESSFUL TRANSFER HAS BEEN COMPLETED, YOUR LINK FILES WILL BE IRRETRIEVABLY LOST!!!

Correct the problem and try again.

CAUTION!!!!!!!!!!!! IMPROPER USE OF THIS MODULE CAN CAUSE THE LOSS OF YOUR LINK DATA FILES. THERE IS NO POSSIBLE RECOVERY OF A LINK FILE THAT HAS BEEN OVERWRITTEN SINCE ALL ENTRIES IN THE FILE ARE SET TO -9999.

The procedure for retrieving a set of link files from a floppy disk is very similar. The screen shown as Figure 8 will appear if the entry "R" is made from the screen shown in Figure 5.

MAKE SURE BEFORE YOU RETRIEVE A NEW SET OF FILES THAT THE FILES IN THE DLOS DIRECTORY HAVE BEEN SAVED TO A FLOPPY OR ANOTHER DIRECTORY. IF YOU OVERWRITE THESE FILES BEFORE A SUCCESSFUL TRANSFER HAS BEEN COMPLETED, YOUR LINK FILES WILL BE IRRETRIEVABLY LOST!!!

```
FILE TRANSFER

Transfer files                                R
Save files to a floppy disk.....S
Retrieve files from a floppy disk.....R

Retrieve files from drive                    D
Retrieve files from directory                DLOS

Type X to continue
```

Figure 8. Transferring files to the hard disk.

When the transfer has been completed, the main menu will return to the screen.

The procedure described above should be followed in detail to minimize the chance that a set of link files will be lost. As was said in the File Description section, the link files are part of a closed set and must be handled and moved from disk to disk and directory to directory as a unit. The link files must always be accompanied by the appropriate link name file so that they can be found by the DLOS software.

4.3 The "EARTH GEOMETRY" Module

This module allows the entry of geometric coordinates for the sites, the antenna tower heights, and the identification of the applicable spheroid. From the coordinate information and the internally stored constants of the spheroid selected, the module calculates the length of the path, the azimuth from the transmitter to the receiver, and the azimuth from the receiver to the transmitter. The algorithms are based on standard spherical trigonometric formulae and use an inverse path calculation developed for the U. S. Navy Oceanographic Office described in a report by Thomas (1970). The technique for determining map edge crossings used here is based on a routine described by Hause (1986). This routine accepts a latitude or a longitude on the path and calculates the complementary coordinate and the distance from the transmitter site to the crossing point by a successive-approximation method. For convenience in referring to the sites, the left-hand site is called the transmitter site and

the right-hand site is called the receiver site, in spite of the fact that transmission occurs in both directions. This convention is significant when the antenna diversity spacing is considered since only at the receiver site can a second antenna height be entered. If the operator wishes to check the link for diversity ray path clearance in the opposite direction, the path must be reversed, as described in section 4.1.4.

The initial menu for this module is shown in Figure 9.

```

EARTH GEOMETRY

Options
  I = Input/Edit
  C = Calculate
  M = Map crossings
  X = eXit
Option ? __

```

Figure 9. The Earth geometry initial menu.

The operator types the letter corresponding to the desired function. When work is started on a link, the first one to select would be "I", for input and editing the input values. The display shown in Figure 10 is presented.

INPUT / EDIT	TRANSMITTER	RECEIVER
Antenna latitude	° ' " -	° ' " -
Antenna longitude	° ' " -	° ' " -
Magnetic declination from true N	° ' " -	° ' " -
Tower base elevation above msl	m	m
Earth spheroid options		
International.....1		
Clark 1866.....2		
Clark 1880.....3		
Everest.....4		
Bessel.....5		
Australian National.....6		
Airy.....7		
Fisher.....8		
Malayan.....9		

Figure 10. The Earth geometry input-edit display.

This screen allows the entry of latitudes of 0° to 90° north or south and longitudes of 0° to 180° east or west. The minutes are whole numbers from 1 to 59 and the seconds can be numbers from 0.01 to 59.99. The default latitudes are north and east. To change the display to give south latitude or west longitude, simply move the cursor to the N or E and type in S or W. The entry of the magnetic declination is optional and if no entry is made, the magnetic azimuths will be equal to the true azimuths. The tower base elevations are requested here although they will not be used in calculations in this module. 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. To exit the display, type "x", upper- or lowercase. If the coordinate locations entered result in a path length greater than 399 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 operator exits without bringing the coordinates closer together.

4.3.1 Map Crossings

The map crossings option allows the operator to determine the point at which the path crosses a given latitude or longitude within the length of the path. The operator must have entered the site geographic coordinates before this program will execute. 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. The module takes either the latitude or the longitude at the edge of a map and calculates the complementary coordinate for the map edge as well as the distance along the path to the point in question. The results from the map crossing screen are displayed on the input screen as the calculations are made and must be printed before that screen is exited in order to save a copy of the output data. The screen display is shown in Figure 11.

The program calculates the limits on the latitude and longitude entries for which calculations will be made. The operator can enter either latitude or longitude using the arrow keys to get to the starting point of the entry field

FELSN Map Crossings

Limits 50°14'34.50"N - 50°55' 1.50"N8°29'49.50"E - 9°25'23.50"E

Latitude	Longitude	Distance from Transmitter (km)
50° 30' 0.00" N	8° 50' 45.38" E	61.789
50° 36' 44.40" N	9° 00' 0.00" E	54.195
° ' " -	° ' " -	
° ' " -	° ' " -	
° ' " -	° ' " -	
° ' " -	° ' " -	
° ' " -	° ' " -	
° ' " -	° ' " -	
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° ' " -	° ' " -	
° ' " -	° ' " -	
° ' " -	° ' " -	

Figure 11. The map crossing display with sample data.

and the arrow keys or the ENTER key to move to the next field. If an out-of-range entry is made, a cautionary note will appear at the bottom of the screen informing the operator that the value entered will not allow a calculation to be performed. When the cursor is moved 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, the calculations are automatically completed and the display appears as shown in Figure 11. Eighteen entry and output sets are available which should suffice for even a long path. When the operator exits from the map crossing module, the values entered and the calculated results are lost. If a permanent copy is needed, use the PRINT SCREEN function on the computer. If more than the 18 points are needed, the first 18 can be calculated and printed out using PRINT SCREEN and "X" typed to exit the module. Typing "M" again will display the map crossing screen with all operator entry fields blank and another 18 entries can be made. Using this technique, as many crossings as desired can be calculated. Note that the distance cannot be entered to calculate a set of

coordinates. The entry "X", upper- or lowercase, returns the Earth geometry display to the screen.

4.3.2 The Output Display

The output display shows what the operator entered on the input screen and shows the results of the calculations. The output screen for the link distance, forward azimuth, and forward magnetic azimuth calculations is shown in Figure 12.

The output summary shows the constants associated with the selected Earth spheroid, the path length, and the forward true and magnetic azimuths for each site. If no magnetic declinations had been entered, the true and magnetic azimuths would be the same.

INPUT SUMMARY	FELDBERG	to SCHWARZENBORN
Antenna latitude	50° 55' 2.00" N	50° 14' 34.00" N
Antenna longitude	9° 25' 24.00" E	8° 29' 49.00" E
Magnetic declination from true N	2° 26' 0.00" W	2° 44' 0.00" W
Tower base elevation above msl	634.00 m	684.00 m
Earth spheroid option	International	
OUTPUT SUMMARY		
Equatorial radius	6378.3880 km	
Polar radius	6356.9120 km	
Link distance	99.6730 km	
Forward azimuth	221° 31' 52.45"	40° 48' 56.06"
Forward magnetic azimuth	223° 57' 52.45"	43° 32' 56.06"

Figure 12. The Earth geometry output display.

4.4 The "PATH PROFILE DATA AND EFFECTIVE EARTH RADIUS" Module

This module accepts information on the local value of the refractivity gradient to calculate the effective Earth's radius or "k" value. It also allows the entry of path ground elevations and tree or building heights to develop a terrain profile for the path. This profile information will be read from topographic maps based on the locations of the radio sites. The map locations where the path crosses map edges were calculated in the Earth geometry module. This program is started by entering "B" in the main menu.

The concept of effective Earth's radius is an approximation commonly used to account for the effects on the radio rays due to the variation with height of the refractive index of the atmosphere. The prediction algorithm used here is based on conversion of a normalized surface refractivity, N_0 , read from a large-scale map, to a value of surface refractivity, N_s , determined by the site elevations, and thence to a value of k , the effective Earth's radius factor (Department of Defense, 1984).

This allows determination of a value of effective Earth's radius used in plotting the ray paths.

A standard map of normalized surface refractivity for determining N_0 in "N-units" is shown in Figure 13. The surface refractivity, N_s , is calculated from the altitude of the sites, h_t and h_r , and the normalized refractivity by

$$N_s = N_0 [e^{(-0.1057 h_t)} + e^{(-0.1057 h_r)}] \quad . \quad (1)$$

A value of k corresponding to the N_s is calculated by

$$k = [1 - 0.04665 e^{(0.00557N_s)}]^{-1} \quad . \quad (2)$$

The terrain profile menu is shown in Figure 14.

The selection of option 3 will not have any effect until at least ten points are entered. If the operator selects option 1, the display shown in Figure 15 will appear.

The information required here is the surface refractivity at the transmitter referenced to mean sea level. The operator should simply find the location of the path on the map, Figure 13, and read an interpolated value for this constant. Failing this, an average value of 315 could be used with little loss in accuracy

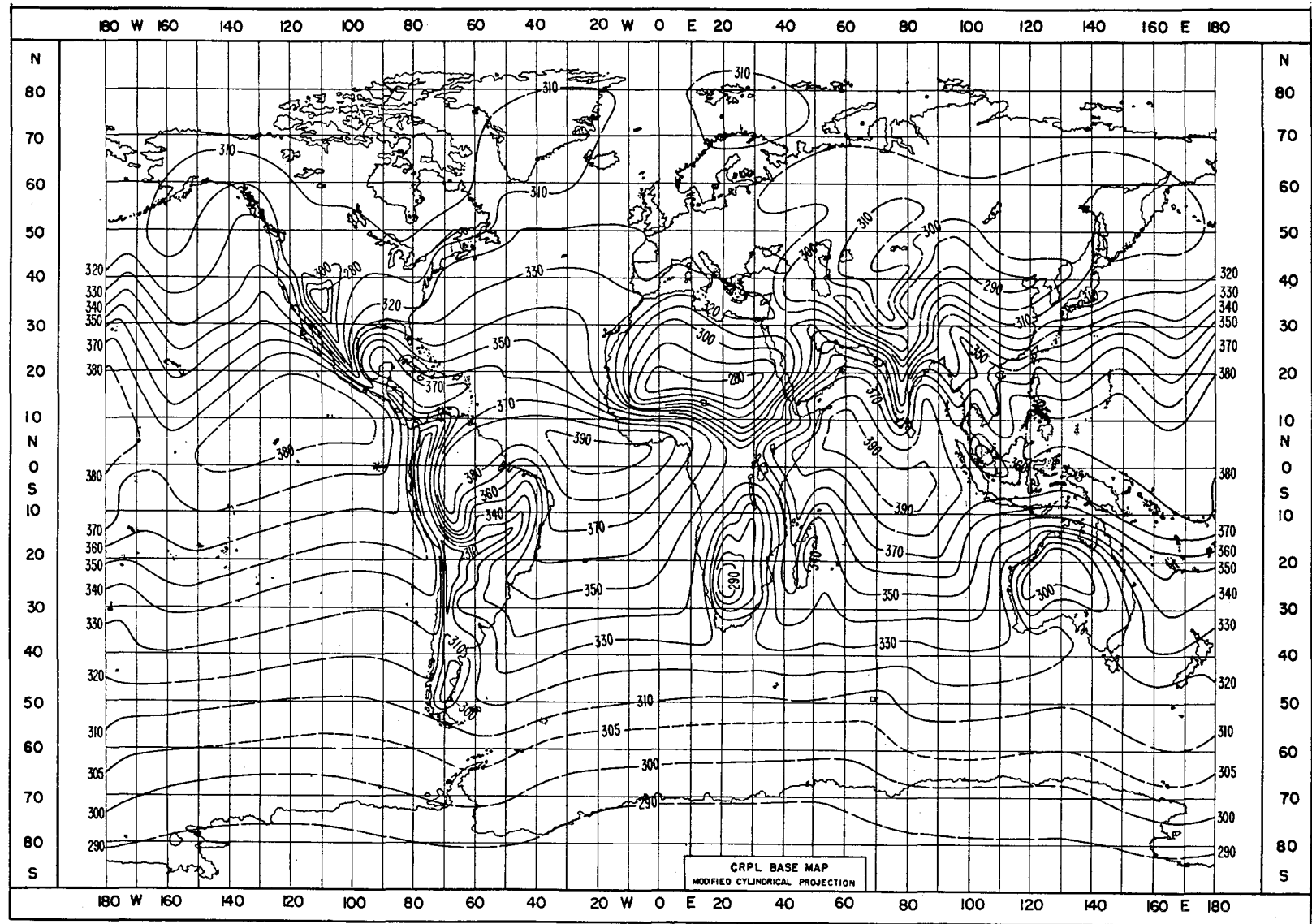


Figure 13. Minimum monthly mean values of surface refractivity referred to mean sea level (from Bean et al. 1960)

```

                                FELSBN TERRAIN PROFILE

Select an option:
  Edit input data.....1
  Output table (screen).....2
  Output table (printer).....3
  Edit terrain points.....4
  Exit to main menu.....X

Enter option:

```

Figure 14. Path profile data main menu.

```

                                FELSBN TERRAIN PROFILE ENTRY AND EDITING

LINK DISTANCE                               (km)           99.67
TRANSMITTER TOWER BASE ELEVATION ABOVE MSL (m)           634.
RECEIVER TOWER BASE ELEVATION ABOVE MSL (m)           684.
REFRACTIVITY (msl), N0                          (N-units)
TO EXIT TYPE "X"

```

Figure 15. Refractivity entry screen.

of the prediction. Typing "X" will display Figure 16 if no profile points have been entered or return to the terrain profile main menu if points have been entered.

If the operator selects option 4, the display shown in Figure 16 will appear and the selection of whether the data are to be entered in English or metric units is made.

As soon as the choice of "1" or "2" is made and ENTER is pressed, the screen shown in Figure 17 is displayed.

When this screen is initially displayed, the cursor will be in position for the first Distance entry. When this entry is made in the units chosen, and the ENTER key is pressed, the cursor is advanced to the Elevation position. This entry is made, the ENTER key is pressed, and the cursor advances to the Obstacle

```

PATH PROFILE UNITS OPTION
  ELEV. ABOVE MSL IN METERS AND DISTANCE IN KILOMETERS....1
  ELEV. ABOVE MSL IN FEET AND DISTANCE IN MILES.....2

UNITS BEING ENTERED AS:

```

Figure 16. Choice of units for path profile.

```

FELSNB TERRAIN PROFILE ENTRY AND EDITING

DISTANCE FROM ELEVATION          OBSTACLE          OBSTACLE HEIGHT
TRANSMITTER                     TREE=T, BLDG=B, OTHER=O
                                WATER STARTS=S, WATER ENDS=E

TO EXIT TYPE "X"

```

Figure 17. Entering and editing terrain profile points.

column. If the profile data indicate that no obstacle is present, press the ENTER key and the cursor will be positioned for the second entry in the Distance column. This technique is continued, and if an obstacle is to be entered, the appropriate letter key is pressed. Do not press the ENTER key, as the cursor positions automatically to the Obstacle Height column. If you inadvertently press ENTER, use the up-arrow key to move to the previous line and press ENTER twice to bring the cursor to the Obstacle column. Reenter the obstacle type letter and then the obstacle height in appropriate units. Figure 18 is an example of the first page of a typical profile.

The profile points can be scrolled up and down the screen with the arrow keys. When all data have been entered to the satisfaction of the operator, the "X" key may be pressed to return to the Profile Entry main menu. When "X" is entered from the Profile Entry main menu, the data that were entered are written to the COMMON.FIL file for use by other DLOS programs.

FELSNB TERRAIN PROFILE ENTRY AND EDITING

DISTANCE FROM TRANSMITTER	ELEVATION	OBSTACLE TREE=T, BLDG=B, OTHER=O WATER STARTS=S, WATER ENDS=E	OBSTACLE HEIGHT
.610	600.00		
1.200	560.00	T	30.00
1.450	578.00	T	30.00
2.300	515.00	T	30.00
2.810	510.00		
3.450	460.00		
5.080	370.00		
6.050	360.00		
8.060	250.00		
8.640	330.00		
8.720	310.00		
11.360	310.00		
11.590	370.00		
15.000	230.00		
16.630	280.00		

TO EXIT TYPE "X"

Figure 18. A typical terrain profile entry.

4.5 The "PRIMARY ANTENNA HEIGHT RECOMMENDATIONS" Module

The inputs that this module requires are an extreme Earth radius factor and a desired first Fresnel zone clearance fraction during extreme refractive conditions. The development of reliable extreme Earth's radius factor information requires extensive study of meteorological information, which is not always possible. If good information on k_e is available, it should be used. If, as in most cases, it is not, a value of 0.667 is reasonable. The Fresnel zone clearance fraction will usually be specified by the engineering agency responsible for the system design. The DCA, for example, uses the value 0.6.

This module calculates an antenna height for one or both ends of the path that provide adequate clearance for terrain within 1 km of each end of the path and for the selected Fresnel zone clearance for the center portion of the path.

The clearance required within 1 km of each antenna is 3 m plus one-half of the local antenna's vertical dimension plus the Fresnel zone clearance. The clearance required over the rest of the path is the operator-entered fraction

of the first Fresnel zone plus the ray path clearance for the extreme sub-refractive Earth's radius factor, k_e .

The ray path elevation, h_r , in meters above mean sea level (msl) is calculated from

$$h_r = \frac{d^2}{(12.75 k)} + \frac{d(h_{rx} - h_{tx})}{D} - \frac{D}{(12.75 k)} + h_{tx} \quad (3)$$

where

- h_{tx} = transmitter height above msl, meters,
- h_{rx} = receiver height above msl, meters,
- d = distance along the path in kilometers,
- D = total path distance in kilometers, and
- k = the Earth's radius factor (k_e in this case).

The Fresnel zone radius, r_F , in meters in a plane perpendicular to the path center line is

$$r_F = 17.3 \sqrt{\frac{(dD - d^2)}{fD}}, \quad (4)$$

where f is the carrier frequency in GHz.

The algorithm first considers the clearance within 1 km of the antennas. If adequate clearance is unavailable at one end, the local antenna height is increased by the amount of the local negative clearance, B_t , below that required above. Once the proximal clearance requirements are met, the following equations indicate the increased antenna height required to provide full path clearance where I_{at} and I_{ar} are the required increases (or if negative, decreases) in tower heights in meters.

$$I_{at} = B_t \left(\frac{2d_B}{D} + 1 \right) \left(1 - \frac{d_B}{D} \right), \quad \text{and} \quad (5)$$

$$I_{ar} = B_t \left(\frac{d_B}{D} \right) \left(3 - \frac{2d_B}{D} \right), \quad (6)$$

where B_t = the negative of the minimum Fresnel zone clearance in meters,
 d_B = the distance from the transmitter to the point of minimum clearance in kilometers, and
 D = the path length in kilometers.

If the appropriate information is available in the COMMON.FIL file, the screen shown in Figure 19 will appear when "C" is entered from the DLOS main menu.

ANTENNA HEIGHT RECOMMENDATIONS VARIABLE ENTRY AND EDITING	
DISTANCE AND HEIGHT UNITS (1 = km and m, 2 = mi and ft).....	1
IS ONE ANTENNA HEIGHT KNOWN (1 = yes, 2 = no).....	2
WHICH HEIGHT IS KNOWN? (1 = Xmit, 2 = Recv).....	N/A
LINK DISTANCE.....	99.673 km
FREQUENCY.....	8.37 GHz
TRANSMIT TOWER BASE ELEVATION ABOVE MSL.....	634 m
RECEIVE TOWER BASE ELEVATION ABOVE MSL.....	684 m
EXTREME EARTH-RADIUS FACTOR, k_e667
1ST FRESNEL ZONE CLEARANCE FRACTION.....	.6
TRANSMIT RECOMMENDED ANTENNA HEIGHT.....	m
RECEIVE RECOMMENDED ANTENNA HEIGHT.....	m
TO MOVE DOWN, PRESS ENTER KEY	
TO MOVE UP, PRESS BACKSPACE	
TO EXIT, TYPE X	

Figure 19. Antenna height calculation entry screen.

If the Earth geometry and profile entry modules have been run prior to this one, the link distance and the tower base elevations will be in the data file. The inputs required are the units in which the distance and height are expressed; whether or not one antenna height is known, and if one is, which one; the extreme Earth radius factor; and the Fresnel zone clearance fraction. The extreme Earth radius factor may be found from other sources and, lacking any other information,

a typical value of 0.667 can be used. The value of the Fresnel zone clearance is 0.6 according to current DCEC practice. When all entries have been made, typing "X" will perform the calculations and return a menu to the screen that allows the operator to return to the entry and edit screen, proceed to the output screen, or exit to the main DLOS menu. This select menu is shown in Figure 20.

```

Select an option:
  Enter and edit data.....1
  Recommended antenna heights.....2
  Exit to main menu.....X
  
```

Figure 20. Antenna heights select menu.

The recommended antenna heights are given on the display shown in Figure 21. The input parameters are repeated followed by the recommendations. These recommended heights are not automatically used in the path profile drawing program. These values can be entered in that module but other considerations may require that other heights be used.

```

FELDBERG TO SCHWARZENBORN ANTENNA HEIGHT RECOMMENDATIONS

WAS ONE ANTENNA HEIGHT KNOWN? .....NO
IF YES, WHICH ANTENNA HEIGHT WAS KNOWN? .....N/A
LINK DISTANCE.....99.673km
FREQUENCY..... 8.37 GHz
TRANSMIT TOWER BASE ELEVATION ABOVE MSL.....634 m
RECEIVE TOWER BASE ELEVATION ABOVE MSL.....684 m
EXTREME EARTH-RADIUS FACTOR, ke..... .667
1ST FRESNEL ZONE CLEARANCE FRACTION..... .6
TRANSMIT RECOMMENDED ANTENNA HEIGHT.....1.02 m
RECEIVE RECOMMENDED ANTENNA HEIGHT.....7.853 m
  
```

Figure 21. Antenna height recommended values.

Typing "X" will return the menu shown in Figure 20 to the screen, and typing "X" again will return the main menu to the screen.

4.6 The "PATH PROFILE AND RAY TRACES" Module

This module presents a great deal of information about the physical layout of the link. One of its features is a display of the path profile on screen including the ray paths for normal and sub-refractive conditions. The presentation of the profile shows the Earth's surface as a plane (a straight line in the elevation view used) and shows the ray paths as curved lines. Other presentations show an effective Earth curvature for the terrain profile, and for a single value of k , the ray paths are then straight lines. The difficulty with the latter presentation is that for different k values, multiple profiles on the same plot or a number of separate plots are necessary if the normal and extreme conditions are to be studied. The "flat Earth" presentation allows the showing of multiple rays with different curvatures to illustrate the effects of different meteorological conditions using different line types to clarify the presentation.

Calculations are performed in this module for the mean atmospheric pressure along the ray path, mean path height above ground, mean terrain elevation, standard deviation of terrain elevation, and the root-mean-square (rms) value of terrain slopes. These values are used in subsequent modules to calculate atmospheric absorption and multipath fading occurrence. The equation for atmospheric pressure as a function of altitude is from List (1951),

$$P_a = 101.3 (1 - 2.26 h_r \times 10^{-5})^{5.2553} , \quad (7)$$

where P_a = the atmospheric pressure in kiloPascals (kPa) and
 h_r = the height of the ray above msl in meters for $-10^2 < h_r < 10^5$.

The path mean atmospheric pressure, P_{am} , is the mean of 10 values of P_a at approximately equidistant points along the path calculated using the average Earth's radius factor, k . The terrain points used in (8), (9), and (10) exclude the site elevations, and the terrain points used in (11) exclude the terrain points within 1 km of either site. The mean ray path height above ground, h_{rg} , in meters is calculated from

$$h_{rg} = \frac{\sum_{n=1}^p \frac{(h_r - h_e)(d_{n+1} - d_{n-1})}{2}}{D} , \quad (8)$$

where h_r = the ray path height above msl for the n^{th} profile point in meters,
 h_e = the terrain height above msl plus the obstacle height for the n^{th} profile point in meters,
 D = the path length in kilometers,

d_n = the distance to the n^{th} profile point in kilometers,
 n = the profile point ordinal, and
 p = the number of profile points for the path excluding the end points.

The mean terrain elevation above msl, h_{me} , in meters, is a function of the weighted average of the profile point elevations, h_n , and their distances, d_n .

$$h_{me} = \frac{\sum_{n=1}^p (d_{n+1} - d_n) \frac{(h_n + h_{n+1})}{2}}{\sum_{n=1}^p (d_{n+1} - d_n)} \quad (9)$$

The standard deviation of terrain elevations, s_1 , in meters, is

$$s_1 = \left\{ \frac{\sum_{n=1}^p (d_{n+1} - d_n) \left[h_{me} - \frac{h_{n+1} + h_n}{2} \right]^2}{\sum_{n=1}^p (d_{n+1} - d_n)} \right\}^{\frac{1}{2}} \quad (10)$$

The rms value of terrain slopes, s_2 , in milliradians is

$$s_2 = \left[\sum_{n=1}^p \frac{(d_{n+1} - d_n)}{D} \left(\frac{h_{n+1} - h_n}{d_{n+1} - d_n} \right)^2 \right]^{\frac{1}{2}} \quad (11)$$

This module requires that some terrain elevations as well as the site elevations be entered before calculations can be made. In general, before the calculations are started, be sure to enter 10 or more points using program "B" to ensure that all will run smoothly.

The first display shown when "D" is typed at the main menu display is given in Figure 22. Again, if all previous modules (in the alphabetic progression) have been run, much of the required information will be available. This display allows the operator to enter the diversity type, the antenna polarization, the average Earth radius factor, the transmit and receive primary and diversity antenna heights, and values for annual tree growth and snow depth. The current module does not use the antenna polarization, the snow depth, nor the tree growth but these values may be entered for record purposes or left blank as you wish.

```

                PATH PROFILE AND RAY TRACES VARIABLE ENTRY AND EDITING

DISTANCE AND HEIGHT UNITS (1 = km and m, 2 = mi and ft).....1
DIVERSITY TYPE.....(1 = none,2 = space, 3 = freq).....2
ANTENNA POLARIZATION.....(1 =horizontal, 2 = vertical).....N/A
LINK DISTANCE.....99.673 km
FREQUENCY.....8.37 GHz
RECOMMENDED AVERAGE EARTH-RADIUS FACTOR,k.....1.28515
AVERAGE EARTH-RADIUS FACTOR,k.....1.04893
EXTREME EARTH-RADIUS FACTOR,ke......667
1ST FRESNEL ZONE CLEARANCE FRACTION......6
TRANSMIT TOWER BASE ELEVATION ABOVE MSL.....634      m
RECEIVE TOWER BASE ELEVATION ABOVE MSL.....684      m
TRANSMIT ANTENNA HEIGHT.....30.6      m
RECEIVE ANTENNA HEIGHT (PRIMARY).....96.3      m
RECEIVE ANTENNA HEIGHT (DIVERSITY).....83.3      m
MAXIMUM ANNUAL SNOW DEPTH.....1      m
TREE GROWTH PER YEAR......75      m

TO MOVE DOWN, PRESS ENTER KEY
TO MOVE UP, PRESS BACKSPACE KEY
TO EXIT, TYPE X

```

Figure 22. Path profile and ray trace input screen.

As values are entered, pressing ENTER will fix the value. Typing "X" will perform calculations and bring the option menu shown in Figure 23 to the screen.

```

                Select an option:
                Enter and edit data.....1
                Path statistics.....2
                Antenna pointing data.....3
                Path profile (screen).....4
                Path profile (plotter).....5
                Exit to main menu.....X

```

Figure 23. The path profile and ray trace menu.

If "2" is typed, a list of the input values will be given, augmented by several values that are calculated in this module. This list is shown in Figure 24.

SBN TO FEL PATH PROFILE AND RAY TRACE DATA	
DIVERSITY TYPE.....	NONE
ANTENNA POLARIZATION.....	HORIZONTAL
LINK DISTANCE.....	99.673 km
FREQUENCY.....	8.37 GHz
AVERAGE EARTH-RADIUS FACTOR, k	1.04893
EXTREME EARTH-RADIUS FACTOR, k_e667
1ST FRESNEL ZONE CLEARANCE FRACTION.....	.6
TRANSMIT TOWER BASE ELEV. ABOVE MSL.....	634 m
RECEIVE TOWER BASE ELEV. ABOVE MSL.....	684 m
TRANSMIT ANTENNA HEIGHT.....	30.6 m
RECEIVE ANTENNA HEIGHT (PRIMARY).....	96.3 m
RECEIVE ANTENNA HEIGHT (DIVERSITY).....	83.3 m
MAXIMUM ANNUAL SNOW DEPTH.....	1 m
TREE GROWTH PER YEAR.....	.75 m
ANTENNA SPACING (VERTICAL).....	13 m
STD DEVIATION OF TERRAIN ELEV. (S1).....	95.377 m
R.M.S. VALUE OF TERRAIN SLOPES (S2).....	.043785
EFFECTIVE PATH LENGTH.....	99.673 km
MINIMUM TERRAIN CLEARANCE DISTANCE.....	37.88 km
MINIMUM 1ST FRESNEL ZONE CLEARANCE.....	2.8756 m
MEAN ATMOSPHERIC PRESSURE ON RAY PATH.....	94.234 kPa
MEAN RAY PATH HEIGHT ABOVE GROUND.....	312.08 m

Figure 24. Path statistics display.

To exit this display, type "X" and the menu shown in Figure 23 appears. If a "3" is entered from this menu, a display giving certain geometric data about the antenna pointing as shown in Figure 25 will be invoked. Typing "4" will bring a profile plot of the path to the screen and typing "5" will send the profile information to a plotter. Figure 26 is an example of a profile plot.

Typing an "X" will return the menu of Figure 22 to the screen, and typing an "X" at that point will return the DLOS main menu to the screen.

4.7 The "ATMOSPHERIC ABSORPTION" Module

Although the loss to a radio signal due to atmospheric absorption at frequencies below 10 GHz is not a major factor in link design, it is included

ANTENNA POINTING INFORMATION			
FELDBERG TO SCHWARZENBORN LINK:			
FREQUENCY.....	8.37	GHz	
ANTENNA POLARIZATION.....	HORIZONTAL		
AT FELDBERG:			
TRANSMIT ANTENNA HEIGHT.....	30.6	m	
TRANSMIT ANTENNA ELEVATION ANGLE.....	-21'	37.80"	
TRANSMIT FORWARD AZIMUTH.....	221° 31'	52.45"	
TRANSMIT FORWARD MAGNETIC AZIMUTH.....	223° 57'	52.45"	
AT SCHWARZENBORN:			
RECEIVE ANTENNA HEIGHT (PRIMARY).....	96.3	m	
RECEIVE ANTENNA HEIGHT (DIVERSITY).....	83.3	m	
RECEIVE ANTENNA ELEVATION ANGLE.....	-29'	36.64"	
RECEIVE FORWARD AZIMUTH.....	40° 48'	56.05"	
RECEIVE FORWARD MAGNETIC AZIMUTH.....	43° 32'	56.05"	

Figure 25. Antenna pointing information screen.

in the DLOS program set for completeness and it may make a difference in marginal link situations. At frequencies above 15 GHz, atmospheric absorption can be the major component of path loss at certain frequencies, but these considerations are addressed by other link design techniques. Basically, the loss is a function of the air pressure along the path, the absolute humidity of the air, the radio carrier frequency, the air temperature, and the path length.

The equations to determine atmospheric absorption loss are truncated versions of the formulae developed by Liebe and Gimmestad (1978). Essentially, the contributions of absorption lines well above 10 GHz are neglected, an approximation that will not cause large errors below 10 GHz. Atmospheric absorption, A_{abs} , is calculated by adding the water vapor absorption per kilometer, a_w , to the absorption per kilometer due to other atmospheric gasses, a_o , and multiplying the sum by the path length in kilometers, d_{km} , or

$$A_{abs} = d_{km} (a_o + a_w) . \tag{12}$$

The normalized components of absorption are calculated from

$$a_o = \frac{(0.626 \times 10^{-6} f^2 p_o^2 t^{2.9})}{(f^2 + (3.14 \times 10^{-5} p_o^2 t^{1.8}))} \tag{13}$$

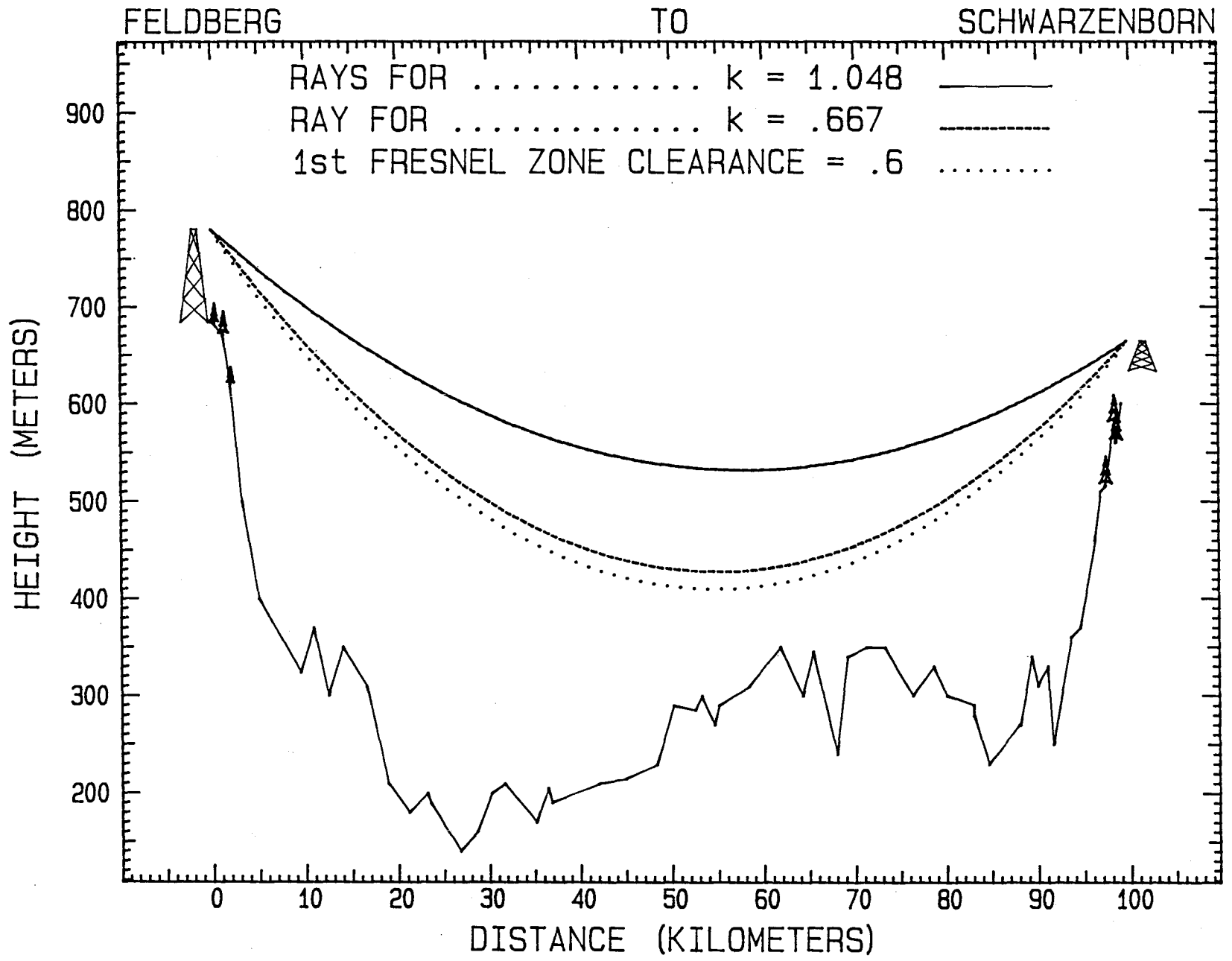


Figure 26. Feldberg to Schwarzenborn Profile Plot

and
$$a_w = 3.4034 \times 10^{-7} f^2 p_o p_w t^{3.1} , \quad (14)$$

where
$$t = \frac{300^\circ}{T^\circ + 273.16^\circ} , \quad (15)$$

f = the frequency in GHz (for $f \leq 1$, $A_{abs} = 0$) ,

T = the air temperature in degrees Celcius,

$$p_o = p_m - p_w, \text{ partial pressure of other atmospheric gasses in kPa,} \quad (16)$$

p_m = the mean air pressure in kPa,

$$p_w = 4.6151 \times 10^{-4} q_w (T + 273.16), \quad (17)$$

 water vapor partial pressure in kPa,

and q_w = the air water vapor density in g/m^3 .

The temperature in degrees Celcius, T , is the average summertime temperature when the air water vapor density would probably be the largest. An internal default value of $20^\circ C$ may be used with small error.

The mean air pressure, p_m , is calculated in module D, the path profile module, and will range between 80 and 105 kPa. If no better value is available, the sea level pressure of 101.3 kPa is provided as an internal default value.

The absolute humidity or air water vapor density, q_w , can be obtained from meteorological atlases, or the internal default value of $15 g/m^3$ can be used.

Certain other data are requested by the program but since these values do not enter the calculations, they need not be entered. If the previous modules have been run, the only values that must be entered are the average summer temperature and the air water-vapor density. Default values have been provided, so if no better estimates are available, the defaults can be safely used. Figure 27 is the atmospheric absorption menu which appears when "E" is entered from the main menu.

Figure 28 shows the input and edit screen with default values for the average latitude, summer temperature, polarization, and air pressure set.

If "X" is typed after the entries are made, the atmospheric absorption menu, Figure 27, appears. Typing "C" will call up the output screen shown in Figure 29.

Figure 29 shows the output screen with entered and calculated values for the various parameters. Note that the bottom line indicates that the atmospheric absorption loss is indeed small.


```

ATMOSPHERIC ABSORPTION MODULE

Options
  I = Input/Edit
  C = Calculate
  X = eXit
Option?

```

Figure 27. Atmospheric absorption menu.

```

INPUT / EDIT          SCHWARZENBORN TO FELDBERG
Link distance                km
Frequency                    7.50 GHz
Average Latitude             40° 0' 0.00" N
Average July temperature     30.00°C
Average January Temperature  15.00°C
Average summer temperature   20.00°C
Primary frequency antenna polarization: Vertical
  H = Horizontal
  V = Vertical
Mean atmospheric pressure on ray path 101.30 kPa
Air water-vapor density        15.00 gm/cu. m

```

Figure 28. The input and edit screen for atmospheric absorption.

4.8 The "MULTIPATH FADING" Module

The term "multipath fading" as applied to a microwave link is an effect that manifests itself in reduction of the signal energy at a receiving location, occasionally by a factor of 10,000. The microwave system is designed with a fade margin or safety factor large enough to counteract even this severe a signal loss. This module calculates the fraction of the worst month during which multipath fading will occur, so that later modules can determine if sufficient margin is available from a given set of path parameters and equipment configuration. The inputs to the module are the antenna heights, the frequency, the general geographic region, the climate and terrain within the region, the standard deviation of terrain elevations, the effective path length, and the rms

INPUT SUMMARY	FELDBERG	to SCHWARZENBORN
Link distance		99.67 km
Frequency		7.50 GHz
Average latitude		40° 0' 0.00" N
Average July temperature		30.00°C
Average January Temperature		15.00°C
Average summer temperature		20.00°C
Primary frequency antenna polarization		Horizontal
Mean atmospheric pressure on ray path		94.23 kPa
Air water-vapor density		15.00 gm/cu. m
OUTPUT SUMMARY		
Temperature function		1.023
Water vapor pressure		2.0294
Oxygen absorption per kilometer		0.0057 dB/km
Total oxygen absorption loss		0.5671 dB
Water-vapor absorption per kilometer		0.0048 dB/km
Total water vapor absorption loss		0.4777 dB
Atmospheric absorption loss		1.0448 dB

Figure 29. The atmospheric absorption output screen.

value of terrain slopes. The first five of these factors are entered in previous modules or in this one as either selected or typical parameters for the link under study. The last three parameters are obtained from consideration of the path profile, and the analysis made in the path profile and ray trace program. The algorithms used to determine these values are fairly complicated (although not theoretically difficult to understand). The numerical values themselves vary over a wide range and, in turn, have a strong influence on the estimated link performance. For this reason, it would be difficult to provide typical values for these parameters that would give meaningful results for a variety of paths. The value of the multipath occurrence factor can take on values between zero and one (indicating the range from NO multipath during the worst month to ALWAYS having multipath during that month) and this value is used in the digital link design summary module.

Following Hause (1986), equation 3 from CCIR (1986), Report 338-5 is separated into a "path fixed" part called the multipath occurrence factor (which includes those components which depend only on path terrain and climate) and the

part that symbolizes the fraction of time that a specific fade depth is exceeded. The equation for calculating the multipath occurrence factor (MOF) is :

$$\text{MOF} = K Q f^B d_e^C , \quad (18)$$

where

f = the carrier frequency in GHz,

d_e = the effective path length in kilometers,

B and C are empirically derived constants, and

K and Q are the climatic region and terrain constants.

The fraction of fading time that the effective fade margin is exceeded is calculated in section 4.10, equations 31, 32, and 33 for particular diversity configurations. This is multiplied by the MOF to determine the probability of outage, $P(o)$, during the worst fading period.

The effective path length is calculated in module D and is that part of the radio path which passes through the atmosphere at a penetration angle of less than 1 degree. The climate and terrain constants have been measured for a number of areas of the world and published by the CCIR (1986). Table 2 is extracted from the reference and gives these empirical constants for areas for which they are available.

The multipath fading initial menu is shown in Figure 30.

```
MULTIPATH FADING

Options
  I = Input/edit
  C = Calculate
  X = eXit
Option?
```

Figure 30. The multipath fading menu.

If "I" is typed, the input/edit screen shown in Figure 31 is displayed. The figure shows data in all of the parameter locations that were passed from the COMMON.FIL file for the example path.

For certain of the country/region options, no climate/terrain choice is offered. An example is the Continental Europe region. This is reflected in Table 2, which shows a value for a single terrain and climate type. Some of the entries in Table 2 suggest a range of values for some of the expressions. In such cases, DLOS uses a value within the limits that appears reasonable. If

Table 2. Empirical Constants for the MOF Equation CCIR (1986)

Proposed for	Japan (1)	N.W. Europe	United Kingdom	United States	USSR	Northern Europe (2)
Reference	[Morita, 1970]		[Doble, 1979]	[Barnett, 1972; Vigants, 1975]	[Nadenenko, 1980]	[Laine, 1979; Blomquist et al., 1980; Danielson, 1983; Tanem, 1985]
B	1.2	1.0	0.85	1.0	1.5	1.0
C	3.5	3.5	3.5	3.0	2.0	3.0
K·Q for maritime temperate, mediterranean, coastal or high-humidity-and-temperature climatic regions				$\frac{4.1 \times 10^{-5}}{S_1^{1.3}}$	2×10^{-5}	
K·Q for maritime sub-tropical climatic regions				$\frac{3.1 \times 10^{-5}}{S_1^{1.3}}$		
K·Q for continental temperate climates or mid-latitude inland climatic regions with average rolling terrain	10^{-9}	1.4×10^{-8}	$\frac{8.1 \times 10^{-7}}{S_2^{1.4}}$ to $\frac{4.0 \times 10^{-6}}{S_2^{1.4}}$	$\frac{2.1 \times 10^{-5}}{S_1^{1.3}}$	4.1×10^{-6}	$\frac{2.3 \times 10^{-5}}{S_1^{1.3}}$
K·Q for temperate climates, coastal regions with fairly flat terrain	$\frac{9.9 \times 10^{-8}}{\sqrt{h_1 + h_2}}$				2.3×10^{-5} to 4.9×10^{-5}	$\frac{6.5 \times 10^{-5}}{S_1^{1.3}}$
K·Q for high dry mountainous climatic regions	3.9×10^{-10}			$\frac{10^{-5}}{S_1^{1.3}}$		10^{-4}
K·Q for temperate climates, inland regions with fairly flat terrain					7.6×10^{-6} to 2×10^{-5}	$\frac{3.3 \times 10^{-5}}{S_1^{1.3}}$
Accuracy of equation (3) with coefficients indicated		$\bar{\epsilon} = -2.9$ dB $\sigma = 6.6$ dB 47 links in UK/France, 7.5-95 km 2-37 GHz	$\bar{\epsilon} = 1.3$ dB $\sigma = 5.0$ dB 28 links, 7.5-75 km, 2-37 GHz		$\bar{\epsilon} = -0.04$ dB $\sigma = 2.0$ dB 26 links, 36-75 km, 3.7-8 GHz	

(1) The Japanese data apply for the worst season.

(2) The coefficients are based on data from Finland and Sweden for non-mountainous regions, and data from Norway for mountainous regions.

Note. - h_1 and h_2 are antenna heights in metres.

S_1 is the terrain roughness measured in metres by the standard deviation of terrain elevations at 1 km intervals ($6 \text{ m} < S_1 < 42 \text{ m}$). The height of the radio sites has to be excluded. S_2 is defined as the r.m.s. value of the slopes (mrad) measured between points separated by 1 km along the path, but excluding the first and the last complete km interval ($1 < S_2 < 80$).

It is possible that some of these parameters may be distorted by the inclusion of data from paths which experience surface reflection problems and/or diffraction fading.

$\bar{\epsilon}$ is the mean value of the errors (predicted minus measured fade depths) (dB).

σ is the standard deviation of the errors (dB).

INPUT / EDIT		FELDBERG to SCHWARZENBORN	
Transmit antenna height		30.60 m	
Receive antenna height		96.30 m	
Frequency		8.37 GHz	
Standard deviation of terrain elevation		95.38 m	
Effective path length		99.67 km	
RMS value of terrain slopes		0.04	
Country/Region option		Pacific	
Pacific (e.g. Japan, Korea, Philippines).....	1		
United States.....	2		
United Kingdom.....	3		
Continental Europe.....	4		
Scandinavia.....	5		
Continental Asia (Russia).....	6		
Climate/Terrain (for Pacific)		Temperate Coastal	
Temperate inland/average rolling terrain.....	1		
High dry mountains.....	2		
Temperate costal/flat region.....	3		

Figure 31. The multipath fading input and edit display.

the operator wishes to use another value, a hand calculation of the MOF can be made and the new value entered into the input table in module "H". When the appropriate entries are made, "X" may be typed to leave the entry mode. Typing "C" at the menu will result in the calculations being run and the output screen being displayed as shown in Figure 32. The final value is passed to the link performance module through the COMMON.FIL.

4.9 The "MINIMUM RECEIVED SIGNAL LEVEL (BER THRESHOLD)" Module

This module calculates the performance threshold of a given digital microwave radio in terms of the value of received signal level (RSL) at which the error ratio in a derived 64 kb/s circuit would be such that one error could be expected each second. This value is a requirement for military systems (Department of Defense, 1984); it corresponds to a bit error ratio of 0.0000156 or 1.56×10^{-5} . Since a manufacturer's value for these quantities may not always be available, the algorithm calculates an RSL based on equipment parameters or it converts a threshold based on some other BER threshold to the value consistent with the MIL-STD.

The algorithm may be operated in two modes, depending on the information available:

INPUT SUMMARY		FELDBERG to SCHWARZENBORN	
Transmit antenna height	30.60	m	
Receive antenna height	96.30	m	
Frequency	8.37	GHz	
Standard deviation of terrain elevation	95.38	m	
Effective path length	99.67	km	
RMS value of terrain slopes	0.04		
Country/Region option	Pacific		
Climate/Terrain (for Pacific)	Temperate Coastal		
OUTPUT SUMMARY			
Multipath occurrence factor	0.7864		

Figure 32. The multipath fading output display.

MODE A

If the first two values, MANUFACTURERS BER VALUE AT THRESHOLD and RSL VALUE AT MANUFACTURERS THRESHOLD, are not input (see Figures 34 and 36), then RECEIVER NOISE FIGURE, DATA RATE (FOR THE RADIO), MODULATION SCHEME OPTION, and IMPLEMENTATION FACTOR are all necessary to calculate E_b/N_0 at RSL_m and RSL AT BER THRESHOLD (RSL_m).

MODE B

If the first two values, MANUFACTURERS BER VALUE AT THRESHOLD and RSL VALUE AT MANUFACTURERS THRESHOLD, are input (see Figures 35 and 37), along with RECEIVER NOISE FIGURE, DATA RATE (FOR THE RADIO), MODULATION SCHEME OPTION, then IMPLEMENTATION FACTOR can be calculated, leading to the calculation of E_b/N_0 at RSL_m and RSL AT BER THRESHOLD (RSL_m).

To differentiate between numerical and decibel ratios, numerical ratios are shown as lowercase and decibel ratios are shown as uppercase. To perform the calculations in MODE A, recall from Smith (1985) that the signal-to-noise ratio at threshold, S/N_t , can be expressed as

$$S/N_t = RSL_m - KTBF = E_b/N_0 + IMPF + 10 \log(R/B) . \quad (19)$$

This expression can be rearranged to obtain

$$RSL_m = kT_0 + N_f + 60\log(R) + E_b/N_0 + IMPF. \quad (20)$$

In (20), the thermal noise density, kT_0 , is -174 dBm/Hz and the data rate, R , is expressed in Mb/s. The noise figure (N_f), E_b/N_0 , and the implementation factor (IMPF) are in dB.

For a given digital modulation scheme, the form of the expression for the probability of bit error is

$$P(e) = K_1 \operatorname{erfc}[K_0 (e_b/n_0)^{\frac{1}{2}}] . \quad (21)$$

The value of K_1 varies from 0.75 to 2 in the various formulations, but it is a weak constant in determining the slope of the curve in the region of interest, $P(e) = 10^{-5}$ so K_1 has been set to 1.5. Based on curves by Proakis (1983) and other sources, values have been found for K_0 as shown in Table 3. To calculate the bit error ratio, $P(e)$ is divided by the constant, K_2 , which is equal to $2(\log_2)M$ for DPSK and equal to $2[\log_2(M^{\frac{1}{2}})]$ for QAM and QPR. The expression for BER is

$$BER = \{K_1 \operatorname{erfc}[K_0 (e_b/n_0)^{\frac{1}{2}}]\} / K_2 . \quad (22)$$

Table 3. Symbol-Error-Probability Equation Constants

Modulation Type No.	Modulation Name	Number of Symbols	E_b/N_0 for $P(e) = 10^{-5}$ (dB)	e_b/n_0 Ratio	K_0	K_2
1	DPSK	4	11.9	15.488	0.8079	2
2	DPSK	8	15	31.623	0.5655	3
3	DPSK	16	19.5	89.125	0.3368	4
4	QAM	16	14.5	28.184	0.5990	2
5	QAM	64	19	79.433	0.3568	4
6	QPR	9	13	19.953	0.7120	1.585
7	QPR	49	19.3	85.114	0.3446	2.808

The constants for the modulation scheme option selected are used for the E_b/N_0 calculation, which is then used in subsequent calculations along with the default or input value of BER_m . The technique for determining an e_b/n_0 from a BER value (BER at threshold or BER_m) employs a technique of successive approximations. The routine has BER_m and the appropriate modulation scheme option as inputs. The output is a value of e_b/n_0 which is a value at the performance threshold and symbolized by $e_b/n_0(t)$, which is converted to a decibel ratio, $E_b/N_0(t)$.

To calculate the implementation factor, we need two pieces of information from specifications about the manufacturer's radio, namely the manufacturer's BER value at threshold, or BER_m , and the RSL value at the manufacturer's

threshold, RSL_m in dBm. Using BER_m in place of BER_t , calculate a manufacturer's value for e_b/n_0 at the threshold of acceptable performance called $e_b/n_0(m)$. Using (22) and (20), and setting $IMPF = 0$, a manufacturer's value of RSL_{th} is obtained. Since the manufacturer's curve for BER vs. RSL is the implemented situation, the difference between the manufacturer's RSL_m and the theoretical value for RSL_{th} is the value of the implementation factor.

When "G" is typed at the main menu, the threshold menu, shown in Figure 33 is displayed.

```
MINIMUM RECEIVED SIGNAL LEVEL (BER THRESHOLD)

Options
  I = Input/edit
  C = Calculate
  X = eXit
Option ?
```

Figure 33. The threshold menu.

To review the input data and complete any inputs that still need a value, type "I" and the input/edit menu appears. This display has two default values to start with although either can be changed by the operator. These are the thermal noise density with a default value of -174 dBm/Hz and the bit error ratio at threshold, 0.0000156, which is made to agree with MIL-STD-188-323. The algorithm accepts certain sets of inputs and from these calculates all of the outputs. For instance, if the manufacturer's BER value at threshold and the RSL at this threshold are both provided, as well as the type of digital modulation employed, an implementation factor, the E_b/N_0 and RSL at threshold will be computed. If manufacturer's specifications are not available, an implementation factor can be estimated and the E_b/N_0 and the RSL at threshold, will be computed. Figure 34 shows the threshold input/edit screen with no entry for the manufacturer's data, and Figure 35 shows the screen for entries of a manufacturer's data.


```

INPUT/EDIT      FELDBERG to SCHWARZENBORN

Manufacturer's BER value at threshold
RSL value at manufacturer's threshold
Receiver noise figure
Thermal noise density
Data rate (for the radio)
Modulation scheme option:
  4-ary DPSK.....1
  8-ary DPSK.....2
  16-ary DPSK.....3
  16-ary QAM.....4
  64-ary QAM.....5
  9-ary QPR.....6
  49-ary QPR.....7
Bit error ratio (threshold) at RSLm
(for MIL-STD-188-323, BER = 0.0000156)
Implementation factor

```

	dBm
	dB
	-174.00 dBm/Hz
	Mb/s
	0.0000156
	dB

Figure 34. Input/edit screen for threshold, no manufacturer's data.

In order to proceed with the calculations, all of the blanks except the first two for manufacturer's information must be entered.

```

INPUT/EDIT      FELDBERG to SCHWARZENBORN

Manufacturer's BER value at threshold
RSL value at manufacturer's threshold
Receiver noise figure
Thermal noise density
Data rate (for the radio)
Modulation scheme option:
  4-ary DPSK.....1
  8-ary DPSK.....2
  16-ary DPSK.....3
  16-ary QAM.....4
  64-ary QAM.....5
  9-ary QPR.....6
  49-ary QPR.....7
Bit error ratio (threshold) at RSLm
(for MIL-STD-188-323, BER = 0.0000156)

```

	0.00001000
	-74.50 dBm
	4.00 dB
	-174.00 dBm/Hz
	25.00 Mb/s
	4ary DPSK
	0.0000156

Figure 35. Input/edit screen for threshold, with manufacturer's data.

Note that with the manufacturer's data, no implementation factor can be entered. The implementation factor is a measure of how closely the manufacturer's threshold RSL approximates the theoretical value. The output screen repeats all of the input values and supplies those values that were calculated. Figure 36 shows the output screen corresponding to the inputs of Figure 34, namely with no manufacturer's data.

INPUT SUMMARY	FELDBERG to SCHWARZENBORN
Receiver noise figure	4.00 dB
Thermal noise density	-174.00 dBm/Hz
Data rate (for the radio)	25.00 Mb/s
Modulation scheme option	4-ary DPSK
Bit error ratio (threshold)	0.0000156
Implementation factor	5.50 dB
OUTPUT SUMMARY	
E_b/N_0 at BER threshold	11.4323 dB
RSL at BER threshold	-74.6984 dBm

Figure 36. Output screen for threshold, no manufacturer's data.

Note that the manufacturer's specifications are not calculated because no BER value could be assigned. Figure 37 shows the output screen with manufacturer's data input. In this instance, the implementation factor moves to the output summary. The outputs of this module are saved to the COMMON.FIL when an "X" is typed in, followed by "X" to return to the DLOS main menu.

4.10 The "DIGITAL LINK DESIGN SUMMARY" Module

The digital link design summary module takes all of the information developed in the previous modules and determines whether the equipment configuration chosen shows sufficient system gain that the expected link performance will meet the level required by MIL-STD-188-323. This module requires that all remaining physical link parameters be selected so that the calculations of diversity gain and total system gain can be completed.

The antenna gain is calculated from its diameter, A, in feet, the aperture efficiency of 0.55, and the carrier frequency, f_c , in GHz from

INPUT SUMMARY		FELDBERG to SCHWARZENBORN	
Manufacturers BER value at threshold		0.00000100	
RSL value at manufacturers threshold		-74.50	dBm
Receiver noise figure		4.00	dB
Thermal noise density		-174.00	dBm/Hz
Data rate (for the radio)		25.00	Mb/s
Modulation scheme option		4-ary	DPSK
Bit error ratio (threshold)		0.0000156	
OUTPUT SUMMARY			
Implementation factor		5.50	dB
E_b/N_0 at BER threshold		11.4323	dB
RSL at BER threshold		-74.6984	dBm

Figure 37. Output screen for threshold, with manufacturer's data.

$$G = 20 \log (2.3689 \times A \times f_c) \text{ dB.} \quad (23)$$

Free space path loss in dB is calculated from the carrier frequency, f_c in GHz, and the path distance, d , in km using the equation

$$L_{bf} = 92.45 + 20 \log f_c + 20 \log d_{km} . \quad (24)$$

The total constant loss is the sum of the total line loss, L_f ; the branching loss, L_{bxx} ; the miscellaneous loss, L_{msc} ; the free space path loss, L_{bf} ; and the atmospheric absorption, A_{abs} .

$$L_c = L_f + L_{bxx} + L_{msc} + L_{bf} + A_{abs} . \quad (25)$$

The net constant loss in dB is the total constant loss minus the sum of the antenna gains, G_{xr} :

$$L_n = L_c - G_{xr} . \quad (26)$$

The unfaded median RSL for the path, RSL_m in dBm, is the transmitter power, W_o , minus the net constant loss, L_n :

$$RSL_m = W_o - L_n . \quad (27)$$

The fade margin for the path, M_f in dB, is the difference between the unfaded median RSL, RSL_m , and the value of RSL at the threshold of acceptable performance, RSL_{th} :

$$M_f = RSL_m - RSL_{th} . \quad (28)$$

The performance of microwave links is discussed in terms of the fraction of all seconds during which traffic is passed without bit errors. This fraction is called the error-free second performance or EFS. It is a simple linear function of the radio path length, d_{km} :

$$EFS_a = 1 - \{(6.25 \times 10^{-7}/km) \times d_{km}\} . \quad (29)$$

The effective fade margin, M_e , is the flat fade margin, M_f , reduced by the effects of the dispersive fade margin, M_d , and the interference fade margin, M_i :

$$M_e = -10 \log (10^{-M_f/10} + 10^{-M_d/10} + 10^{-M_i/10}) . \quad (30)$$

The nondiversity multipath fading time below a given level, M_e , is

$$P_{ndm} = 10^{-M_e/10} . \quad (31)$$

The space-diversity-improved multipath fading time below a given level, M_e , is

$$P_{sdm} = \frac{412 (10^{B/10} + 10^{-B/10})}{f_c s_d^2 d_{km} 10^{M_e/5}} , \quad (32)$$

where B = the combiner hysteresis in dB and

s_d = the space diversity antenna spacing in meters.

The frequency-diversity-improved multipath fading time below a given level, M_e , is

$$P_{fdm} = \frac{6.213 \times 10^{-3} f_c^2 d_{km} (10^{B/10} + 10^{-B/10})}{(|f_c - f_d|) 10^{M_e/5}} , \quad (33)$$

where B = the combiner hysteresis in dB and

$|f_c - f_d|$ = the frequency diversity separation in GHz.

The fraction of time that the RSL is lower than RSL_{th} which is the probability of outage $P(o)$ is the product of the nondiversity or the space or frequency-diversity-improved multipath fading time, P_{ndm} , P_{sdm} , or P_{fdm} , and the multipath occurrence factor, MOF:

$$P(o) = MOF \times P_{ndm} \text{ for no diversity, or} \quad (34)$$

$$P(o) = MOF \times P_{sdm} \text{ for space diversity, or} \quad (35)$$

$$P(o) = MOF \times P_{fdm} \text{ for frequency diversity.} \quad (36)$$

The calculated EFS performance is the time that the link performance is above the MIL-STD-188-123 threshold given in (34), (35), or (36), or

$$EFS_c = 1 - P(o) . \quad (37)$$

The EFS performance of the link is expected to be adequate if the calculated EFS performance exceeds the allocated EFS performance, that is, if EFS_c is greater than EFS_a .

Figure 38 shows the initial menu for this module.

```
DIGITAL LINK SUMMARY DESIGN

Options
  I = Input/edit
  C = Calculate
  X = eXit
Option ?
```

Figure 38. The design summary menu.

Typing "I" displays the input and edit screen shown in Figure 39.

This display will not fit on a single screen, so the operator can move up and down using the arrow keys or the "Page up/Page down" keys. All of the highlighted entries must be made before a calculation can be done. If the operator needs information on the acceptable range of values for one of the quantities, typing a "?" on the entry line will show the allowable limits. Typing "X" returns the menu shown in Figure 38 to the screen. Typing "C" from the menu shows the input summary/output screen. This is shown as Figure 40.

5. CONCLUSIONS

The program set described in this report fills a gap in the set of link design tools available to the Government user. Previous programs have necessitated the use of expensive and highly specialized computing, printing, and plotting equipment to perform link design calculations. DLOS allows the user with access to a PC-AT computer or suitable clone to take advantage of the precise algorithms developed in the earlier efforts to perform link calculations in a highly interactive manner and simultaneously to prepare preliminary documentation of the design.

INPUT/EDIT	FELDBERG	to SCHWARZENBORN
Site designator	FEL2	SBN2
Transmission line type	WG-235	WG-235
Antenna height	96.30 m	30.60 m
Horizontal line length	18.70 m	20.00 m
Line loss dB per 100 meters	3.70 dB	3.70 dB
Antenna diameter options	10.00 ft	10.00 ft
3 feet.....	3	
4 feet.....	4	
6 feet.....	6	
8 feet.....	8	
10 feet.....	10	
12 feet.....	12	
15 feet.....	15	
Path length		99.67 km
Frequency		8.37 GHz
Branching loss		1.70 dB
Miscellaneous losses		2.20 dB
Atmospheric absorption		1.04 dB
Diversity Type option		Space diversity
Non-diversity.....	N	
Space diversity.....	S	
Frequency diversity..	F	
Antenna spacing (vertical)		12.30 m
Frequency spacing		N/A
Combiner hysteresis		3.00 dB
Multipath occurrence factor (Worst month)		0.7864
Receiver noise figure		3.50 dB
Data rate (for the radio)		25.00 Mb/s
Modulation scheme option:		4-ary DPSK
4-ary DPSK.....	1	
8-ary DPSK.....	2	
16-ary DPSK.....	3	
16-ary QAM.....	4	
64-ary QAM.....	5	
4-ary QPR.....	6	
9-ary QPR.....	7	
49-ary QPR.....	8	
Bit error ratio (threshold) at RSLm (for MIL-STD-188-323, BER = 0.0000156)		0.00001560
RSL at BER threshold (RSLm)		-73.1 dBm
Transmitter power output (Wo) option		37.00 dBm
0.1 Watt.....	20 dBm	
0.2 Watt.....	23 dBm	
0.5 Watt.....	27 dBm	
1 Watt.....	30 dBm	
2 Watts.....	33 dBm	
5 Watts.....	37 dBm	
10 Watts.....	40 dBm	
20 Watts.....	43 dBm	
Dispersive fade margin		48.00 dB
Interference fade margin		60.00 dB

Figure 39. The digital link design input/edit display

INPUT SUMMARY	FELDBERG	SCHWARZENBORN
Site designator	FEL2	SBN2
Transmission line type	WG-235	WG-235
Antenna height	96.30 m	30.60 m
Horizontal line length	18.70 m	20.00 m
Line loss dB per 100 meters	3.70 dB	3.70 dB
Antenna diameter options	10.00 ft	10.00 ft
Path Length	99.67 km	
Frequency	8.37 GHz	
Branching loss	1.70 dB	
Miscellaneous loss	2.20 dB	
Atmospheric absorption	1.04 dB	
Diversity Type option	Space diversity	
Antenna spacing (vertical)	12.30 m	
Combiner hysteresis	3.00 dB	
Multipath occurrence factor	0.7864	
Receiver noise figure	3.50 dB	
Data rate (for the radio)	25.00 Mb/s	
Modulation scheme option:	4-ary DPSK	
Bit error ratio (threshold) at RSLm	0.0000156	
RSL at BER threshold (RSLm)	-73.11 dBm	
Transmitter power output (Wo) Option	37.00 dBm	
Dispersive fade margin	48.00 dB	
Interference fade margin	60.00 dB	
OUTPUT SUMMARY	FELDBERG	SCHWARZENBORN
Total transmission line length	115.00 m	50.6 m
Line loss	4.26 dB	1.87 dB
Gain of parabolic antenna	45.95 dB	45.95 dB
Total line losses	6.13 dB	
Free space path loss	150.88 dB	
Total constant loss	161.94 dB	
Total antenna gain	91.89 dB	
Net constant loss	70.05 dB	
Unfaded median RSL for the path	-33.05 dBm	
Fade margin for the path	40.05 db	
Allocated EFS performance	0.999993770	
Effective fade margin	39.370637 dB	
Type of diversity	Space diversity	
Diversity improved multipath	0.000001082	
Probability of outage	0.000000851	
Calculated EFS performance	0.999999149	
Is link performance adequate?	Yes	
Calculations were done by JEF for project number 910-5431		

Figure 40. The digital link design output display

6. ACKNOWLEDGMENTS

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7. REFERENCES

- Bean, B. R., J. D. Horn, and A. M. Ozanich, Jr. (1960), Climatic charts and data of the radio refractive index for the United States and the World, National Bureau of Standards Monograph No. 22 (U.S. Government Printing Office, Washington, DC).
- CCIR (1986), Recommendations and Reports of the CCIR, 1986; Vol. V: Propagation non-ionized media, ITU, Geneva, Switzerland.
- Department of the Army (1967), Grid and grid references, Technical Bulletin No. TM 5-241-1, Headquarters, Department of the Army, Washington, DC.
- Department of Defense (Draft, 1984), System design and engineering standards for long haul digital transmission system performance, MIL-STD-188-323.
- Hause, L. G. (1986), Algorithms Used in ARROWS: Autodesign of Radio Relay Optimum Wideband Systems, NTIA Report 86-207 (NTIS Order No. PB 87-126405/AS).
- Liebe, H. J., and G. G. Gimmetad (1978), Calculation of clear air EHF refractivity, Radio Sci. 13, No. 2, March-April 1978.
- List, R. J. (1951), Smithsonian Meteorological Tables, 6th Ed. (Smithsonian Institution, Washington, DC).
- Proakis, J. (1983), Digital Communications, (McGraw-Hill).
- Smith, D. R. (1985), Digital Transmission Systems, (Van Nostrand Reinhold Company, New York, NY 10020).
- Smith, D. R., and H. Smullen, (Draft, 1987), Engineering Publication No. 15-87, DCS digital line-of-sight link design, Defense Communications Engineering Center, 1860 Wiehle Ave, Reston, VA 22090.
- Thomas, P. D. (1970), Spheroidal geodesics, reference systems, and local geometry, U.S. Naval Oceanographic Office, Washington, DC 20390.

APPENDIX: MODULE INPUT VARIABLES

This appendix provides the operator with a list of the input variables required by each module.

Module A, the Earth geometry module.

1.	Transmit antenna latitude	dms	*	0 to 90 N,S
2.	Transmit antenna longitude	dms	*	0 to 180 E,W
3.	Transmit antenna magnetic declination	deg	O	0 to 180 E,W
4.	Tower base elevation above msl	m	*	0 to 10000
5.	Receive antenna latitude	dms	*	0 to 90 N,S
6.	Receive antenna longitude	dms	*	0 to 180 E,W
7.	Receive antenna magnetic declination	deg	O	0 to 180 E,W
8.	Tower base elevation above msl	m	*	0 to 10000
9.	Earth spheroid options		*	
	International.....1			
	Clark 1866.....2			
	Clark 1880.....3			
	Everest.....4			
	Bessel.....5			
	Australian National.....6			
	Airy.....7			
	Fisher.....8			
	Malayan.....9			
10.	Equatorial radius	km	C	
11.	Polar radius	km	C	
12.	Link distance	km	C	
13.	Forward azimuth	dms	C	
14.	Forward magnetic azimuth	dms	C	

LEGEND

* = Must have this value
 C = Calc in this module
 I* = Calc in another module;
 value needed here
 O = Optional value
 D = Default Provided;
 may be changed

Module B, the path profile module.

- 1. LINK DISTANCE (km)
- 2. TRANSMITTER TOWER BASE ELEVATION ABOVE MSL (m)
- 3. RECEIVER TOWER BASE ELEVATION ABOVE MSL (m)
- 4. REFRACTIVITY (msl), N_0 (N-units)
- 5. PATH PROFILE UNITS OPTION

6. PROFILE POINT

- 7. Distance from Transmitter
- 8. Elevation
- 9. Obstacle type at profile point

10. Obstacle height above profile point

I*	1 to 200
I*	-400 to 10000
I*	-400 to 10000
*	200 to 450
*	1=mi,ft
	2=km,m
*	points as available
*	
*	
O	t=tree
	b=bldg
	o=other
	s=water starts
	e=water ends
O	0-500

LEGEND
 * = Must have this value
 C = Calc in this module
 I* = Calc in another module, value needed here
 O = Optional value
 D = Default Provided; may be changed

Module C, the optimum antenna height module.

- 1. DISTANCE AND HEIGHT UNITS
- 2. IS ONE ANTENNA HEIGHT KNOWN
- 3. WHICH HEIGHT IS KNOWN?
- 4. LINK DISTANCE km
- 5. FREQUENCY GHz
- 6. TRANSMIT TOWER BASE ELEVATION ABOVE MSL m
- 7. RECEIVE TOWER BASE ELEVATION ABOVE MSL m
- 8. EXTREME EARTH-RADIUS FACTOR k_e
- 9. 1ST FRESNEL ZONE CLEARANCE FRACTION
- 10. TRANSMIT RECOMMENDED ANTENNA HEIGHT m
- 11. RECEIVE RECOMMENDED ANTENNA HEIGHT m

*	1=km/meters 2=mi/feet
*	1=yes 2=no
O	1=Xmtr 2=Rcvr
I*	0 to 200
*	1 to 10
*	
*	
*	0.5 to 1.5
*	0 to 1
C	
C	

LEGEND

- * = Must have this value
- C = Calc in this module
- I* = Calc in another module;
value needed here
- O = Optional value
- D = Default Provided;
may be changed

Module D, the profile plotting module.

1.	DISTANCE AND HEIGHT UNITS		*	1=km/meters 2=mi/feet
2.	DIVERSITY TYPE		*	1=none 2=space 3=freq
3.	ANTENNA POLARIZATION		O	1=horizontal 2=vertical
4.	LINK DISTANCE	km	I*	1 to 200
5.	FREQUENCY	GHz	*	1 to 10
6.	RECOMMENDED AVERAGE EARTH-RADIUS FACTOR		C	k
7.	AVERAGE EARTH-RADIUS FACTOR		O	k, 0.5 to 1.5
8.	EXTREME EARTH-RADIUS FACTOR		*	k_e , 0.5 to 1.5
9.	1ST FRESNEL ZONE CLEARANCE FRACTION		*	0 to 1
10.	TRANSMIT TOWER BASE ELEVATION ABOVE MSL	m	I*	-500 to 10000
11.	RECEIVE TOWER BASE ELEVATION ABOVE MSL	m	I*	-500 to 10000
12.	TRANSMIT ANTENNA HEIGHT	m	*	
13.	RECEIVE ANTENNA HEIGHT (PRIMARY)	m	*	
14.	RECEIVE ANTENNA HEIGHT (DIVERSITY)	m	*	
15.	MAXIMUM ANNUAL SNOW DEPTH	m	O	
16.	TREE GROWTH PER YEAR	m	O	
17.	ANTENNA SPACING (VERTICAL)	m	O	
18.	STD DEVIATION OF TERRAIN ELEV. (S1)	m	C	
19.	R.M.S. VALUE OF TERRAIN SLOPES (S2)		C	
20.	EFFECTIVE PATH LENGTH	km	C	
21.	MINIMUM TERRAIN CLEARANCE DISTANCE	km	C	
22.	MINIMUM 1ST FRESNEL ZONE CLEARANCE	m	C	
23.	MEAN ATMOSPHERIC PRESSURE ON RAY PATH	kPa	C	
24.	MEAN RAY PATH HEIGHT ABOVE GROUND	m	C	
25.	TRANSMIT ANTENNA ELEVATION ANGLE	d/m/s	I*	
26.	TRANSMIT FORWARD AZIMUTH	d/m/s	I*	
27.	TRANSMIT FORWARD MAGNETIC AZIMUTH	d/m/s	I*	
28.	RECEIVE ANTENNA ELEVATION ANGLE	d/m/s	I*	
29.	RECEIVE FORWARD AZIMUTH	d/m/s	I*	
30.	RECEIVE FORWARD MAGNETIC AZIMUTH	d/m/s	I*	

LEGEND

* = Must have this value
 C = Calc in this module
 I* = Calc in another module;
 value needed here
 O = Optional value
 D = Default Provided;
 may be changed

Module E, the atmospheric absorption module.

1.	LINK DISTANCE	km	I*	1 to 200
2.	FREQUENCY	GHz	*	0 to 10
3.	TRANSMIT ANTENNA LATITUDE	dms	O	0/0/0 to 90/0/0 N,S
4.	AVERAGE JULY TEMPERATURE	Celsius	O	-5 to 37
5.	AVERAGE JANUARY TEMPERATURE	Celsius	O	-98 to 20
6.	AVERAGE SUMMER TEMPERATURE	Celsius	D	-5 to 37 Default = 20
7.	TEMPERATURE FUNCTION (t)		C	
8.	PRIMARY FREQ.ANT.POLARIZATION (H,V)		O	As Shown
9.	MEAN ATMOSPHERIC PRESSURE ON RAY PATH	kPa	D	20 to 120 Default=101.3
10.	AIR WATER-VAPOR DENSITY	gm/m ³	D	5 to 40 Default = 15
11.	OXYGEN ABSORPTION PER KILOMETER	dB/km	C	
12.	TOTAL OXYGEN ABSORPTION LOSS	dB	C	
13.	WATER-VAPOR ABSORPTION PER KILOMETER	dB/km	C	
14.	TOTAL WATER VAPOR ABSORPTION LOSS	dB	C	
15.	ATMOSPHERIC ABSORPTION LOSS	dB	C	

LEGEND

* = Must have this value
 C = Calc in this module
 I* = Calc in another module;
 value needed here
 O = Optional value
 D = Default Provided;
 may be changed

Module F, the multipath occurrence factor module.

1.	TRANSMIT ANTENNA HEIGHT	m	I*	h_t	1 to 300
2.	RECEIVE ANTENNA HEIGHT (PRIMARY)	m	I*	h_r	1 to 300
3.	FREQUENCY	GHz	*	f_c	1 to 10
4.	STANDARD DEVIATION OF TERRAIN ELEVATION	m	I*	s_1	6 to 42
5.	EFFECTIVE PATH LENGTH	km	I*	d_e	1 to 200
6.	RMS VALUE OF TERRAIN SLOPES	mrاد	I*	s_2	1 to 80
7.	COUNTRY/REGION OPTION		*		
	Pacific (e.g. Japan, Korea, Phillipines)...	1			
	United States.....	2			
	United Kingdom.....	3			
	Continental Europe.....	4			
	Scandanavia.....	5			
	Continental Asia (Russia).....	6			
8.	CLIMATE/TERRAIN (FOR PACIFIC)				
	Temperate Inland/Average Rolling Terrain...	1			
	High Dry Mountains.....	2			
	Temperate Coastal/Flat Region.....	3			
9.	CLIMATE/TERRAIN (FOR UNITED STATES)				
	Temperate Inland/Average Rolling Terrain...	1			
	High Dry Mountains.....	2			
	Maritime Temperate/High Humidity.....	3			
	Maritime Sub-tropical.....	4			
10.	CLIMATE/TERRAIN (FOR SCANDANAVIA)				
	Temperate Inland/Average Rolling Terrain...	1			
	Temperate Coastal/Flat Terrain.....	2			
	High Dry Mountains.....	3			
	Temperate Inland/Flat Terrain.....	4			
11.	CLIMATE/TERRAIN (FOR CONTINENTAL ASIA)				
	Temperate Inland/Average Rolling Terrain...	1			
	Maritime Temperate/High Humidity.....	2			
	Temperate Coastal/Flat Terrain.....	3			
	Temperate Inland/Flat Terrain.....	4			
12.	MULTIPATH OCCURRENCE FACTOR		C		

LEGEND

* = Must have this value
 C = Calc in this module
 I* = Calc in another module;
 value needed here
 O = Optional value
 D = Default Provided;
 may be changed

Module G, the receiver threshold performance module.

- 1. MANUFACTURERS BER VALUE AT THRESHOLD
- 2. RSL VALUE AT MANUFACTURERS THRESHOLD dBm
- 3. RECEIVER NOISE FIGURE dB
- 4. THERMAL NOISE DENSITY dBm/Hz
- 5. DATA RATE (FOR THE RADIO) Mb/s
- 6. MODULATION SCHEME OPTION
 - 4-ary DPSK.....1
 - 8-ary DPSK.....2
 - 16-ary DPSK.....3
 - 16-ary QAM.....4
 - 64-ary QAM.....5
 - 9-ary QPR.....6
 - 49-ary QPR.....7
- 7. IMPLEMENTATION FACTOR dB
- 8. BIT ERROR RATIO (THRESHOLD) AT RSL_m
(For MIL-STD-188-323, BER = 0.0000156)
- 9. E_b/N_0 at RSL_m dB
- 10. RSL AT BER THRESHOLD (RSL_m) dBm

-	BER _{th}	10 ⁻⁷ to 10 ⁻²
-	RSL _{th}	-90 to -50
*	N _f	0 to 20
D	kT	-190 to -160
*		1 to 80
*	As shown	
*	IMPF	0 to 20
D	BER _m	10 ⁻⁷ to 10 ⁻²
C		
C	RSL _m	

LEGEND

- * = Must have this value
- C = Calc in this Module
- I* = Calc in another module;
value needed here
- O = Optional value
- D = Default value provided;
may be changed

Module H, the link performance module

1. LINK DISTANCE	km	I*	d_{km}	1 to 200 km
2. FREQUENCY	GHz	*	f_c	1 to 10 GHz
3. TRANSMITTER TRANSMISSION LINE TYPE		O	String	
4. TRANSMIT ANTENNA HEIGHT	m	I*	h_{ax}	1 to 300 m
5. TRANSMIT HORIZONTAL LINE LENGTH	m	*	l_{ax}	1 to 100 m
6. TRANSMIT LINE LOSS PER 100 METERS	dB	*	K_{xf}	1 to 10 dB
7. TRANSMIT LINE LOSS	dB	C	L_{xf}	
8. TRANSMIT ANTENNA DIAMETER OPTIONS	ft	*	A_{ftx}	As Shown
3 FEET.....	3			
4 FEET.....	4			
6 FEET.....	6			
8 FEET.....	8			
10 FEET.....	10			
12 FEET.....	12			
15 FEET.....	15			
9. TRANSMIT ANTENNA GAIN	dB	C	G_x	
10. RECEIVER TRANSMISSION LINE TYPE		O	String	
11. RECEIVE ANTENNA HEIGHT (PRIMARY)	m	I*	h_{ar}	1 to 300 m
12. RECEIVE HORIZONTAL LINE LENGTH	m	*	l_{ar}	1 to 100 m
13. RECEIVE LINE LOSS PER 100 METERS	dB	*	K_{rf}	1 to 10 dB
14. RECEIVE LINE LOSS	dB	C	L_{rf}	
15. RECEIVE ANTENNA DIAMETER OPTION	ft	*	A_{ftr}	As Shown
3 FEET.....	3			
4 FEET.....	4			
6 FEET.....	6			
8 FEET.....	8			
10 FEET.....	10			
12 FEET.....	12			
15 FEET.....	15			
16. RECEIVE ANTENNA GAIN	dB	C	G_r	
17. LINE LOSSES (TOTAL)	dB	C	L_{rf}	
18. BRANCHING LOSS	dB	*	L_{bxx}	0 to 10 dB
19. MISCELLANEOUS LOSSES	dB	*	L_{msc}	0 to 10 dB
20. FREE SPACE PATH LOSS	dB	C	L_{bf}	
21. ATMOSPHERIC ABSORPTION	dB	I*	A_{abs}	
22. TOTAL CONSTANT LOSSES	dB	C	L_c	
23. ANTENNA GAIN (TOTAL)	dB	C	G_{xr}	
24. NET CONSTANT LOSS (L_n)	dB	C	L_n	
25. DIVERSITY TYPE OPTION		*		As Shown
NONDIVERSITY	N			
SPACE DIVERSITY.....	S			
FREQUENCY DIVERSITY.....	F			
26. ANTENNA SPACING (VERTICAL)	m	O	s_d	1 to 50 m
27. FREQUENCY SPACING	MHz	O	$ f_c - f_d $	1 to 800 MHz
28. COMBINER HYSTERESIS	dB	*	B	0 to 10 dB
29. MULTIPATH OCCURRENCE FACTOR (WORST MONTH)		I*	MOF	0 to 1
30. FRACTION OF TIME THAT $RSL < RSL_m$ (PROBABILITY OF OUTAGE)		C	$P(o)$	
31. RECEIVER NOISE FIGURE	dB	*		0 to 20 dB
32. DATA RATE (FOR THE RADIO)	Mbs	*		1 to 50 Mb/s

LEGEND

* = Must have this value
 C = Calculated in this module
 I* = Calc in another module; value needed here
 O = Optional Entry

33. MODULATION SCHEME OPTION

- 4-ary DPSK.....1
- 8-ary DPSK.....2
- 16-ary DPSK.....3
- 16-ary QAM.....4
- 64-ary QAM.....5
- 4-ary QPR.....6
- 9-ary QPR.....7
- 49-ary QPR.....8

34. BIT ERROR RATIO (THRESHOLD) AT RSL_{th}
 (For MIL-STD-188-323, BER = 0.0000156)

35. RSL AT BER THRESHOLD (RSL_{th})

36. TRANSMITTER POWER OUTPUT (W_o) OPTION

- 0.1 Watt.....20
- 0.2 Watt.....23
- 0.5 Watt.....27
- 1 Watt.....30
- 2 Watts.....33
- 5 Watts.....37
- 10 Watts.....40
- 20 Watts.....43

37. SYSTEM GAIN ($W_o - RSL_{th}$)

38. FLAT FADE MARGIN ($W_o - L_n - RSL_{th}$)

39. DISPERSIVE FADE MARGIN

40. INTERFERENCE FADE MARGIN

(If value unknown, enter 60)

40. EFFECTIVE FADE MARGIN

41. ALLOCATED EFS PERFORMANCE

(MIL-STD-188-323)

42. CALCULATED EFS PERFORMANCE

43. IS EFS PERFORMANCE ADEQUATE?

44. LONG-TERM MEDIAN RSL, RSL_m

46. MULTIPATH FADING TIME, SPACE DIV, P_{sdm}

47. MULTIPATH FADING TIME, FREQ DIV, P_{fdm}

dBm
dBm

dB
dB
dB
dB

dBc

0	
*	BER 10^{-7} to 10^{-2}
*	RSL_{th} -99 to -50 dBm
*	W_o As Shown
C	G_s
C	M_f
*	M_d 20 to 70 dB
*	M_i 20 to 70 dB
C	M_e
C	EFS _a
C	EFS _c
C	YES or NO
C	RSL_m
C	P_{sdm}
C	P_{fdm}

LEGEND

- * = must have value
- C = calc this module
- I* = calc other mod value needed here
- O = optional

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15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) This report provides a description of and operating instructions for Digital Line-of-Sight (DLOS) programs. These programs, which run on a desk-top computer, automate the calculations involved in design of line-of-sight microwave radio relay paths. The programs manipulate information about Earth geometry, terrain profiles, ray paths, median basic transmission loss, variability of loss, equipment effects, and path performance. The computer hardware and software configurations are designed to be convenient to operate and to give the design engineer immediate access to calculated results corresponding to changes in design parameters. The programs are intended to be used interactively by persons having no experience in programming. The algorithms may be applied over a wide range of path parameters. The frequency range is from 1 GHz to 10 GHz; the path length may be up to 200 km; and the path must have adequate terrain clearance. The results of the calculations are given in terms of the requirements of MIL-STD-188-323.			
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