Overview

A terrain profile consists of a table of distances and elevations along the great circle arc between two sites. On most practical paths less than 150 kilometers, the difference between a straight line and the great circle arc is negligible. The Terrain data design section is used to create a terrain profile using any of the following methods:

- Elevations are read from a terrain data base.
- Manual entry of distances and elevations taken from topographic maps.
- Direct entry of distance - elevation data from topographic maps using a digitizing tablet.
- Conversion of distance - elevation data in text files from other sources.

Optional structures and ranges can be added to the path. The display consists of the data entry form at the top and the profile display at the bottom. Once the second point has been entered, the profile will be drawn and will be continually updated as the data entry proceeds.

To move to a specific point on the profile, click on the profile display. The first point past the mouse cursor will be selected. Alternately, you can click on a line in the terrain data entry form.

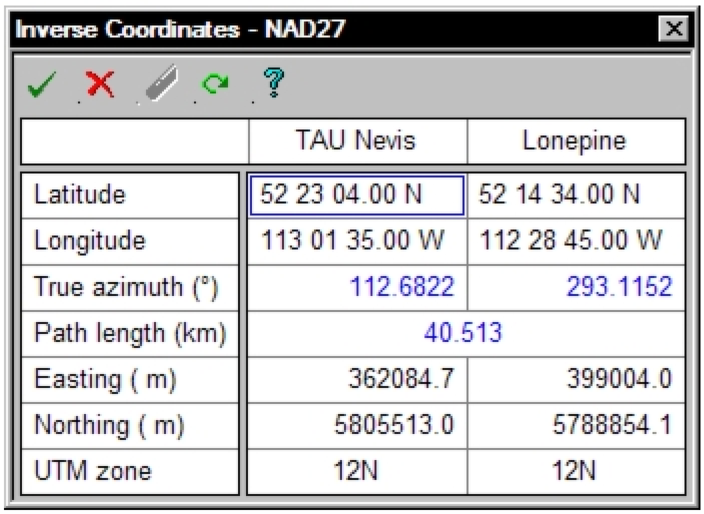
The Home, End, PgUp, PgDn keys, the up and down cursor keys and the vertical scroll bar are used to move through the profile.

You need to know

- Path profile generation is carried out in the automated link design procedures and in local-area studies. The specific options used to create path profiles (primary - secondary terrain elevation models, clutter model selection and distance increment) can be set in the terrain data design section; however, any changes made to these options will be lost when the program is closed. To set the default options use the Configure - Set PL50L program options menu selection.
- Any calculations which depend on a terrain profile will be erased if changes made to a terrain profile. This includes diffraction loss, reflection analysis and a reflective plane definition.

Inverse coordinates

Inverse coordinates means that the coordinates of both sites are entered. The program will calculate the path length and azimuth.



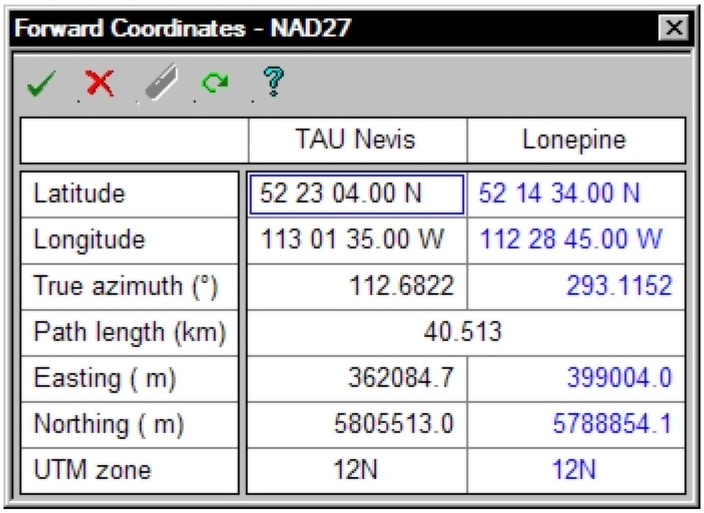
Coordinates can be entered as geographic latitude and longitudes or as projected coordinates. The other coordinates are automatically calculated.

Note that the distance - azimuth calculation and the conversion between geographic coordinates use the ellipsoid parameters defined by the current datum setting. This is show on the caption.

Select Coordinates - Inverse from the Terrain Data menu bar. SIte coordinates can be entered in the Site data entry form and various other locations in the program,

Forward coordinates

Forward coordinates means that the Site 1 coordinates and the distance and azimuth to site 2 are entered, The Site 2 coordinates and azimuth will be calculated.


Forward Coordinates - NAD27

	TAU Nevis	Lonepine
Latitude	52 23 04.00 N	52 14 34.00 N
Longitude	113 01 35.00 W	112 28 45.00 W
True azimuth (°)	112.6822	293.1152
Path length (km)	40.513	
Easting (m)	362084.7	399004.0
Northing (m)	5805513.0	5788854.1
UTM zone	12N	12N

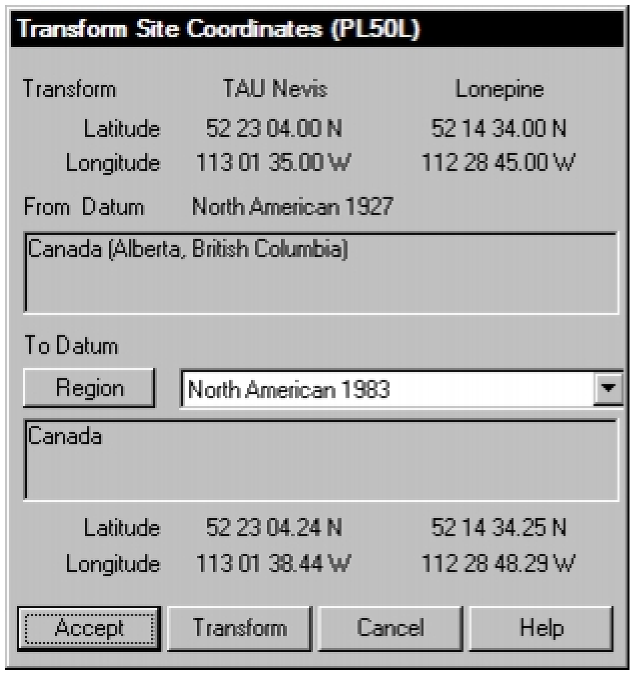
The Site 1 coordinates can be entered as geographic latitude and longitude or as projected coordinates. The other coordinates are automatically calculated. Distance is entered in either miles or kilometers depending on the measurement system. The azimuth is entered in degrees from true north.

Note that the distance - azimuth calculation and the conversion between geographic coordinates use the ellipsoid parameters defined by the current datum setting. This is show on the caption.

Select Coordinates - Forward from the Terrain Data menu bar. The forward coordinate calculation can only be made in this data entry form.

Coordinate transformation

Select Coordinates - Transform from the Terrain Data menu bar to access the coordinate transformation dialog box.



The format of this dialog will depend if it was accessed from the terrain data design section in standalone PL50L application or from the PL50 program.

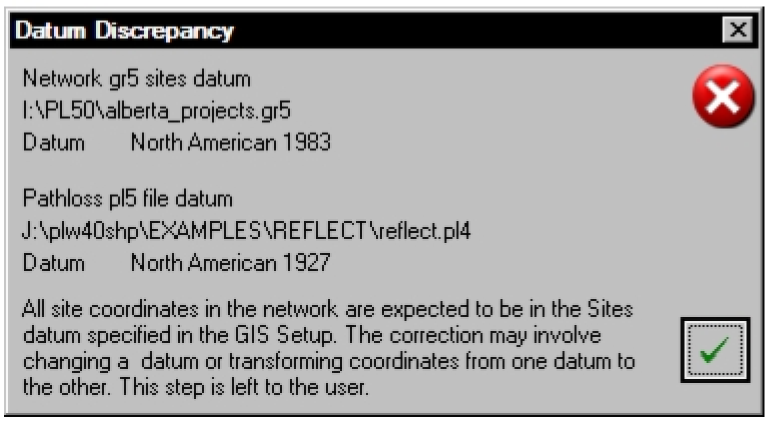
PL50L standalone application

The example shown above is in from the standalone application. When the pathloss data file was loaded the datum and projection settings in the GIS configuration are reset to those in the file. Therefore the "From Datum" setting represents the file setting and the user is responsible for the "To Datum" setting. The default "To Datum" is WSGS-84.

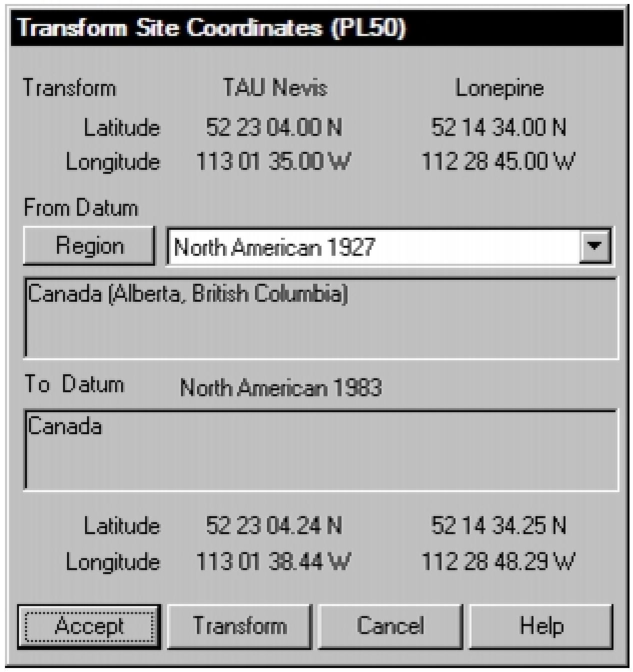
Select the new datum and region and click the Transform button. Click the Accept button to use the transformed coordinates. The datum will also be changed in the GIS configuration.

PL50 application

In the PL50 application, the datum must be the same for all sites. If the PL50L program is accessed by clinking on a link in the PL50 network display, the error message below will occur if the file datum and the GIS configuration datum are different.



When the coordinate transformation dialog is accessed from this application the format is shown below. In this case the "To Datum" is fixed and represents the datum specified in the GIS configuration. The "From Datum" is set by the user. The initial setting will be the file datum.


Transform Site Coordinates (PL50)
Transform
TAU Nevis
Lonepine
Latitude
52 23 04.00 N
52 14 34.00 N
Longitude
113 01 35.00 W
112 28 45.00 W
From Datum
Region
North American 1927
Canada (Alberta, British Columbia)
To Datum
North American 1983
Canada
Latitude
52 23 04.24 N
52 14 34.25 N
Longitude
113 01 38.44 W
112 28 48.29 W
Accept
Transform
Cancel
Help

Structures on a terrain profile

At terrain profile consists of a list of distance and elevation points along a path. A structure can be defined at any of these points. The following categories of structures are used:

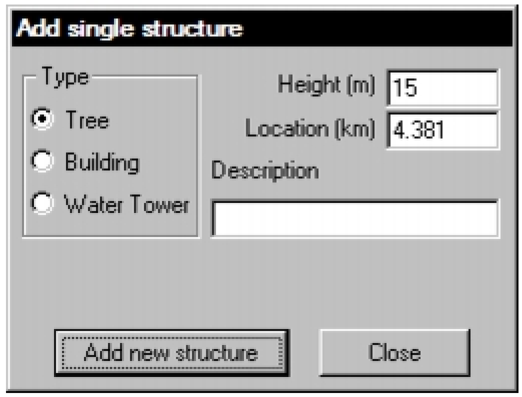
- single structure - height, description and type (tree, building or water tower)
- range of structures -. height and type (tree or building).
- off path structure - distance off path, ground elevation, height, description and type
- clutter - height and description

Any combination of these structures can be used on a terrain profile; however only one structure type can be defined at any point. A structure range requires two points to define the start and end points and can overlap the other structure types; however overlapping ranges are not allowed.

A structure can be entered at the ends of a path. This will be strictly for information purposes. For example if the antenna at site 1 is located on a building, a building could be entered at the first point. Antenna heights are always measured from ground level and therefore the building will only serve as a visual effect on the profile display.

Clutter refers to data read from a terrain database and is described in the next section. The other types are manually entered by the user. Single structures can also be entered in the Antenna heights design section. This display allows structures to positioned on the critical points on the profile

Single structure



Adding a new single structure

Double click on an empty row in the structure column and select Single Structure from the popup menu, The initial location will be the distance of the selected row. You can change the location by clicking on the profile display or entering the distance in the location edit box.

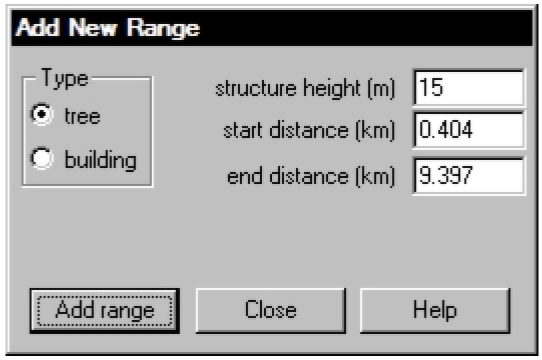
Select the structure type, enter the structure height and an optional description if required and click the Add new structure button. The structure will be added to the profile. The Add single structure dialog remains open; however, a "structure exists at this location" appears and no further changes can be made. To continue to add new structures, change the location and the height if necessary and click the Add new structure button again.

Editing an existing structure

Double click on the row in the structure column containing the structure to edit to bring up the Edit single structure dialog. Change the height. type, location, or description as required and click the OK button. The dialog will close and the profile will be re formatted to show the changes. The structure height can also be changed by editing the value in the structure height column.

To delete a structure, click the delete button in this dialog or enter a zero value in the structure height column.

Range of structures



Adding a new range

Double click on an empty row in the structure column and select Range of structures from the popup menu, Left and right marker arrows will appear on the profile display which correspond to the start and end distances of the range. These locations are set with the left and right mouse buttons or the values can be entered in the start and end distance edit controls. Note that the locations cannot be the same as an existing structure

Once the extents are set, select the structure type, enter the structure height and click the Add new range button and the profile will be reformatted to include the range. The Add new range dialog remains open; however, a "structure exists at this location" appears and no further changes can be made. To continue to add new ranges, select new start and end locations, change the height and type if necessary and click the Add new range button again.

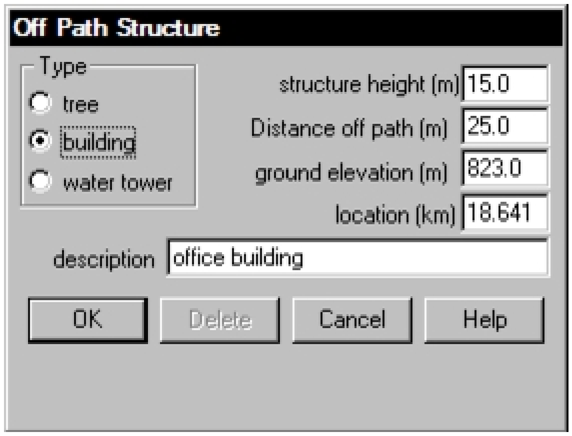
Click the Close button on completion

Editing an existing range

To access the Edit range dialog, double click on the row in the structure column containing the start or end point of the range to edit. Change the height, type, start or end distances as required and click the OK button. The dialog will close and the profile will be re formatted to show the changes. The structure height can also be changed by editing the value in the structure height column.

To delete a range, click the delete button in this dialog or enter a zero value in the structure height column at the start range row.

Off path structures



Adding an off path structure

Double click on an empty row in the structure column and select Off path structure from the popup menu, The initial location and the ground elevation will be the distance and elevation of the selected row. You can change the location by clicking on the profile display or entering the distance in the location edit box, Note that the ground elevation does not change if the location is changed and must be entered manually

Note that the locations cannot be the same as an existing structure

Select the structure type, enter the structure height and the distance off path and the ground elevation of the structure. Off path distances are measured in meters or feet as determined by the program settings and represent the horizontal distance from the path centerline to the edge of the structure. Enter a description of the structure if required and click the OK button. The profile will be reformatted to include the structure and the dialog will close.

Editing an existing off path structure

Double click on the row in the structure column containing the off path structure to edit. Change the required parameters including the location if necessary and click the OK button. The dialog will close and the profile will be re formatted to show the changes. The off path structure height can also be changed by editing the value in the structure height column.

To delete an off path structure, click the delete button in this dialog or enter a zero value in the structure height column at the of path structure row.

Off path structure clearance

The antenna height clearance report show the horizontal clearance from the path centerline to the edge of the off path structure in terms of a percent of the first Fresnel zone.

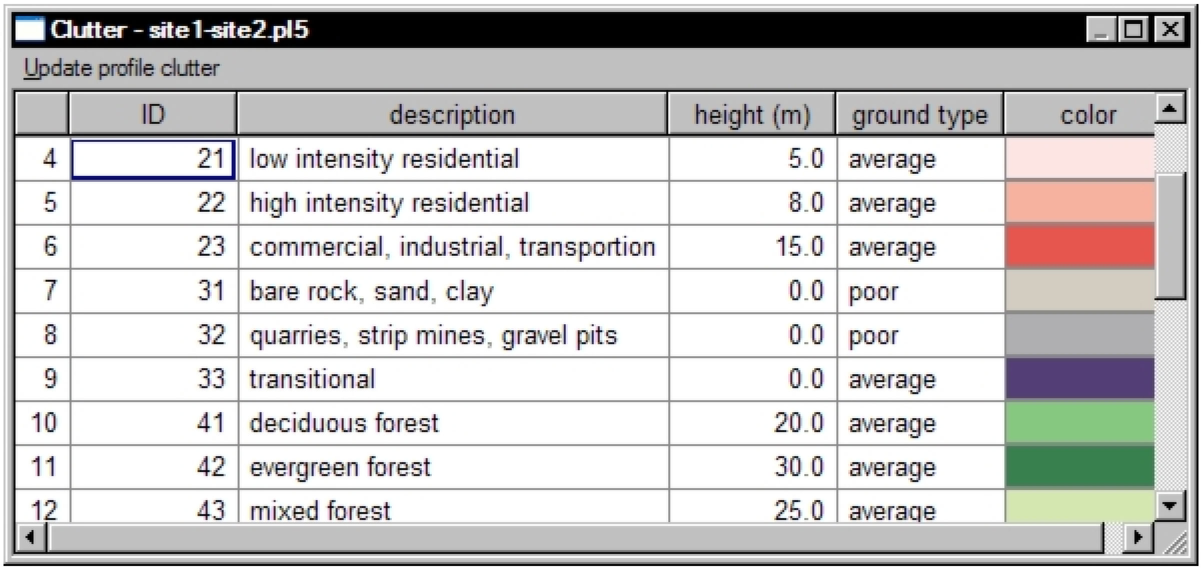
Clutter

The term clutter in the Pathloss program refers to land cover, terrain clutter, terrain morphology.. or in other words anything above the bare earth. The height of the clutter above ground level determines the clearance on a path profile. Clutter information is read from a database. There are two basic types of terrain clutter databases.

- The database contains the actual clutter height above ground level. The data could be contained in a single database or it could be read as the difference between two databases - one containing terrain elevations and the other containing terrain plus clutter elevations.
- The clutter database contains an index to a clutter definition table. This table provides a description of the clutter; however in general, there is no height information available.

The first type or clutter database is straight forward. The clutter heights are read at each point in the profile and identified simply as clutter. Unfortunately this type of clutter base is not available through the public terrain data sources and the majority of available clutter databases are of the second type. To handle these, the clutter definition table in the Pathloss program contains two additional fields - clutter height and ground type. The ground type (poor, average, good, fresh and salt water) set the surface conductivity and the relative dielectric constant which are used to calculate the theoretical reflection coefficient. As part of the GIS configuration procedure, the user will enter a preliminary estimate of the clutter heights and specify the ground types.

Editing the clutter definition table


Clutter - site1-site2.pl5

Update profile clutter

	ID	description	height (m)	ground type	color
4	21	low intensity residential	5.0	average	
5	22	high intensity residential	8.0	average	
6	23	commercial, industrial, transportion	15.0	average	
7	31	bare rock, sand, clay	0.0	poor	
8	32	quarries, strip mines, gravel pits	0.0	poor	
9	33	transitional	0.0	average	
10	41	deciduous forest	20.0	average	
11	42	evergreen forest	30.0	average	
12	43	mixed forest	25.0	average	

When a path profile is generated, a copy of the clutter definition table is saved in the pl5 datafile. The clutter height at a point can be edited directly by changing the value in the structure height column; however it may be more expedient to edit the copy of the clutter definition file and then reset these values in the path profile. Double click on row in the structure column which contains a clutter entry. Modify the required clutter heights and then select the Update profile clutter. The path profile will be changed with the new heights.

When a clutter database is used each point will have a clutter definition. To add a single or off path structure, delete the clutter entry at the desired point by entering a zero structure height column

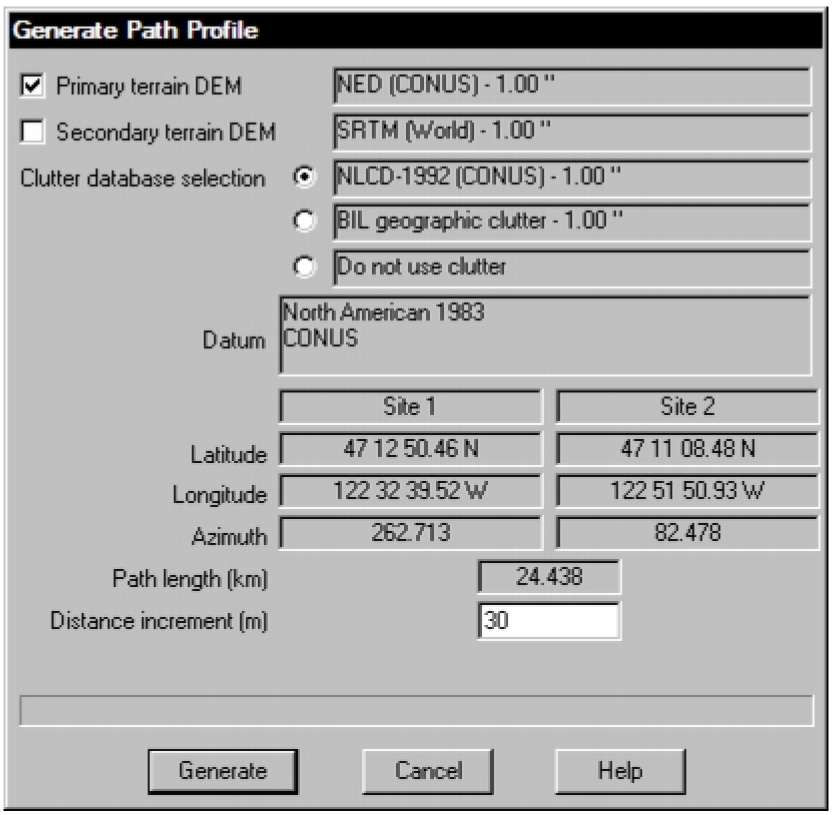
Calibrating clutter heights

Two clutter databases can be configured in the GIS system; however, unlike the primary and secondary terrain elevation databases only one clutter database can be used at a time. The intention was to use SRTM data the second database as a means of calibrating the clutter definition table in the first clutter data base. The SRTM data acquisition system produces a canopy effect to some extent and the elevations will include the heights of buildings and heavily treed areas. The second clutter database is set as a BIL geographic clutter model using the clutter option "The primary DEM has terrain elevations only. The clutter database has composite terrain and clutter elevations..".

Generate profiles using the two clutter options in turn and note the difference in clutter heights. This information can be used to modify the local copy of clutter definition table and possibly the GIS clutter definition table.

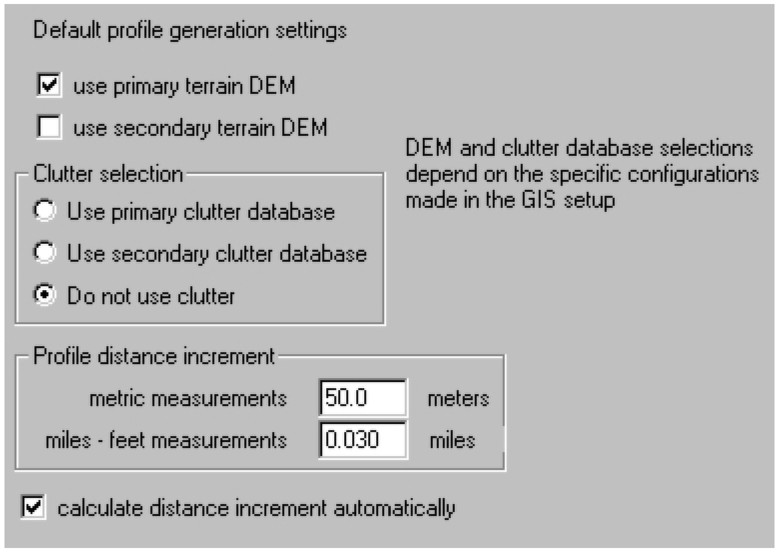
Generate path profile

Select *Operations - Generate path profile* to access the profile generation dialog. Path profile generation is carried out in the automated link design procedures and in local-area studies. This dialog presents all of the options and settings that will be used to create profiles. Use this method to verify the GIS configuration and diagnose any profile generation problems.



This dialog is also used to calibrate a clutter definition file. Refer to the section on clutter.

The specific options used to create path profiles (primary - secondary terrain elevation models, clutter model selection and distance increment) can be set in the terrain data design section; however, any changes made to these options will be lost when the program is closed.

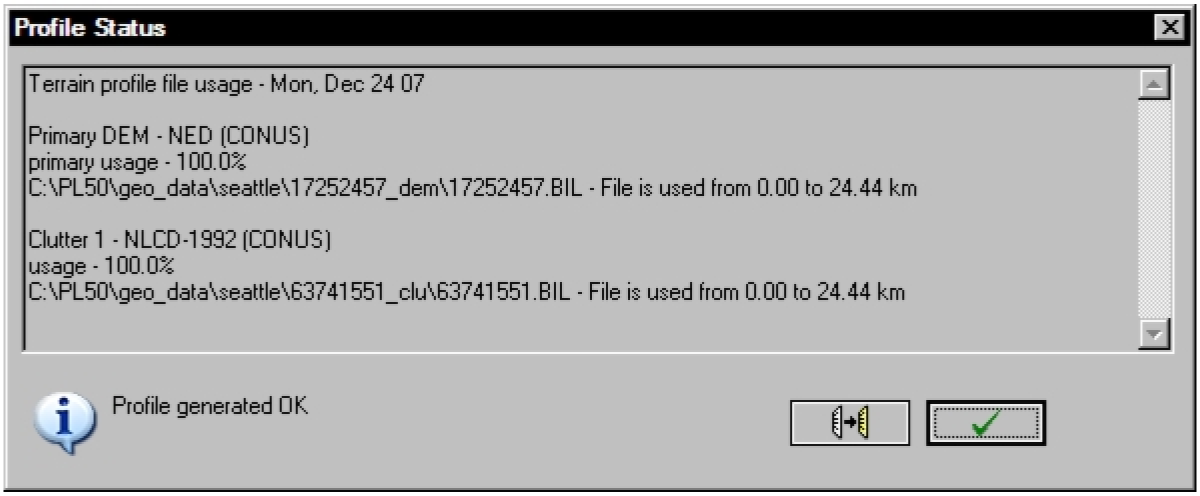


To set the default options use the *Configure - Set PL50L program options* menu selection and then select *Terrain data - Profile generation*. Note that the availability of certain options will depend on the current GIS configuration.

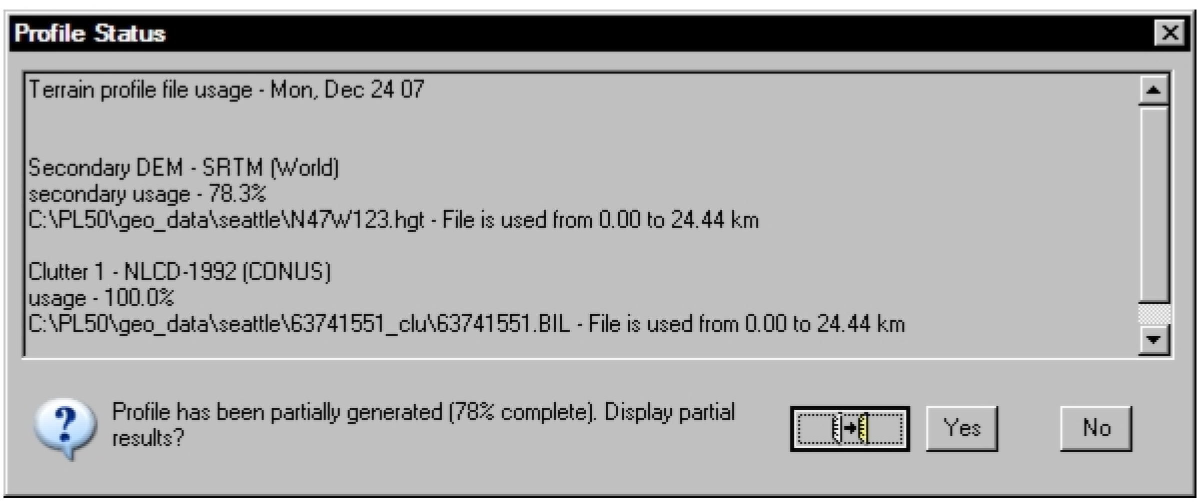
Primary - secondary terrain DEM

The intent is to use a high resolution DEM for the primary and a lower resolution DEM for the secondary. For each point on the profile, the program will attempt to read an elevation from the primary DEM. The secondary DEM is only used if the elevation at the current point is not available in the primary DEM.

These options can be used to compare two DEMS.



The default setting is to use the primary DEM only. In the Terrain data section, the database usage is shown on completion of the profile generation and the user can decide to use the secondary database. Most profiles will be generated as part of an automatic design procedure. In this mode, there is no indication of which database is being used. If the notepad is empty, then the profile generation status is inserted into the note pad.



In the event that the database is incomplete, the profile will be partially generated and the user is given the option to view and edit the results. This is a highly restrictive mode and no other design sections can be accessed with the profile in this condition.

Clutter database selection

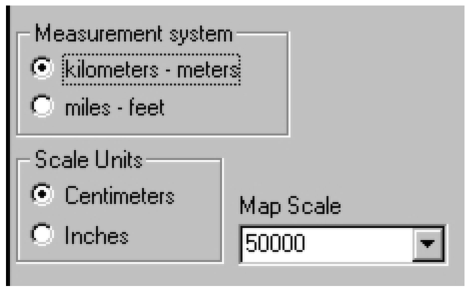
Unlike the primary and secondary elevation databases, only one clutter data base can be selected. Refer to the section on Clutter for details.

Distance increment

A profile consists of a series of uniformly spaced points. The distance increment can be set by the user or can be automatically determined based on the highest resolution data base. The choice is made under the *Configure - Set PL50L program options - Terrain data - Profile generation* selection.

Measurements

Select *Operations - Measurements* to access the measurement settings for the Terrain data design section. This is equivalent to *Configure - Set PL50L options - Terrain data - Measurement system*.



System

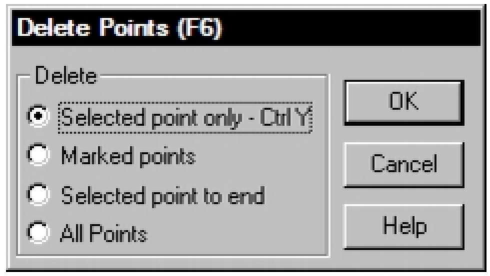
Select either kilometers-meters or miles-feet as the units of measure. The measurement system can be changed at any time. All data in the program is automatically converted to the new system. The measurement system can also be changed using the F5 key or by clicking the left mouse button on the units box in the status bar.

Scale Units - Map Scale

The scale units and map scale set the conversion between the scale distance and path distance. As an example, using centimeter units and a map scale of 50,000 (1:50,000), a one centimeter entry in the scale column is converted to 0.500 kilometers in the distance column.

These settings are critical when a digitizing tablet is used to enter terrain data and whenever distances are taken from a map in inches or centimeters.

Delete points



Select *Operations - Delete points*, The following terrain point deletion options are provided:

Selected point only

This selection deletes the current point only. Alternately, hold down the Ctrl key and press the letter 'Y' to delete the current point.

Marked points

This selection will delete the marked points in the path profile data entry form. A selection of points is created by clicking on the entries in the first column (the line number column). Hold down the shift or Ctrl key to select a continuous range or specific lines only.

Selected point to end

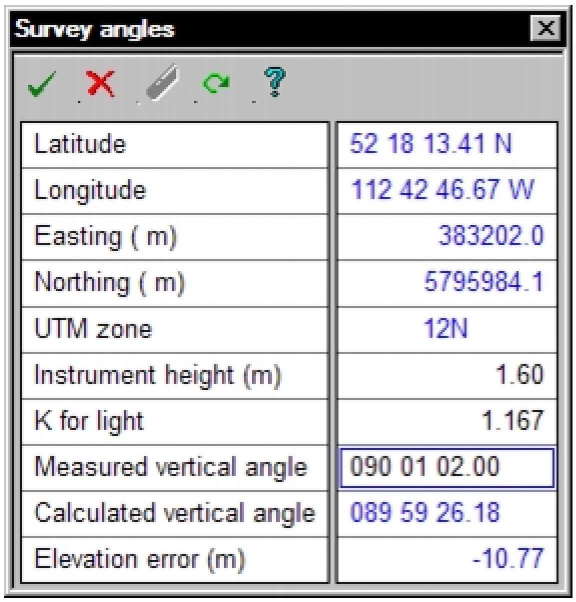
This selection deletes all points after the selected point. The selected point will become the last point in the terrain data entry form.

All points

All terrain points are deleted. Note that all other parameters, including site names, coordinates and the equipment parameters are unchanged.

Survey angles

The survey angles data entry form calculates the elevation difference derived from the measured and calculated vertical angles from Site 1 to a point on the profile. *Select Operations - Survey Angles* from the Terrain Data menu bar. The cursor must not be positioned at Site 1.


Survey angles

Latitude	52 18 13.41 N
Longitude	112 42 46.67 W
Easting (m)	383202.0
Northing (m)	5795984.1
UTM zone	12N
Instrument height (m)	1.60
K for light	1.167
Measured vertical angle	090 01 02.00
Calculated vertical angle	089 59 26.18
Elevation error (m)	-10.77

The following entries are required:

- The height of the instrument above ground level. The default height is 1.6 meters. If the measurement is being made on top of a building, the building height must be included
- This is the value of K for light. The default value is K = 7/6.
- The vertical angle measured from the zenith. This can be entered in degrees minutes seconds or as a decimal.

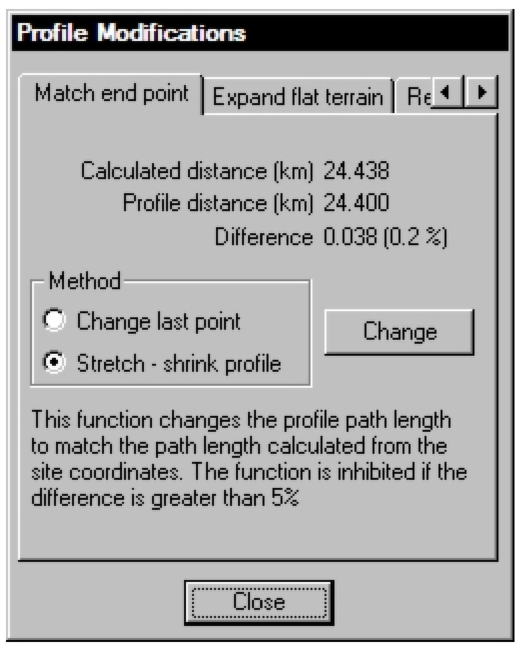
The data entry form shows the calculated latitude and longitude of the selected point and optionally the projected coordinates. The calculated vertical angle and the elevation difference derived from the measured vertical angle are shown. This is the change that would be made to the path profile elevation.

Profile modifications

This section contains several utilities intend for path profiles created from topographic maps either using manual data entry or a digitizing tablet and a strip point feature applicable to all profiles. Select *Operations - Profile modifications*. The following utilities are available as tab selections in the Profile Modifications dialog.

Match end point

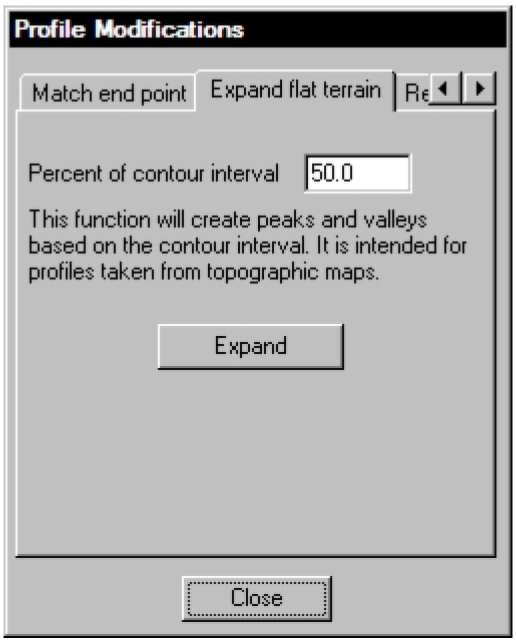
This utility modifies the path profile distance either by only changing the end point or by uniformly stretching the profile to match the distance calculated from the site coordinates.



This can only be used if the difference between the two distances is less than 5 percent.

Expand flat terrain

A profile is manually generated from a topographic map by measuring the distance to each contour and entering that distance and the contour elevation at the current profile point. In this case there will be a uniform spacing between elevations. This value is the map contour interval. The profile is scanned to determine if this condition exists and calculates the contour interval. This procedure will fail on a profile created using a terrain database

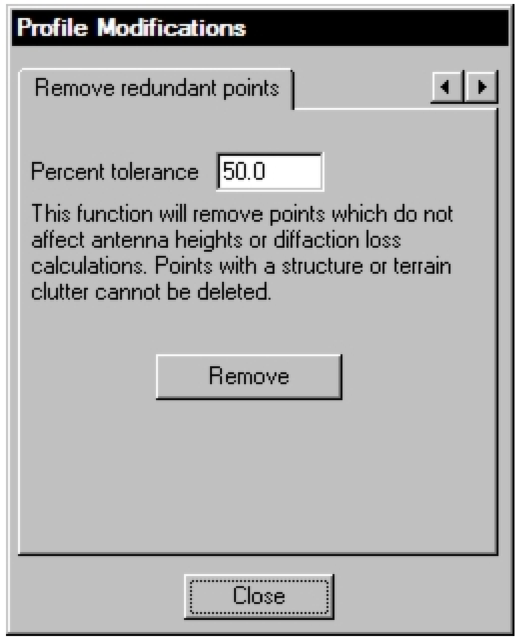


Additional points will be added to flat top hills and flat bottom valleys using the specified percent of the contour interval.

Experience has shown that a 50% contour interval setting provides a realistic representation of the actual terrain.

Remove redundant points

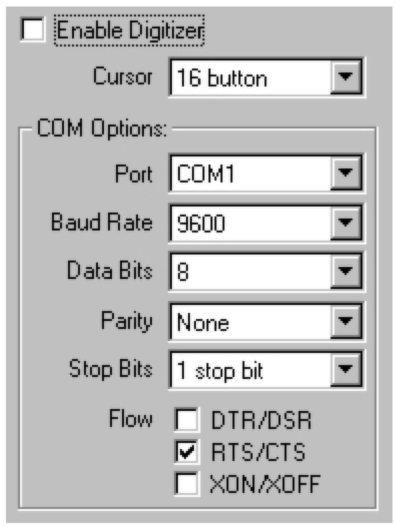
This feature is applicable to all profiles whether manually generated or generated from a terrain database. It is possible to have graphic profile display problems if a profile contains too many points (in the order of 10,000), This utility will remove points which do not have any affect on the calculations. Peaks, valleys and any point with a structure or clutter will not be deleted. Note that this utility may not work on a profile derived using a clutter database.



The percent tolerance is a relative term used to determine the deviation of points on a line between a peak and a valley. Some experimentation may be required

Digitizer operation

Terrain profiles can be generated from topographic maps using a digitizing tablet compatible with the GTCO Digi-Pad 5 series. A digitizing tablet completely eliminates manual data entry and will improve the overall accuracy. Select *Operations - Setup digitizer* to access the required settings. Note that the digitizer must be enabled and the comm port set to access the digitizer. The remaining settings correspond to the default digitizing table default parameters.



Digitizer buttons

The following descriptions apply to a four button digitizing cursor. The functions of these buttons cannot be changed. The additional features of a 16 button cursor are given later in this section. In the following descriptions, buttons will be referred to as SET REF, SAME, UP and DOWN. The action of these buttons are described in the following paragraphs.

Button 4 - Set Reference Point - SET REF

This button establishes a reference location on the tablet. This is always the first step in entering terrain data. All distances will be relative to this point. Unless the reference location has been selected, data entry cannot proceed. The reference location can be changed at any time. There is no data entry associated with this button press.

Button 1 - Go Up One Contour - UP

If the last elevation is an exact multiple of the contour interval, the UP button enters a terrain point using the last elevation plus the contour interval. Otherwise, the elevation will be the nearest contour greater than the last elevation.

Example - Contour Interval = 50 meters

Last Elevation 1500 meters (1500 is exactly divisible by 50)

New Elevation 1550 meters

Example - Contour Interval = 50 meters

Last Elevation 1521 meters (1521 is not exactly divisible by 50)

New Elevation 1550 meters

Button 3 - Go Down One Contour - DOWN

If the last elevation is an exact multiple of the contour interval, the DOWN button enters a terrain point using the last elevation minus the contour interval. Otherwise, the elevation will be the nearest contour less than the last elevation.

Example - Contour Interval = 50 meters

Last Elevation 1500 meters (1500 is exactly divisible by 50)

New Elevation 1450 meters

Example - Contour Interval = 50 meters

Last Elevation 1521 meters (1521 is not exactly divisible by 50)

New Elevation 1500 meters

Button 2 - Use Last Elevation - SAME

The SAME button always enters a terrain point using the same elevation as the last point. This is true even if the previous elevation is not exactly divisible by the contour interval.

Example - Contour Interval = 50 meters

Last Elevation 1500 meters (1500 is exactly divisible by 50)

New Elevation 1500 meters

Example - Contour Interval = 50 meters

Last Elevation 1521 meters (1521 is not exactly divisible by 50)

New Elevation 1521 meters

Initial preparations

Verify the following settings in the measurements dialog box:

System

Select the same units (miles-feet or km-meters) as the contours on the topographic map which will be used to digitize the profile.

Scale Units

Select the same units (inches or centimeters) that were used to configure the digitizing tablet.

Map Scale

Select the scale of the topographic map which will be used to digitize the profile.

Any errors in the above settings will result in a terrain profile with wrong distances or elevations. This can only be corrected by totally redigitizing the profile.

Locate the sites and draw a pencil line between the two sites to mark the path profile. Note that the profile can span any number of maps.

Attach the topographic map to the digitizing tablet using removable tape.

Digitizing procedure

- Enter the first elevation in the terrain data entry form. This is the ground elevation above sea level at Site 1. This elevation must be taken from the map.
- Press the F9 key to enable the digitizer. You will be prompted to enter the contour interval.
- Place the cursor on the starting point (Site 1) and press the SET REF button. All distances will be referenced to this point.
- Move the cursor to the first contour interval and press the UP, DOWN or SAME button as applicable. The distance-elevation is automatically entered into the terrain data entry form. Continue this process until the end of the profile is reached. After the second point has been entered, the profile will be displayed as data entry proceeds.
- Press the F9 key to exit the digitizing mode and return to normal data entry and editing. If you return to the digitizing mode, the same reference point will be in effect.
- Note that the reference point can be changed at any time during the digitizing process. If the terrain profile traverses several topographic maps, it will be necessary to re-establish a new reference point at the start of each map.

Sixteen button cursor

The following additional button functions are available using a sixteen button digitizing cursor.

- Button 5 UP_1/2 - up one half contour interval
- Button 6 SAME - same as last contour
- Button 7 DOWN_1/2 - down one half contour interval
- Button 8 Set the ground type of the last point to fresh water
- Button 12 Set the ground type of the last point to salt water
- Button 13 Enter a spot elevation
- Button 14 Enter the last spot elevation

Button 16 toggles the digitizing mode between the point /line mode and the continuous mode. The program must operate in the point /line mode and this toggle action cannot be disabled. Therefore, button 16 must not be pressed while digitizing a profile.

Switch settings

This section lists the switch settings required to operate the program with a GTCO Digi-Pad 5 compatible digitizing tablet. The shaded areas represent the required switch settings.

Table 1: Switch 1 Settings (GTCO Digi-Pad 5)

	BAUD RATE					
	300	600	1200	2400	4800	9600
Switch S1-1	OFF	ON	ON	ON	OFF	OFF
Switch S1-2	OFF	OFF	ON	OFF	OFF	OFF
Switch S1-3	ON	ON	ON	OFF	OFF	ON
Switch S1-4	OFF	OFF	OFF	ON	ON	ON
	Switch OFF			Switch ON		
Switch S1-5	Parity Off			Parity On		
Switch S1-6	Parity Odd			Parity Even		

Switch S1-7	1 Stop Bit	2 Stop Bits
Switch S1-8	7 Data Bits	8 Data Bits

Table 2: Switch 2 Settings (GTCO Digi-Pad 5)

<table>
<tr><td></td><td colspan="2">Switch OFF</td><td colspan="2">Switch ON</td></tr>
<tr><td>Switch S2-1</td><td colspan="2">No Pushbutton Code</td><td colspan="2">Include Pushbutton Code</td></tr>
<tr><td>Switch S2-2</td><td colspan="2">No Space</td><td colspan="2">Include Space (ASCII)</td></tr>
<tr><td>Switch S2-3</td><td colspan="2">No Carriage Return</td><td colspan="2">Include Carriage Return (ASCII)</td></tr>
<tr><td>Switch S2-4</td><td colspan="2">No Line Feed</td><td colspan="2">Include Line Feed (ASCII)</td></tr>
<tr><td>Switch S2-5</td><td colspan="2">Low Res ASCII if S3-7 is OFF
Low Res Binary if S3-7 is ON</td><td colspan="2">High Res ASCII if S3-7 is OFF
High Res Binary if S3-7 is ON</td></tr>
<tr><td></td><td colspan="3">Active Serial Port</td><td rowspan="2">GPIB PORT</td></tr>
<tr><td></td><td>A and B</td><td>A Only</td><td>B Only</td></tr>
<tr><td>Switch S2-6</td><td>OFF</td><td>ON</td><td>OFF</td><td>ON</td></tr>
<tr><td>Switch S2-7</td><td>OFF</td><td>OFF</td><td>ON</td><td>ON</td></tr>
<tr><td></td><td colspan="2">Switch OFF</td><td colspan="2">Switch ON</td></tr>
<tr><td>Switch S2-8</td><td colspan="2">Alarm Disabled</td><td colspan="2">Alarm Enabled</td></tr>
</table>

Table 3: Switch 3 Settings (GTCO Digi-Pad 5)

	Switch OFF	Switch ON

Switch S3-1	Not Used		Not Used	
	Rate - Coordinates / Second			Incremental Mode
	12	100	200	
Switch S3-2	OFF	ON	OFF	ON
Switch S3-3	OFF	OFF	ON	ON
	Switch OFF		Switch ON	
Switch S3-4	Point - Line Mode		Continuous Mode	
Switch S3-5	Stylus 4B or 5B Cursor		16 Button Cursor	
Switch S3-6	Inch Scale		Metric Scale	
Switch S3-7	ASCII Formats		Binary Formats	
>Switch S3-8	No Hardware Flow Control		Hardware Flow Enabled	

Convert text file

A standard utility is used to convert a text file of distance and elevations into a path profile. The same utility is used in other parts of the program. Select *Convert Text File* and load the text file. The procedure is sequentially organized and is summarized below.

- Select the data format - either a fixed width or a delimited (separated by commas, spaces..) format
- set the starting line for the conversion
- Select the delimiter and verify that the columns are correctly set
- Identify the column type. Click on each column in turn to select it and then select the column identifier (distance, elevation or structure)
- Specify the distance and elevation units.
- Import the file

Overview

You need to know

- Antenna heights are always meaured from ground level even if a building has been specified at the end of a path
- Antenna heights are measured in feet or meters as specified on the units box on the status. To change the units at any time, click on the units box. This changes the units throughout the progam
- Any changes in the antenna heights are not finalized until, the wrench button or the F2 key is clicked.
- To reset the antenna heights to their original values, click Configure - Set antenna heights to bring up the antenna data entry form and then click the OK button.
- A reflective path with 2nd Fresnel zone clearance will experience signal cancellation. 2nd Fresnel zone clearance is equal to 1.414 F1 or 141.4% of the first Fresnel zone radius.

Microwave radio links

On point to point microwave radio links, the antenna heights are calculated using a set of clearance criteria consisting of the following components:

- the earth bulge for a specified value of the earth radius factor (K)
- a specified percentage of the first Fresnel zone radius
- an arbitrary fixed height
- a minimum clearance value

On a microwave radio link, the first step in the design is to determine the feasibility of the path based on the antenna heights required for free space loss line of sight. The clearance criteria for this condition in a temperate climate is 60% first Fresnel zone at K = 1.33. A 100% first Fresnel zone is often used to provide some margin.

Microwave availability calculations do not usually take into account the outage probability due to diffcaction fading at very low values of K. It has been assumed that the antenna heights are sufficient to provide a usable signal at the lowest expeceted value of K. Traditionally this has been carried out by imposing two sets of clearance criteria. The first criteria establishes free space line of sight heights - the second criteria deals with low values of K. The hightest antenna heights are used, Typical values for this traditional approach are:

- first criteria 100%F1 at K = 4/3
- second criteria 30%F1 at K = 2/3 for heavy route or highest reliability systems
- 60% F1 + 3 meters at K = 1 for light route or medium reliability systems

This analysis can be carried out as two sets of clearance criteria are provided; however this approach is not recommended as exess clearance will usually result and on some path geometry, second Fresnel zone clearance can occur. On short high frequency paths, low values of K have a negligible effect, On long paths, the following procedure is recommended.

Detemine the antenna heights required for 100% first Fresnel zone clearance at the median value of K (4/3 in temperate climates). Calculate the diffraction loss that will occur at the minimum expected value of K. If this loss is greater than 50% of the available fade margin, then increase the antenna heights. This will virtually guarantee neglibible diffraction fading on the path.

On reflective paths, the antenna heights may require adjustments to avoid signal nulls. If space diversity is used to deal with a specular reflection, both the main and diversity antenna heights will be adjusted to avoid simultaneous nulls on the main and diversity antennas.

VHF-UHF radio links

Clearance criteria are not used to determine antenna heights at the lower frequencies. The large Fresnel zone radius would result in prohibitively high towers. As a result, these links generally operate under less than free space line of sight conditions.

In these cases, the link viability is determined by the diffraction loss. This can be carried out in the "antenna heights" or "diffraction loss" design section.

Antenna configurations

Antenna height calculations are based on the selected antenna configuration. Setting the antenna configuration is the first step in a design. If space diversity is an option, then start with the space diversity configuration and calculate the main and diversity heights. You can switch to the non diversity configuration later, if required.

Basic operation

Antenna height tool bar

The antenna heights and configuration are displayed on the tool bar. Each antenna has its own edit box. In the TRDR-TRDR example above there are four edit boxes. The maximum number of antenna height edit boxes is six for the TXRXRD-TXRXDR antenna configuration.

At each site there will be an active antenna. On multiple antenna configurations, e.g. TRDR_TRDR, only one antenna can be active at a site at any time. This would normally be set by the program the main - diversity setting on the tool bar; however, the user can force any antenna combination by checking the "user antcomb" selection. The active antenna is identified by the up down spin control located below the antenna height edit box. The antenna height is changed by clicking the spin control or alternately using the Home-End keys for site 1 and the *Pg Up-Pg Dn* keys for site 2. The height increment is set in the drop down list on the right side of the site 2 antenna box. The range is 0.1 to 25 meters or 1 to 50 feet. The antenna heights can be entered directly in the edit boxes.

Auto - manual operation

When the user clicks the spin control at a site, the active antenna height is changed by the height increment. In the auto mode, the antenna height at the opposite site is automatically calculated. In the manual mode, the opposite site antenna height is not changed. If the user manually enters the antenna height in an edit box, only that antenna height will change for either the auto or manual modes.

Main - diversity and the user antcomb setting

The "user antcomb" selection means that the active antennas at site 1 and site 2 (antenna combination) will be set by the user. Normally this is automatically set by the program. The space diversity antenna configuration TRDR-TRDR is used here as an example to illustrate the behavior of these selections.

With the "user antcomb" selection off, and "main" selected, the active antennas are set to the TR main antennas and the display is formatted using the main clearance criteria. Both TR antennas can be set in this display using the methods described above. Once this is complete, the "divr" is selected. The active antennas are switched to the DR diversity antennas and the display is reformatted using the diversity clearance criteria. In this condition, the main TR heights are fixed and the diversity antenna heights are independently adjusted to meet the clearance criteria. The "optimize" button or F9 key can also be used to set the diversity antenna heights.

With the "user antcomb" selection on, the user must select both the active antenna at each site and the clearance criteria. Click on the antenna height edit box to set the active antenna. The "user antcomb" option was introduced to analyze the path between the two diversity antennas on some radio equipment protection schemes.

On single antenna systems, e.g. TR-TR, the "main - divr" is locked on main when the "user antcomb is off. If the user "ant comb" is on, then the "main - div" selection actually sets the clearance criteria and reformats the display. If the main clearance criteria was set 100% F1 at K = 1.33 and the diversity clearance criteria was set to 60% F1 K = 1.33, then switching between "main" and "divr" would show the difference between 60% F1 and 100% F1.

Tool bar buttons

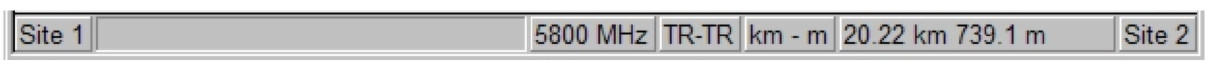
 Optimize antenna heights (F9 key). The algorithm determines the antenna heights at which the sum of the squares is the minimum value.

 Revise antenna heights to the displayed values (F2 key). The antenna heights displayed are temporary values. To restore the original values, select the "Configure - Set antenna heights" menu item and then click the OK button. You will be prompted to revise the antenna heitghs on exiting the antenna heights section.

 Diffraction loss display. Dynamically displays diffraction loss as antenna heights are changed at the minimum value of K and a user defined K. Additional details are given in the Clearance criteria section below.

 Define reflective plane (F6 key to define - F7 key to erase). This feature is common to the Antenna heights, Diffraction and Multipath-reflections sections.

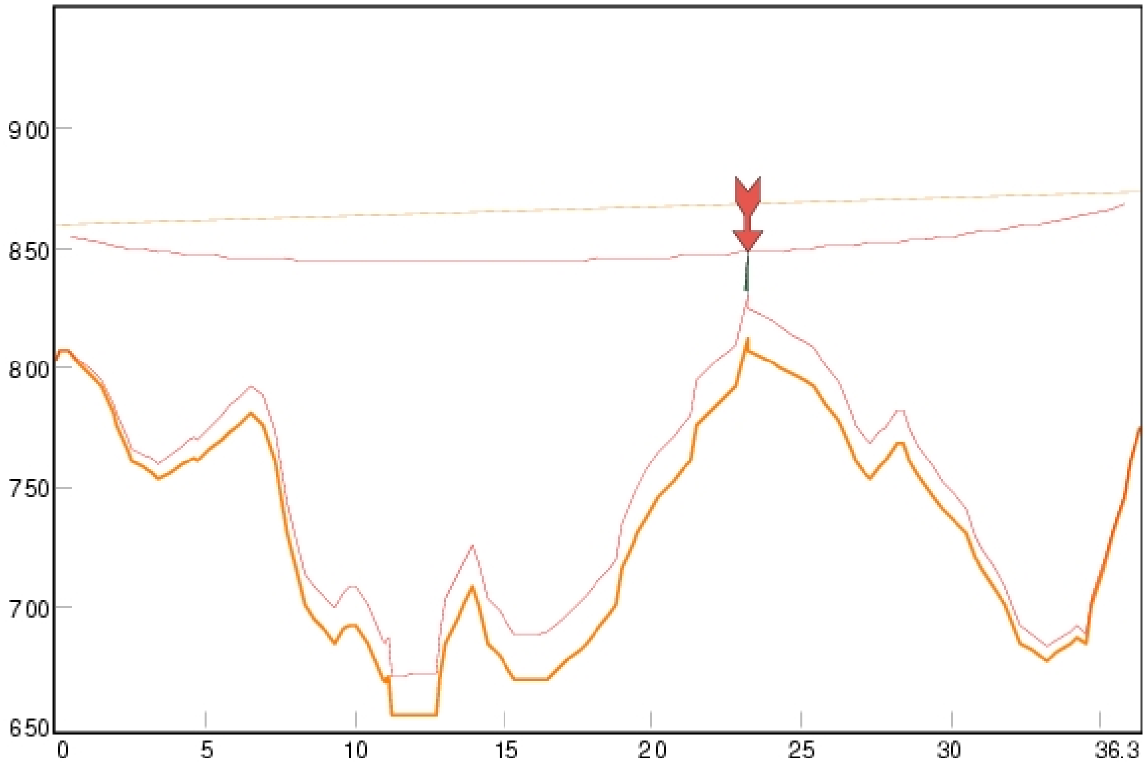
Status bar



Clicking on the status bar provides alternate access to the following data:

- Click **Site names** to access the site data entry form
- Click **Frequency** to access the set clearance criteria data entry form
- Click the **Antenna configuration** to change the antenna configuration
- Click **Units** to toggle the units between metric and miles - feet
- Click the **Arrow location** to access the excess clearance display

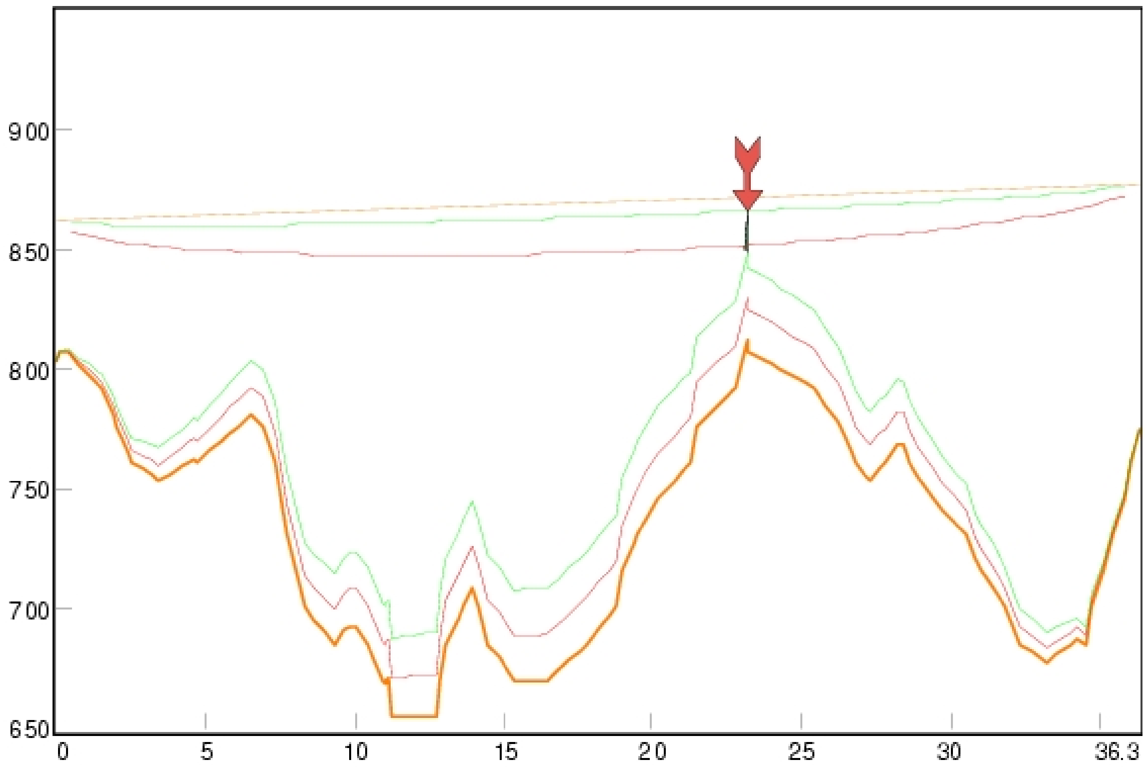
Antenna height display



The antenna height screen display shown above represents a clearance criteria of 100% F1 at K = 4/3. The flat earth profile is shown with a diagonal fill. The profile above this is derived by adding the earth curvature for K. If the clearance criteria includes a fixed height, then this fixed height is added to the upper profile. This would be evident at the end points where the elevation difference between the two profiles would equal the fixed height. The Fresnel zone reference is drawn between the two antenna heights. For clarity structures are only shown on the upper profile. In this representation, the clearance criteria is met if the Fresnel zone line is above or equal to the upper profile.

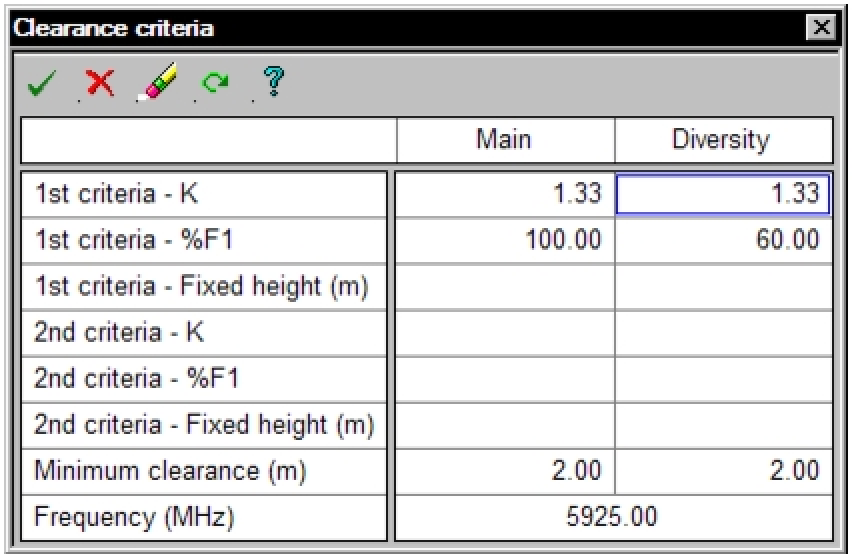
An arrow is located on the upper profile display. Its location is controlled with the left and right cursor keys and the left mouse button. Each time an antenna height calculation is made, the arrow is moved to the critical point on the display if one exists. A point on the profile which exactly meets the clearance criteria (zero excess clearance) is referred to as the critical point.

In the drawing below, a second clearance criteria of 30% F1 at K = 2/3 has been added. The display now has two profiles above the flat earth profile; the lower one representing K = 4/ 3 and the upper on K = 2/3. Similarly two Fresnel zone references at 100% F1 and 30% F1 are shown. In the "auto" calculation mode, the program will determine the controlling criteria. In the example below, the second clearance criteria (30% F1 at K= 2/3 is the controlling criteria).



A special case arises for the antenna configurations TXRX_TXRX and TXRXDR_TXRXDR where separate antennas are used for transmit and receive. Both the TX - RX and RX - TX antenna combinations are simultaneously displayed. Only one combination is active at any time. The active combination is drawn in red and the inactive in blue. To switch between the two, double click the left mouse button on the inactive line.

Set clearance criteria



Clearance criteria

	Main	Diversity
1st criteria - K	1.33	1.33
1st criteria - %F1	100.00	60.00
1st criteria - Fixed height (m)		
2nd criteria - K		
2nd criteria - %F1		
2nd criteria - Fixed height (m)		
Minimum clearance (m)	2.00	2.00
Frequency (MHz)	5925.00	

Select Operations - Set Clearance Criteria to bring up the clearance criteria data entry form. The format shown on the right consists of two sets of clearance criteria for both the main and diversity antennas. The format will depend on the antenna configuration and the application type as follows:

- the diversity antenna configuration is always available when the "user antcomb" selection is on; otherwise, it is available only with diversity antenna configurations
- the second clearance criteria is not available for land mobile applications

Clearance criteria is expressed as the sum of the following components:

- earth curvature for a specified value of K
- percent of the first Fresnel zone radius
- an arbitrary fixed height
- a minimum clearance value - In the immediate foreground of an antenna the value of K and the first Fresnel zone approach a zero value. If the sum of the earth curvature, Fresnel zone

radius and fixed height is less than the specified minimum clearance, then this minimum value will be used

The minimum clearance criteria for free space loss conditions is 60% F1 at K=4/3.

If two sets of clearance criteria are specified, the clearance is taken as the greater of the two criteria. Note that each set of criteria may control the clearance over different ranges of the profile.

Second Fresnel zone (F2) clearance at the median value of K can result under certain conditions. If the terrain is reflective, the addition of the main and reflected signals will produce a signal null. The Multipath - Reflections design section can be used to check for this condition. Several conditions which can result in second Fresnel zone clearance are given below:

- F2 clearance can occur when two sets of clearance criteria are specified. In particular, the classic heavy route criteria, 100% F1 at K = 4/3 and 30% F1 at K = 2/3, can produce F2 clearance on longer paths where the 30% F1 at K = 2/3 criteria controls the clearance in the central part of the profile.
- Using the fixed height to account for future development or tree growth.
- The addition of trees on the profile as a safety factor; when in fact, the actual tree cover does not exist or is sufficiently sparse to be transparent.

Changing antenna heights

The antenna heights displayed on the screen and the tool bar are temporary variables. To reset the antenna heights to their initial values, select Configure - Antenna Heights on the menu bar to bring up the antenna heights data entry form and then select OK. If Cancel is selected the displayed antenna heights do not change.

The temporary display antenna heights are set to the design values by either of the following:

- Click the wrench button on the tool bar.
- Press the F2 key.

You will be prompted to revise the antenna heights when you leave the Antenna Heights module if there have been any changes.

Optimizing antenna heights

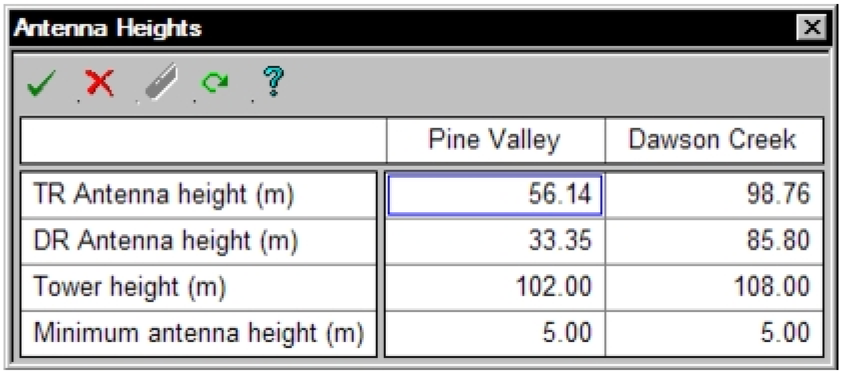
An algorithm is provided to optimize the **main** antenna heights by determining the minimum value of the sum of the squares of the antenna heights. This definition of optimum assumes that tower costs are proportional to the square of the tower height. This optimization algorithm is invoked by either of the following methods:

- Click the calculator button on the tool bar.
- Press the F9 key.

The algorithm may terminate if the antenna heights are controlled by more than one critical point or an antenna height is limited by its minimum value.

If a diversity antenna combination is selected, the optimization simply calculates the minimum diversity antenna heights based on the terrain.

Set antenna heights


Antenna Heights

	Pine Valley	Dawson Creek
TR Antenna height (m)	56.14	98.76
DR Antenna height (m)	33.35	85.80
Tower height (m)	102.00	108.00
Minimum antenna height (m)	5.00	5.00

Select Configure - Set antenna heights to bring up the antenna heights data entry form. This form can be accessed from any design section in the program.

The form will be formatted for the current antenna configuration.

Antenna heights are measured in meters or feet as specified on the status bar and are always measured above ground level even if the antenna is located on a building.

If this form is accessed from the Antenna heights design section, the following operations apply:

- If the form is closed with the OK button, the antenna height display will be reset to the values in the Antenna heights data entry form
- The minimum antenna height simply means that if a calculated antenna height is less than the specified minimum value, then the antenna height is set to the minimum value.
- If an antenna height exceeds the tower height a warning message is issued and the value is displayed in red on the tool bar. The height is **not** limited to the tower height.

The Diffraction and Multipath-Reflections design sections provide calculations as a function of antenna height. The default range is the minimum height and the tower height. These should be entered to facilitate these calculations. A default minimum antenna height of 5 meters is used.

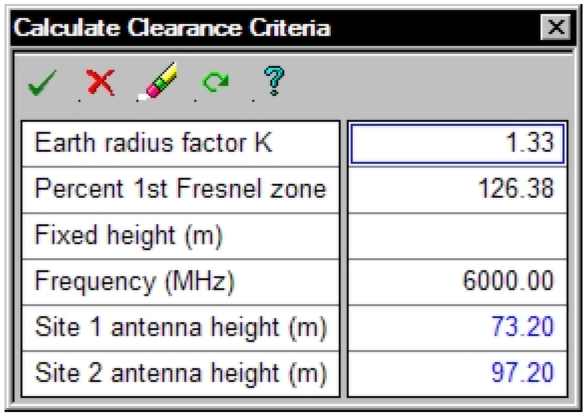
Display zoom feature

Any portion of the antenna height display can be selected as a full screen display. This is particularly useful on profiles which contain "near in" obstructions or buildings or when two sets of clearance criteria are used.

Move the mouse cursor to one corner of the area to be selected. Hold down the Ctrl key and press the left mouse button. Drag the cursor to the opposite corner. Release the mouse button and the selected area will be scaled to fill the window.

To reset the display, hold down the Ctrl key and click the right mouse button.

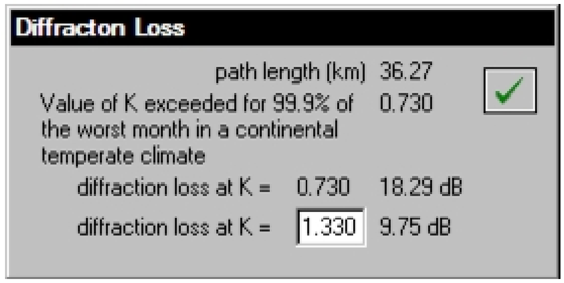
Calculating clearance criteria



When analysing an existing path, you can determine the clearance criteria used in the design. Select Operations - Calculate clearance criteria from the menu bar. If the antenna configuration supports more than one antenna combination, you will be prompted to select an antenna combination.

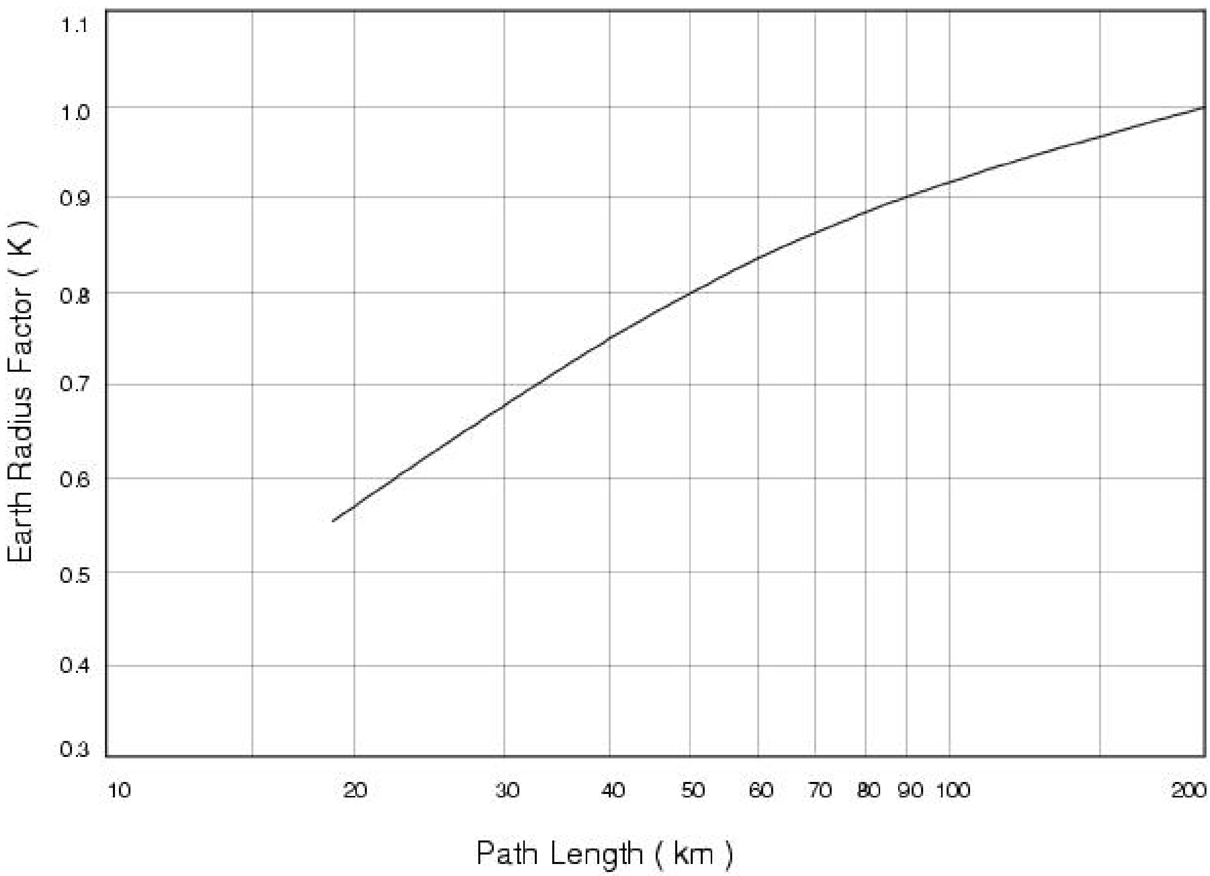
If a percent first Fresnel zone entry is made, the earth radius factor (K) will be calculated. For all other entries (K, fixed height and frequency), the percent first Fresnel zone is calculated.

Diffraction loss



In microwave applications, the diffraction loss at the minimum expected value of K is a key factor in setting antenna heights. In land mobile applications, the diffraction loss at the median value of K is the determining factor.

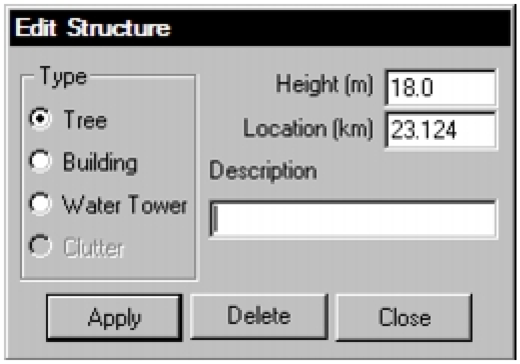
Select Operations - Show diffraction loss or click the diffraction loss button on the tool bar to bring up a dynamic diffraction loss display. The minimum expected value of K for temperate climates is calculated as per ITU-R P.530 and shown in Figure The diffraction loss calculations are automatically updated as the antenna heights are changed.



This feature should be used instead of two sets of clearance criteria to ensure that an outage will not occur due to diffraction fading a low values of K. The following guidelines are suggested

- Calculate the antenna heights using a nominal clearance criteria of 100% F1 @ K = 4/3.
- Calculate the thermal fade margin of the path in the Transmission Analysis section.
- If required increase the antenna heights so that the diffraction loss at the minimum value of K does not exceed 50% or the thermal fade margin

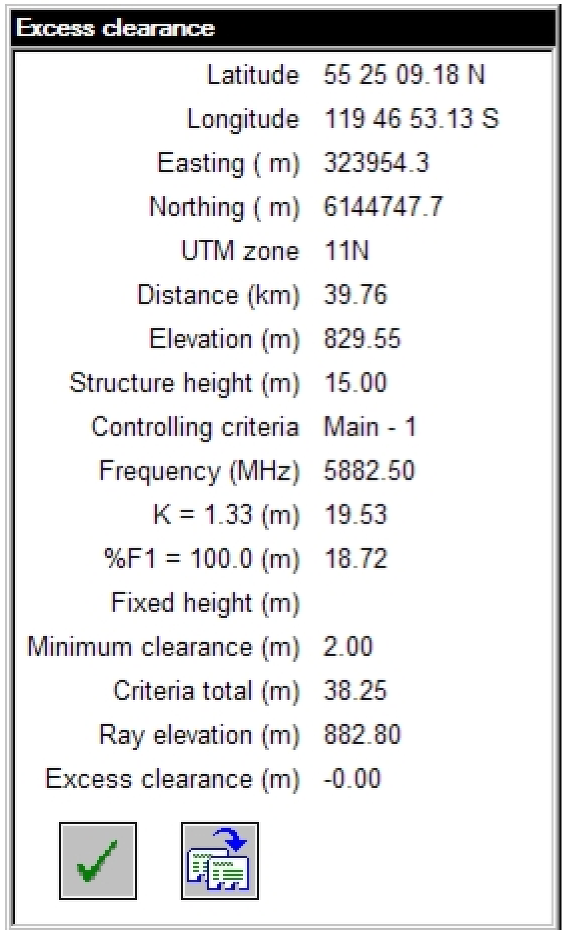
Edit structure



Structures are normally added to the profile in the Terrain Data design section; however, the location of the critical points is not always evident here. Structures can be added, edited or moved in the Antenna heights display. The procedure is limited to a single structure. Ranges and off path structures are not allowed here.

Select Operations - Edit structure on the menu bar. Place the arrow at the location of a new structure or on an existing structure to edit it. Select the type of structure, enter the height and click the "Apply" button.

Excess clearance display



To view the clearance at a point on the display, move the arrow to the point and then bring up the excess clearance display with any of the following commands:

- Press the Ins key.
- Left mouse button click in the status bar location box.
- Right mouse button click anywhere on the display.

The display shows the three components of the controlling clearance criteria at the selected point. If there is an off path structure at the point, the display also shows the horizontal clearance as a percent of the first Fresnel zone radius. The excess clearance is defined as:

excess clearance = ray elevation - (ground elevation + structure height + criteria total)

Reports

Clearance report

The clearance report provides a listing of all points on the profile whose clearance is within a specified tolerance of the clearance criteria. When the clearance report is selected from the report menu, the user enters a tolerance in meters or feet, depending on the measurement system in effect.

At each point on the profile, the elevation difference between the upper profile and the line between the antennas is calculated. If this value is less than the specified tolerance, the value is printed. Since the upper profile represents the clearance criteria on top of the flat earth profile, the elevation difference indicates how close the point is to the clearance criteria.

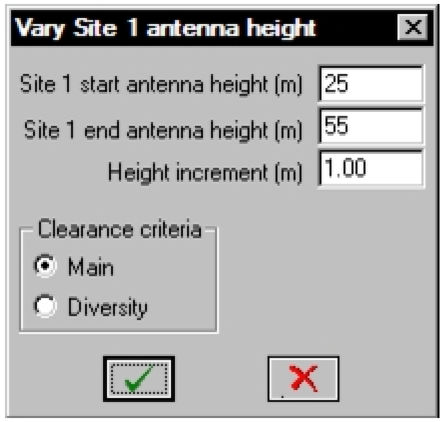
A zero value means that the point exactly meets the clearance criteria. A positive value means that the point is above the clearance criteria and a negative value means the point does not meet the clearance criteria.

The clearance report also calculates the horizontal clearance to any off path structures on the profile. This clearance is expressed as a clearance to first Fresnel zone ratio.

Orientation report

The orientation report lists the horizontal and vertical angles required for antenna orientation. The report also lists the vertical orientation angle errors that occur at extreme values of K.

Antenna height tradeoff report



This report varies one antenna height and calculates the antenna height at the other site to meet the clearance criteria. This report is useful in those cases where the final antenna heights may be changed during construction and the antenna heights can be adjusted accordingly.

Enter the start and end antenna heights.

Select either the main or diversity clearance criteria.

Click the OK button to generate the report.

Clearance criteria

Antenna heights are calculated to meet specified clearance criteria. A clearance criteria is defined as the sum of the following three components:

- the earth bulge for a specified value of the earth radius factor, K
- a percentage of the first Fresnel Zone radius
- an arbitrary fixed height

In order to correctly display the clearance criteria, additional terrain points are inserted into the input data so that the minimum spacing between points is one percent of the path length. Linear interpolation is used to add these points. At each point, the clearance criteria, L, is calculated as shown in Equation (1) and added to the profile elevation.

$$
\begin{aligned}
L &= L_K + L_F + L_{FH} \\
L_K &= \frac{d_1 \cdot (d - d_1)}{12.75 \cdot K} \\
L_{Fz} &= 17.3 \cdot Fz \sqrt{\frac{d_1 \cdot (d - d_1)}{f_{GHz} \cdot d}}
\end{aligned}
\qquad (1)
$$

d path length in kilometers

d_1 distance to the point from Site 1 in kilometers

K earth radius factor

Fz fraction of the first Fresnel zone radius

L_{FH} fixed height component in meters

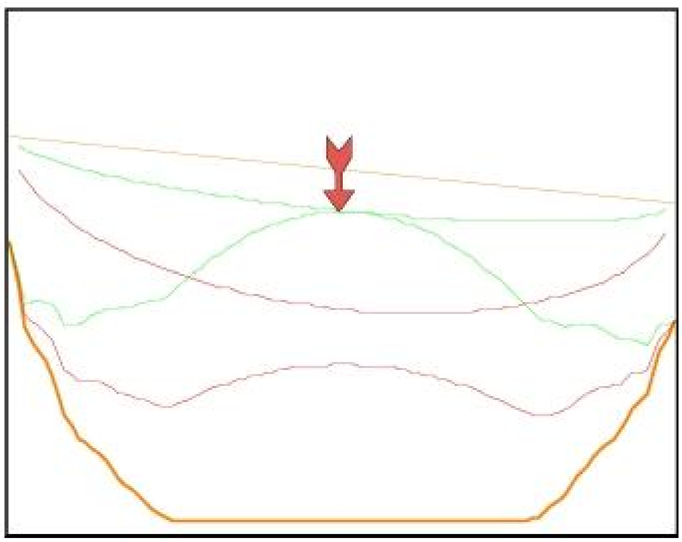
The clearance is met when the Fresnel zone reference is above the profile adjusted for K.

Traditionally, the overall clearance criteria is specified in terms of two independent sets of parameters. At each point on the profile, the clearance criteria is calculated for each set of parameters as in Equation (1). The greater of two values is added to the terrain elevation to construct the clearance criteria curve.

Antenna height considerations

In general, clearance criteria are chosen to meet the following performance objectives:

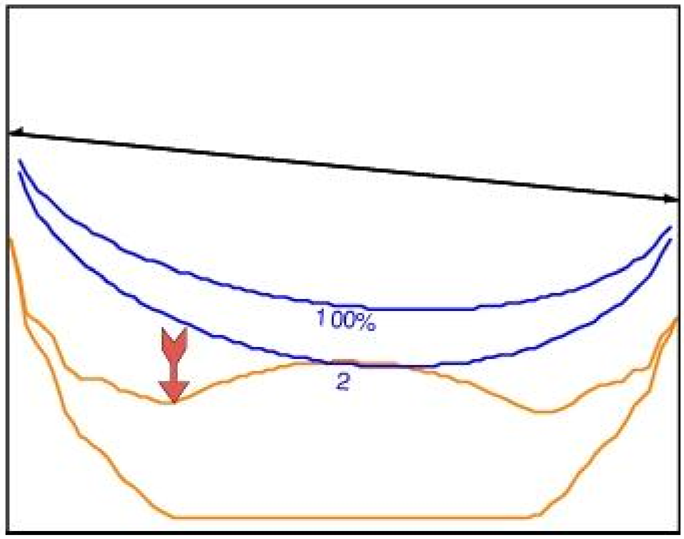
- To achieve free space propagation conditions at the median value of K.
- To control the additional loss which can occur at the lowest expected value of K.



The first objective is relatively straightforward. The minimum clearance for free space loss conditions is 60% of the first Fresnel zone radius. The second objective, unfortunately, is more complex and can lead to excessive tower heights, severe multipath fading and fading due to specular reflections.

Consider the following example of a 60.3 kilometer path designed with the following common clearance criteria, usually referred to as the heavy route:

100% F1 at K = 4/3 and 30% F1 atK = 2/3



The frequency is 1925 MHz. The terrain profile used in this example is included in the Examples section. The antenna centerline calculation is shown in Figure (1).

With the specified clearance criteria, the path will certainly not suffer from serious diffraction fading; however, consider the operation at the median value of K.

Figure (1) shows the second Fresnel zone reference on the path using an earth radius factor of K = 4/3. This display is available in the Diffraction Analysis module. The path has second Fresnel zone clearance in the central region. If the path is actually reflective in this area, then the reflected signal will cancel the direct path signal. This will result in significant fading during average propagation conditions.

It is not possible to specify a rigid set of clearance criteria which will work under all conditions on all paths. The clearance criteria might be better stated as "the minimum antenna heights which achieve the required propagation reliability". This is certainly true from a tower cost viewpoint.

To achieve minimum antenna heights, the following additional considerations are taken into account:

- Multipath fading is most severe at very high or negative values of K and is negligible at low values of K.

In general, multipath fading tends to increase with increasing tower heights and path clearance. Therefore, paths with a minimum clearance would be less subject to multipath fading.

Overview

The Multipath - Reflections design section deals with signal impairment due to specular reflections and ducting. It is important to note that these are not part of the mulipath fading analysis carried out in the Transmission analysis section. The statistical analysis of multipath fading specifically exclude specular reflections and ducting.

Ray tracing techniques under constant and variable refractivity gradients and reflective planes are employed in the analysis

You need to know

- The multipath-reflections

  design section is only applicable to line of sight paths.

- The ray trace display

  transmits from the left side to the right side. Reverse the profile to show the opposite ray trace direction.

- Start the analysis with

  a constant gradient ray trace to display the reflective characteristics or the path. If the path geometry does not allow a reflected signal to reach the site 2 antenna height range, then a specular reflection cannot exist on this path and no further reflection analysis is required.

- When a reflective plane

  is defined, the profile is effectively replaced with the plane and

  the effective antenna heights. If the path does not support a specular reflection as determined above, then any further analysis using this plane will not be valid.

- Use the variable ray trace

  display to analyze the path for surface and elevated ducting. The

  M profiles of the duct are automatically determined from the site

  coordinates using the ITU 453.8 database for surface and elevated

  ducts.

- Receive signal as a function

  of antenna heights or the earth radius factor can be carried out using either ray tracing or a reflective plane definition. The latter reduces the path geometry to a single specular reflection. Ray tracing considers all possible path reflections. On a flat path the two methods are

  equivalent.

Receive signal as a function of frequency or tide levels can only be carried out using a reflective plane.

Constant gradient ray trace

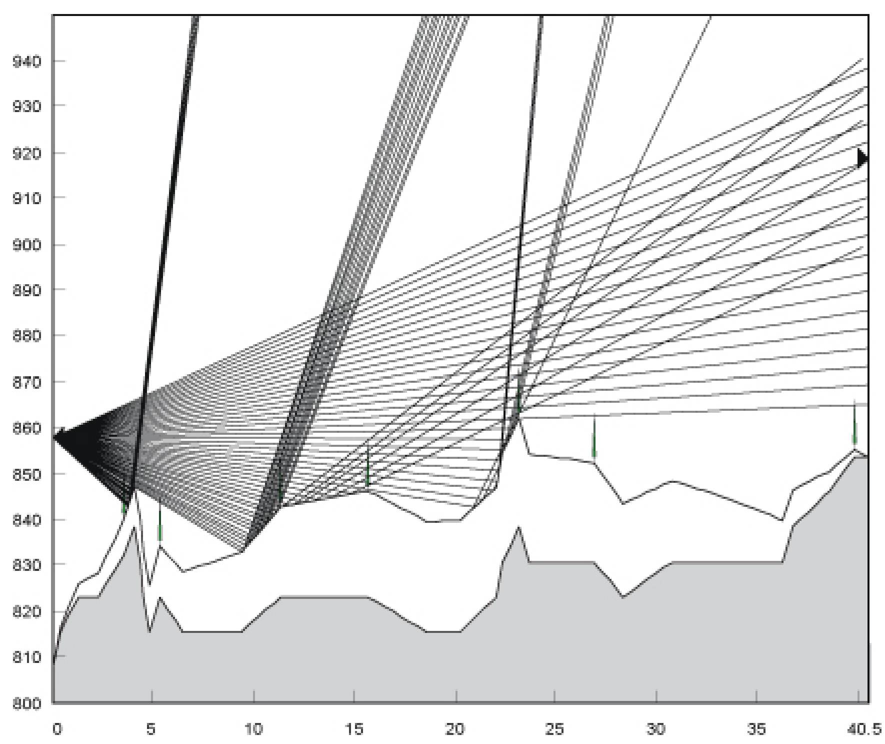
The constant gradient ray trace is used to determine the reflective

characteristics of the path. All rays are straight lines in this display.

The first ray starts at the end antenna height specified in the Constant Gradient dialog box and continues in a clockwise direction until it covers 80 percent of the path. The angle between the rays is determined by the program. Note that not all rays are displayed on the screen; otherwise, the density would obscure the behavior of the ray trace. Once the ray

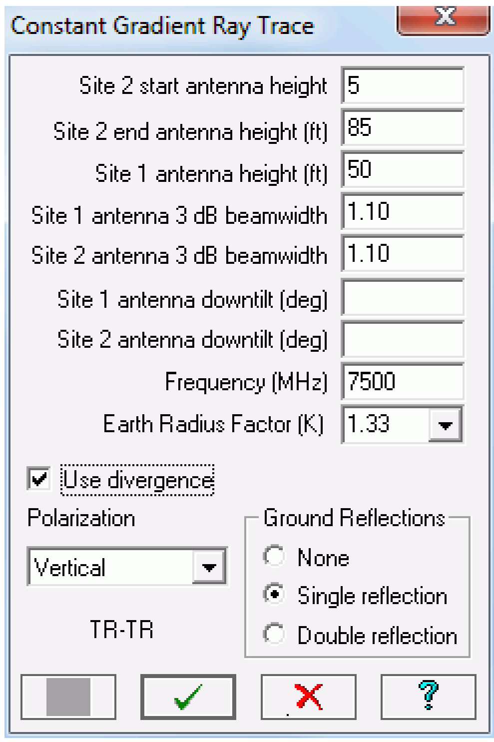
trace is complete, the site 2 receive signal as a function of antenna

height can be displayed.



Constant gradient parameters

Select *Method - Constant gradient ray trace*. Complete the entries and options and Click the green check button to generate the ray trace. The following entries are required:



Site 2 start and end antenna heights

The default start antenna height is the minimum antenna height. The default end antenna height is the tower height. The first ray will terminate at the end antenna height.

Site 1 antenna height

This is the point of origin of the ray trace. If the antenna configuration supports multiple antenna combinations, click the Antenna Combination button to set the Site 1 antenna height to the main or diversity height. Note that the antenna heights are local variables in the Multipath module and any changes made to the antenna heights here are lost when the Multipath module is closed.

Antenna 3 dB beam widths

These are the total 3 dB beam widths (both sides of the main lobe) of the Site 1 and Site 2 antennas. The beam widths affect the amplitude of reflected rays received at Site 2 due to the antenna discrimination.

Antenna downtilt

On paths which can support a specular reflection, it is common practice to tilt the antennas slightly upwards. This is a compromise setting which provides an increase in the discrimination to the reflection point at the expense of a reduction in receive signal. The depth of the signal nulls is a measure of the success of this adjustment. Note that a positive value of antenna downtilt, tilts the antenna downward. Use a negative value to tilt the antenna upwards.

Frequency

Enter the frequency in MHz. This is the global value of frequency and will be changed throughout the program.

Earth radius factor (K)

This sets the constant gradient for the display. The screen display shows the flat earth profile and an upper profile derived from the specified earth radius factor.

Use divergence

Divergence defined as the scattering of reflected rays due to the curvature of the earth. The effect can seen on the constant gradient ray trace example display above. Note that the density of the direct rays arriving at Site 2 (number of rays per unit of elevation) is greater than the reflected ray density.

Including the ray densities, effectively reduces the reflected energy at low values of K and has no effect at high values of K.

Polarization

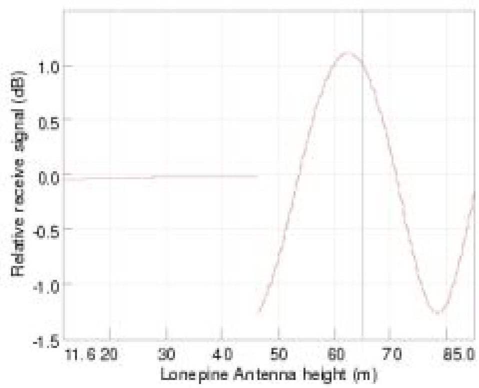
Select either horizontal or vertical polarization. Polarization is a global variable throughout the program. The polarization affects the amplitude of the reflected rays.

Ground Reflections

The maximum allowable number of ground reflections is set as desired to improve the readability of the display. The "None" selection serves no purpose in a constant gradient ray trace. Reflections can also be selectively inhibited along the profile as described in the following paragraph.

Site 2 height gain

Once the constant gradient ray trace is complete, this function provides a quick check of the site 2 antenna height with respect to the possible signal nulls. Select *Method - Site 2 height gain*.



As each ray is traced, the length traversed along the path is calculated. If ground contact occurs, the complex reflection coefficient is calculated based on the grazing angle, frequency, polarization, and the type of terrain. When the ray arrives at Site 2, the angle of arrival and the elevation are recorded. A record for each ray is created containing the following data:

- number
- classification
  - 0 - direct path
  - 1- single ground reflection
  - 2 - double ground reflection
- arrival angle at Site 2
- elevation at Site 2
- amplitude at Site 2. For a direct path, the amplitude is determined by the Site 1 antenna 3 dB beam width. In the case of a reflected wave, the amplitude is reduced by the reflection coefficient.
- path length traversed by the ray.
- the additional delay produced by a ground reflection.

The ray records are separated into subsets, according to the ray classification and the angle of arrival. For direct path rays, the angle of arrival is not considered as the Site 2 antenna is assumed to be exactly oriented at the Site 1 antenna.

Range data records are developed from these subsets by associating sequential ray numbers, in each subset, with an elevation range at Site 2. The result is a series of independent ray records which exist over a certain elevation range at Site 2. Each range data record is examined to determine if the elevation difference between successive rays is consistent and any extreme deviations are discarded.

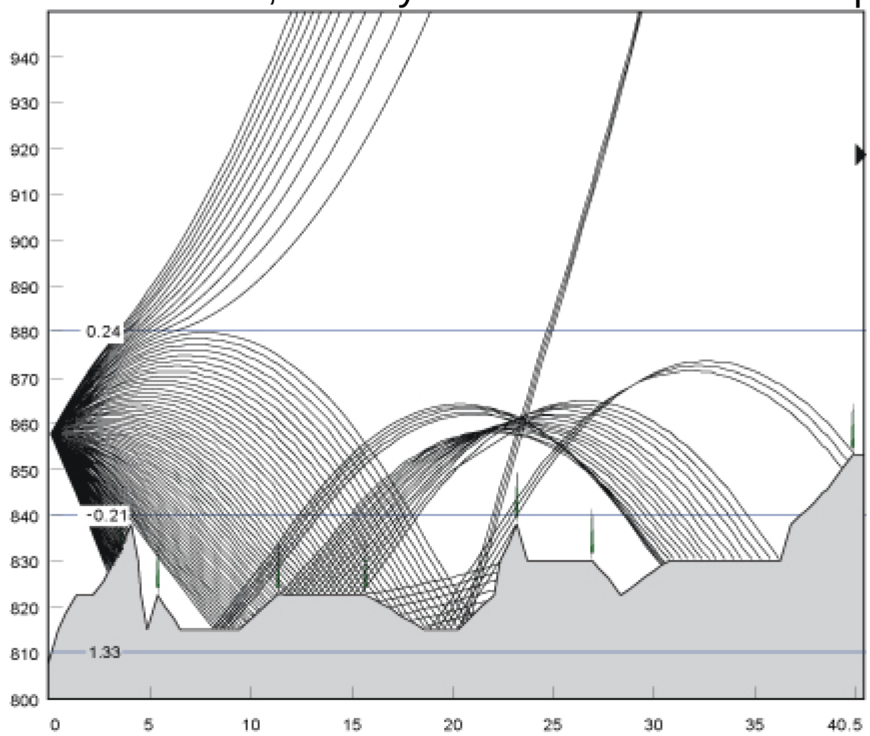
The height gain diagram is developed by calculating the relative receive signal between the start and end antenna heights at the specified height increment.

The magnitude and phase at specific elevations are determined by interpolating the applicable range data records and adding the Site 2 antenna discrimination. The received signal is calculated by the vector addition of these values. The display may show several discontinuities where a different number of rays are used in the vector addition.

No assumptions are made outside of the data ranges. If a given elevation is spanned by a single range, the magnitude is determined by the Site 1 antenna beam width.

Variable gradient ray trace

A number of rays are drawn about a central ray over a user defined angle. The path of the ray is determined by the refractivity gradient versus elevation relationship specified by an M profile. Using M profiles derived from the ITU-R P. 453-8 database for surface and elevated ducts, this ray trace is used to test the path for ducting

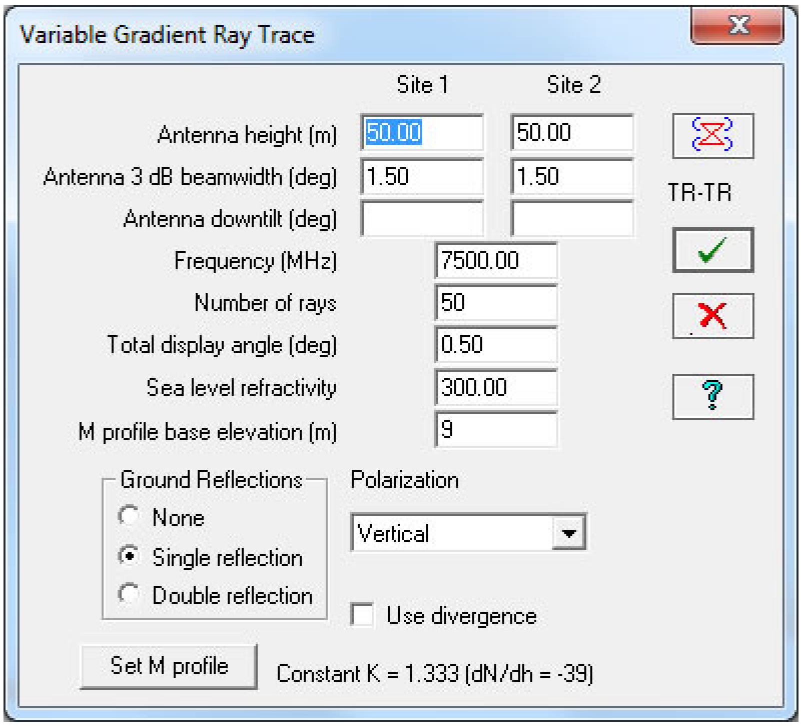


Variable gradient parameters

Select Method - Variable Gradient to bring up the Variable Gradient dialog box. The ray trace will be automatically generated when this dialog is closed.

Antenna down tilt, 3 dB beamwidth, frequency, ground reflections, polarization and divergence are common to the constant and variable gradient ray traces.

The following additional entries are required:



Number of Rays

This is the total number of rays drawn. For example, if 51 rays were specified, then 25 rays would be drawn on each side of a central ray. Some experimentation will be required to produce the desired display.

Total Display Angle

All rays will be contained within the total display angle. For example, suppose that the number of rays has been set to 51, and the total display angle is 0.5 degrees. The ray trace will generate 25 rays in a 0.25 degree segment above the central ray and another 25 rays in the 0.25 degree segment below the central ray. Depending on the path length, some experimentation may be required to produce the desired display.

Sea level refractivity

This parameter determines the antenna orientation and sets the angle of departure of the central ray at site 1. Normally, this is set to a nominal value of 300 N units

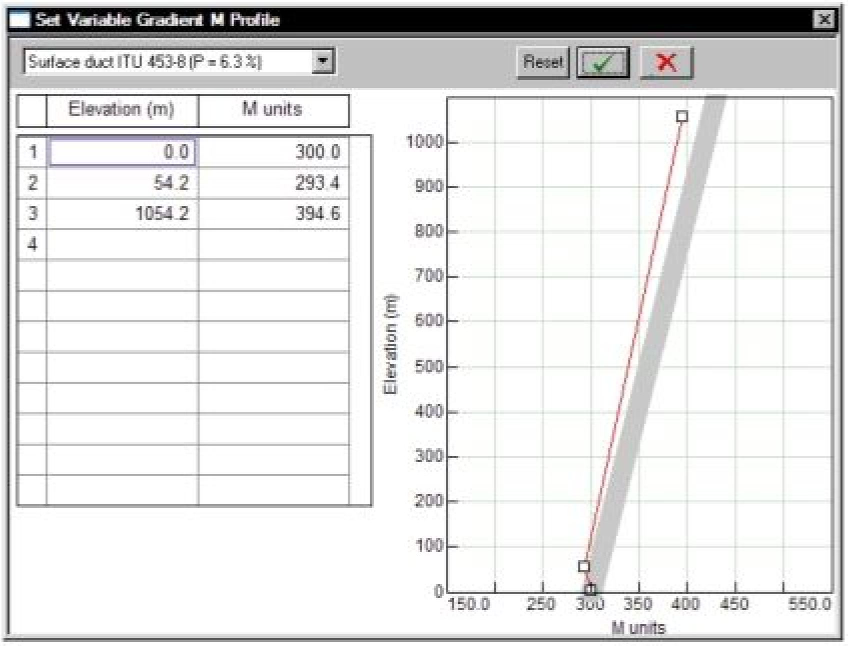
M profile base elevation

This is the start elevation used to draw the M profile. This value is initialized to the reflective plane elevation or the elevation at the mid point of the profile. When the ray trace is on the screen, the base elevation can be changed. Hold the left mouse button down on the box at the bottom of the M profile and raise or lower the profile as required.

Site 1 and site 2 antenna heights

The antenna heights can be directly entered. If the antenna configuration supports multiple combinations, click the Antenna Combination button to select a new combination of main and diversity antennas. Note that the antenna heights are local variables in the Multipath - Reflections design section and any changes made to the antenna heights here are lost when this section is closed.

M profile



Click the Set M profile button to access the M profile definition form. Ducts are described in terms of a modified refractivity or M profile defined as M(h) = N(h) + 157h where N is the refractivity and h is the height above sea level in kilometers. The dropdown list contains the following M profiles:

- Constant K = 1.33 dN/dh = -39 N units / km
- Constant K = 1 dN/dh = 0 N units / km
- Constant K = 0.5 dN/dh = 157 N units / km
- Constant K = infinity dN/dh = -157 N units / km
- Constant K = -0.5 dN/dh = -471 N units / km
- Exponential reference atmosphere
- ITU-R P.453.8 surface and elevated surface ducts
- ITU-R P.453.8 elevated ducts
- User defined M profile

The ITU M profiles are automatically generated based on the site coordinates

Reverse profile

The ray trace starts on the left side of the screen (Site 1). To view ray trace from Site 2, select Operations - Reverse profile. All data including site names, coordinates, antenna heights and the equipment parameters will be switched over

Define reflective plane

A reflective plane must be defined for the following calculations:

- terrain roughness calculation using the Vigants - Barnett multipath

  fade probability algorithm

- grazing angle calculation used in the ITU-R P.530-6 multipath fade

  algorithm

- Specular reflection analysis in the Multipath - Reflections design

  section

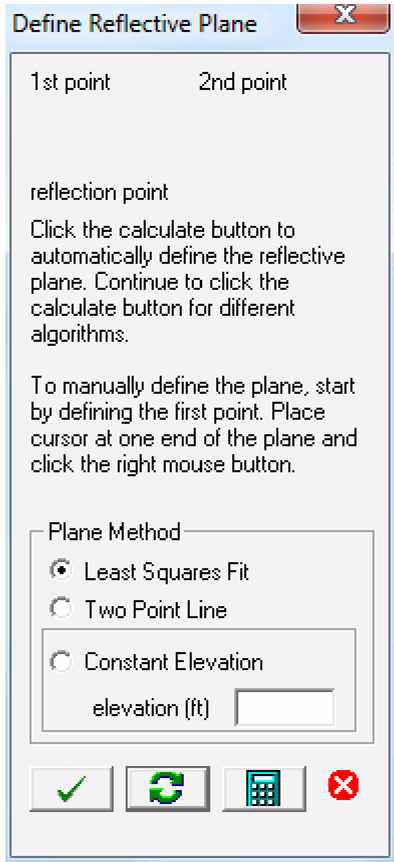
- On line of sight paths with less than 60% first Fresnel zone clearance,

  a reflective plane is used to calculate the diffraction loss using

  two ray optics or the Longley Rice algorithm.

- A reflective plane is used in the antenna heights section to show

  the reflection point location as the antenna heights are changed.



The concept of a reflective plane is only applicable to line of sight

paths and can be considered as the area which is intervisible to the antennas at each end of the path. Select Operations - Define plane to access the

reflective plane dialogue. The plane can be either manually defined or

automatically defined using several different algorithms. Except for a

constant elevation plane, the procedure consists of identifying the end

points of the plane.

Manual reflective plane definition

Three methods are available to manually define a reflective plane

- Least Squares - The plane is derived from a two term least squares

  fit of the form y = ax + b, using 50 uniformly spaced points interpolated over the end points of the reflective plane.

- 2 Point Line - The reflective plane is derived from the two end

  points which define the plane. The reflective plane also takes the

  form y = ax + b.

- Constant Elevation - The plane is drawn at a constant elevation

  (y = Elevation).

To manually define a plane proceed as follows:

- Select the plane method. If an constant elevation is used, enter

  the elevation. This completely defines the plane.

- Place the arrow at one end of the reflective plane and click the

  right mouse button. The arrow will change color to indicate that it

  has been selected. The reset button will cancel the selected point.

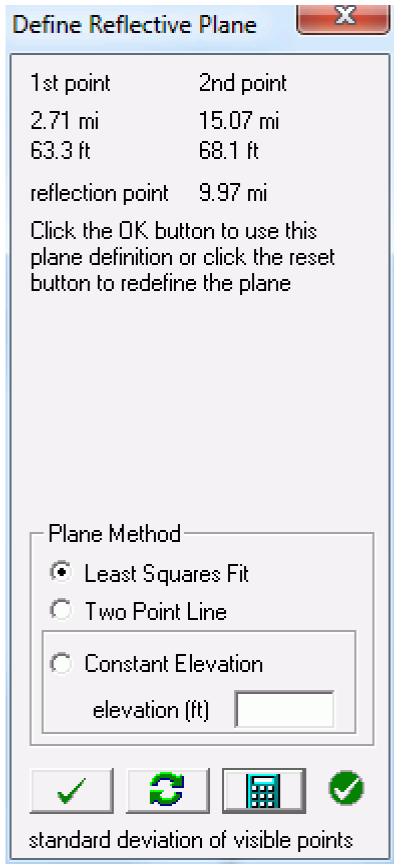
- Place the arrow at the opposite end of the reflective plane and

  click the right mouse button.

- To redefine a plane, click the reset button just repeat the above

  two steps.

- Click the OK button to accept the reflective plane.



Automatic reflective plane definition

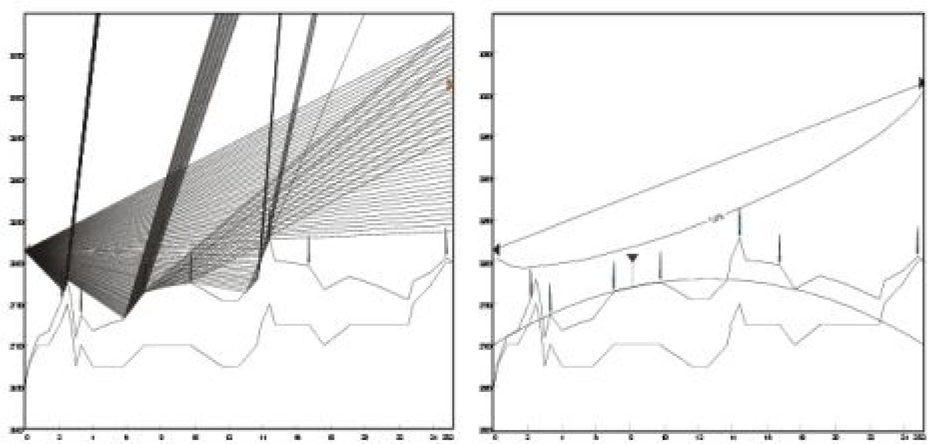
Two automatic algorithms are available for reflective plane definition:

- Standard deviation of visible points. A list of points which are visible to the antennas at each end of the path is generated. The standard deviation and the average of the distance location of the points is calculated. The plane is defined as a least squares fit over the range average plus and minus the standard deviation
- Ray tracing ranges. A ray trace is carried out and depending on

the path geometry, several sections along the path may be identified.

The plane is defined as a least squares fit to the points over this range.

Click the calculate button. The first algorithm will be the standard deviation. Continue to click the calculate button to sequence through the ray tracing versions of the plane.



Error messages

The reflective plane is determined as described above and displayed for the selected value of the earth radius factor. The section between the defined plane end points are drawn as a solid line. The plane is extended to the end points of the profile using dotted lines. The reflection point

location is then calculated and displayed. Effective antenna heights are determined by extending the reflective plane to the ends of the profile.

The effective antenna heights are the heights of the antennas above this

plane.

The following error messages may appear:

- The plane is non line of sight at the specified values of K and

  antenna heights. Select another value of K on the control bar.

- The plane elevation at Site 1 is higher than the antenna height.
- The plane elevation at Site 2 is higher than the antenna height.
- The reflection point is outside the defined limits of the plane.
- The reflection point could not be located. The algorithm failed

  to locate the reflection point. This can occur if the reflection point

  is very close to one of the sites. Increase the antenna heights or

  change the reflective plane.

Reflective plane considerations

On over water paths, or paths which are predominately flat, the selection

of the end points is straightforward. On other paths, some judgment is

required. In many cases, ray tracing in the Multipath - Reflections design section will indicate the extents of the reflection area. In the above

example of a profile with no easily recognizable reflective region, the ray trace shows that reflected signals from the area between 10 and 15

kilometers are directed at the receive antenna. Accordingly, the reflective plane has been defined over that area.

In other cases the following guidelines can be used:

- Draw a 100% first Fresnel zone reference and note the extent of

  the terrain closest to this Fresnel zone reference.

- Place the cursor at the center of this extent and press the Ins

  key to display the terrain point data. Note the clearance to the first

  Fresnel zone ratio (C/F1).

- Using this value as a guide, draw additional Fresnel zone references

  until approximately 50% of the Fresnel zone is below the terrain.

- Define the end points of the reflective plane at the first and

  last intersections of the Fresnel zone reference with the terrain.

- Draw 100% first Fresnel zone references to the reflection point.

  The intersections of the Fresnel zone with the terrain represent the

  area along the profile required to support a specular reflection.

  The end points of the reflective plane should encompass this area.

Inhibit reflections

The ray trace display can be simplified if reflections which have no effect on the receive signal at site 2 are removed in areas.

Reflections can be selectively inhibited over any portion of the profile. Select *Operations-Inhibit reflections* or press the F7 key. The ray trace is cancelled; the arrow appears on the display and its location is displayed on the status bar.

Move the arrow to one end of the segment over which reflections will be inhibited and press the F1 key or the right mouse button. If the first point is selected in error, select *Operations - Cancel Inhibit Reflections*, or press the F8 key . Repeat for the opposite end of the segment.

The profile is redrawn showing a dotted line over the inhibited segment. A ray will not be reflected in this segment in either the constant or variable gradient ray trace modes.

To reset the profile to normal, select *Operations - Reset reflections* or hold down the Ctrl key and press the F7 key.

Change vertical scale

The F11 and F12 keys change the vertical scale of the ray trace drawing as follows"

- F11 - increase vertical scale
- F12 - decrease vertical scale

Variable analysis using a reflective plane

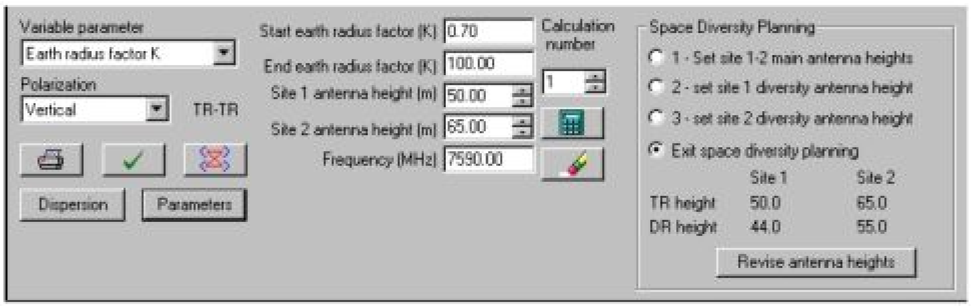
The variations in received signal due to a single specular

reflection are analyzed as a function of antenna heights earth radius factor (K), frequency and tide levels. The analysis is based on a user defined reflective plane and is only valid on line of sight paths with a geometry that will support a specular reflection. The constant gradient ray trace is used to test for this condition. The primary uses of the Reflection module are:

- To determine the receive signal variations due to a specular reflection.
- To set the antenna heights for an odd Fresnel number clearance on paths with excess clearance.
- To determine the optimum vertical antenna spacing when space diversity is used to avoid signal nulls on a reflective path.
- To determine the dispersive characteristics of a path (amplitude and delay of the reflected signal).
- To ensure that a signal null does not occur at the median value of K.
- To evaluate the effects of tilting the antennas vertically to reduce the reflected signal amplitude.

Select *Variable - Analyse* using reflective plane to access the analysis display. If a reflective plane has not been defined, the define plane dialog will appear.

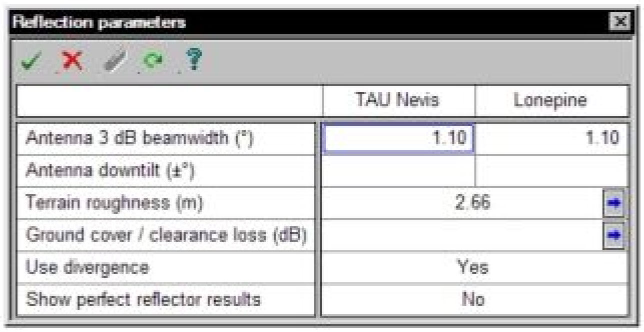
Reflective plane analysis procedure



- Select the variable parameter (antenna heights, earth radius factor, frequency or tide levels)
- Set the calculation number. Four calculations can be displayed for the selected variable parameter.
- Set the polarization
- Enter the start and end values for the variable parameter and the values for the fixed parameters. Then click the calculate button to display the results.

When the variable parameter is set to the earth radius factor, the site 1 and site 2 antenna heights data entry is formatted with an up-down spin control. Set the focus to one of these controls and rotate the mouse wheel. The antenna height is incremented and the results are recalculated and displayed. The effect is to shift the display. This technique is the basis of the optimization procedures for space diversity planning.

Reflection parameters



Click the parameters button to modify the reflection calculations for the parameters in the data entry form on the left. These parameters affect the amplitude of the reflected signal. The relative receive signal variations will be automatically recalculated for the new values of these parameters. The results can be compared with those using only the theoretical reflection coefficient.

The amplitude and delay of the reflected signal can be further analyzed in the Dispersion data entry form.

Antenna beam widths

Depending on the path geometry, the antenna discrimination may reduce the reflected signal amplitude. Enter the total vertical 3 dB beam widths of the antennas. If a zero is entered or the field is left blank, the antenna beam widths will not be used in the calculation.

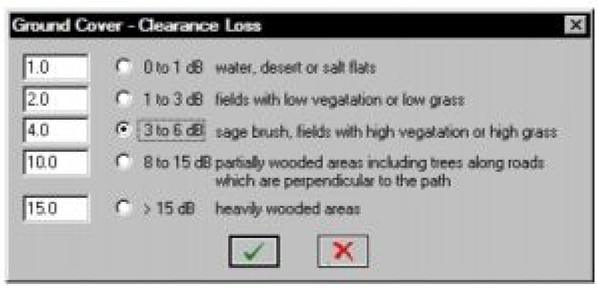
Antenna downtilt

To reduce the null depth produced by a reflected signal, it is common practice to tilt the antennas upwards. This increases the antenna discrimination to the reflection point; however, there will be some loss of received signal due the orientation loss. The antennas are assumed to be oriented at K = 4/3. To tilt an antenna upwards, you must enter a negative value (negative downtilt equals uptilt). If this field is left blank, the antenna downtilt will not be used in the calculation.

Terrain roughness

Terrain roughness can be calculated using the calculate button. In many cases, the elevation detail on the path profile is inadequate for this purpose; and it is necessary to enter the terrain roughness determined by a physical inspection of the path.

Ground cover - clearance Loss



The amplitude of the reflected signal is reduced by ground cover on the path. Click the calculate button on this field to access typical values for various types of terrain. To use this form first select the specific terrain and if required enter your value for the loss. Estimates of these losses are:

- 0 to 1 dB for water, desert or salt flats
- 1 to 3 dB for fields with low vegetation or low grass
- 3 to 6 dB for sage brush, fields with high vegetation or high grass
- 8 to 15 dB for partially wooded areas including trees along roads which are perpendicular to the path
- greater than 15 dB for heavily wooded areas

In addition to the ground cover, the clearance on the paths between the reflection point and each antenna must be considered. If the clearance on the reflected paths is less than 0.6F1, then the additional loss must be taken into account. This can only be analyzed in the Diffraction design section.

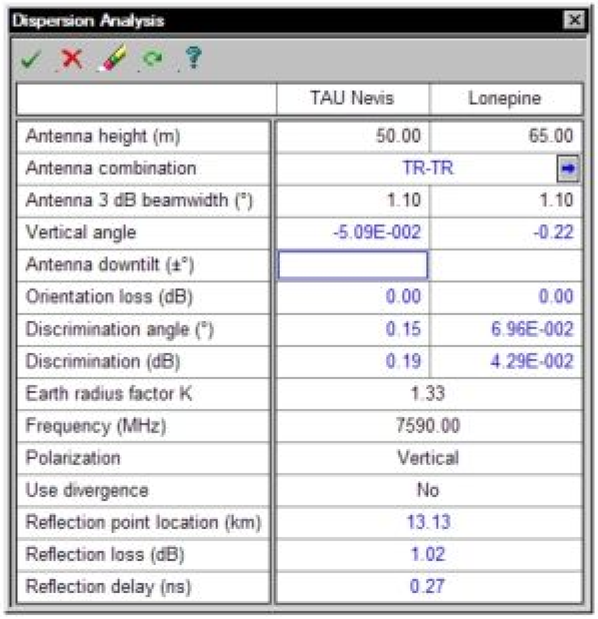
Divergence

Divergence is the scattering of a reflected signal due to the curvature of the earth. This is evident in the constant gradient ray trace over flat terrain. The effect is to reduce the reflected energy at low values of K. At large values of K, divergence has no effect. If K is negative, then divergence becomes convergence and the amplitude of the reflected signal increases.

Show perfect reflector results

The effects of terrain roughness, ground cover - clearance loss, antenna beam widths and divergence can be shown by displaying the unmodified results along with the actual results. The unmodified results consider only the theoretical reflection coefficient.

Dispersion analysis



Dispersion Analysis

	TAU Nevis	Lonepine
Antenna height (m)	50.00	65.00
Antenna combination	TR-TR	
Antenna 3 dB beamwidth (°)	1.10	1.10
Vertical angle	-5.09E-002	-0.22
Antenna downtilt (±°)		
Orientation loss (dB)	0.00	0.00
Discrimination angle (°)	0.15	6.96E-002
Discrimination (dB)	0.19	4.29E-002
Earth radius factor K	1.33	
Frequency (MHz)	7590.00	
Polarization	Vertical	
Use divergence	No	
Reflection point location (km)	13.13	
Reflection loss (dB)	1.02	
Reflection delay (ns)	0.27	

Click the dispersion button The dispersion analysis worksheet calculates the loss and delay of the reflected signal. These values determine the dispersive effects of a specular reflection. The calculation uses the reflective plane definition and the following parameters set in the Reflection Parameters data entry form:

- terrain roughness
- ground cover - clearance loss
- divergence

The following input parameters are local variables in the dispersion analysis worksheet and have no effect on the corresponding parameters outside the worksheet:

- antenna heights
- earth radius factor
- frequency
- polarization

The antenna 3 dB beam widths and downtilts values are global variables. If these are changed, the reflection calculations will be updated when the Dispersion Analysis worksheet is closed.

Note that both the antenna 3 dB beam widths and downtilts are "not included" parameters. If the letter X is entered for a value or the F3 key or erase button is pressed, these values will not be used in the calculation.

The following parameters are calculated:

- antenna discrimination angles
- antenna discrimination
- reflection point location
- reflection loss in dB
- reflection delay in nanoseconds

If the reflected signal delay is greater than 10-20 nanoseconds, performance problems on high capacity systems can occur unless the reflected signal amplitude is at least 40 dB below the direct signal. At very long delays, which approach the symbol rate, the path may not be workable.

Space diversity planning

When space diversity is implemented to deal with a specular reflection, design must satisfy the following criteria as the earth radius factor K is varied:

- both main and diversity receive signals must be at of above free space loss conditions (relative receive signal greater or equal to zero) at the median value of K (4/3).
- simultaneous signal nulls must not occur at any value of K.
- the space diversity improvement factor for multipath fading (non specular) depends on the vertical antenna spacing
- the vertical antenna spacing must not exceed the time delay equalization range of the radio equipment.

The first two requirements are met in this variable analysis using a reflective plane section. The space diversity improvement factor is calculated in the transmission analysis section.

Although various optimization algorithms to calculate antenna heights in a space diversity system exist, the approach used here is to simply use the mouse wheel to vary an antenna height and observe the results. Normally the user enters a value and clicks the calculate button to calculate and display the results. When the mouse wheel is rotated the antenna height is incremented and the calculation is automatically invoked.

The antenna configuration must be set to TRDR_TRDR to enable the space diversity planning feature. If a hybrid diversity configuration is being used (TRTH_TR or TR_TRTH), then it will be necessary to temporarily switch to the TRDR_TRDR configuration. The procedure is given below:

- Select the "Set site 1-2 main antenna heights" button. The site 1 and 2 antenna height edit controls are reset to the current main antenna heights and formatted with an up down spin control. Click on either edit control to set the focus to the up-down control and then use the mouse wheel to vary the antenna height. In the Metric system the height increment is 0.2 meters. In miles - feet, the increment is 0.5 feet. At the median value of K (4/3) the relative receive signal should be on a peak.

- Select the "Set site 1 diversity antenna height" button. The Site 1 antenna height edit control is reset the Site 1 diversity antenna height ante the Site 2 antenna height control is inhibited. Set the diversity antenna height so that at the median value of K, the relative receive signal is at of slightly above zero and any signal nulls are not coincident with a signal null on the main antennas display.
- Select the "Set site 1 diversity antenna height" button and set this antenna height using the same criteria as above.
- If necessary repeat any previous steps. Click the revise antenna heights button to finalize the settings
- Click the "Exit space diversity planning" to return to the variable analysis using a reflective plane main section.

Variable analysis using a constant gradient ray trace

The variations in received signal due to multiple ground

reflections are analysed as a function of antenna heights and earth radius factor (K) using a constant gradient ray trace. The analysis on only applicable to line of sight paths. The procedure is similar to the variable analysis using a reflective plane. The major difference is that the reflective

plane is limited to a single specular reflection whereas the ray trace

method considers all reflections. On a flat path the two methods are equivalent.

This analysis is used for:

- Provides a means of cross checking the results

  using a reflective plane

- To set the antenna heights for an odd Fresnel

  number clearance on paths with excess clearance.

- To ensure that a signal null does not occur

  at the median value of K.

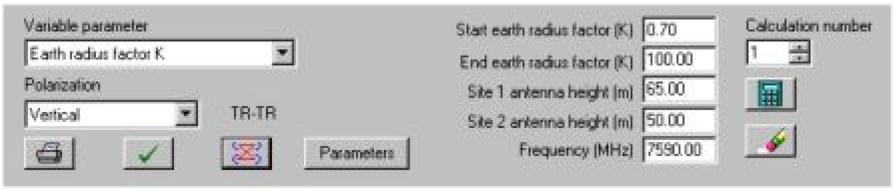
- To evaluate the effects of tilting the antennas

  vertically to reduce the reflected signal amplitude.

Select Variable - Analyse using ray tracing to access the

analysis display.

Ray trace analysis procedure



- Select the variable parameter (antenna heights

  or earth radius factor.

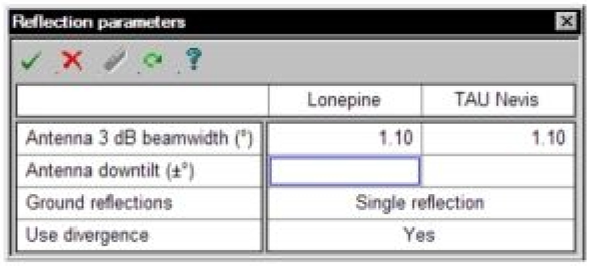
- Set the calculation number. Four calculations

  can be displayed for the selected variable parameter.

- Set the polarization
- Enter the start and end values for the variable

  parameter and the values for the fixed parameters. Then click the calculate button to display the results.

Reflection parameters



Click the parameters button to modify the reflection calculations for the parameters in the data entry form on the left. These parameters affect the amplitude of the reflected signal. The relative receive signal variations will be automatically recalculated for the new values of these parameters. The results can be compared with those using only the theoretical reflection coefficient.

The amplitude and delay of the reflected signal can be further analysed in the Dispersion data entry form.

Antenna beam widths

Depending on the path geometry, the antenna discrimination may reduce the reflected signal amplitude. Enter the total vertical 3 dB beam widths of the antennas. If a zero is entered or the field is left blank, the antenna beam widths will not be used in the calculation.

Antenna downtilt

To reduce the null depth produced by a reflected signal, it is common practice to tilt the antennas upwards. This increases the antenna discrimination to the reflection point; however, there will be some loss of received signal due the orientation loss. The antennas are assumed to be oriented at K = 4/3. To tilt an antenna upwards, you must enter a negative value (negative downtilt equals uptilt). If this field is left blank, the antenna downtilt will not be used in the calculation.

Ground Reflections

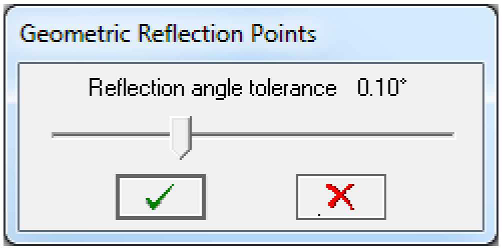
Set the allowable number of ground reflections to one or two. A zero ground reflections trace will only show the radiation pattern of the antenna.

Use Divergence

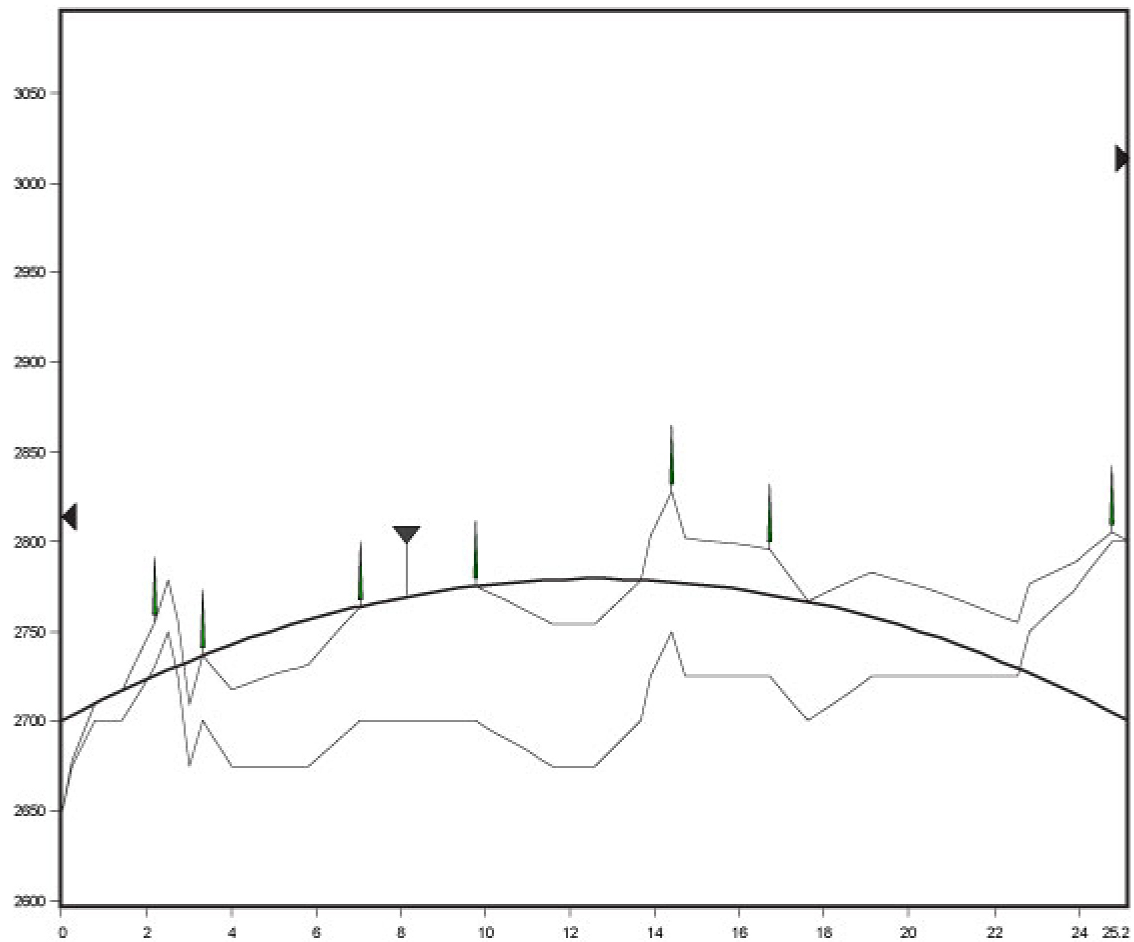
Divergence is the scattering of a reflected signal due to the curvature of the earth. In the ray trace analysis, this is accounted for by comparing the density of the reflected rays to the direct rays.

Mark reflection points

Select *Method-Mark reflection points*. The profile is scanned starting at the left side. At each point the angles formed between the terrain and the lines from the site 1 and 2 antennas are calculated. If the difference between these two angles is less than the reflection angle tolerance, then a vertical reference mark is drawn at the point.



If the next point also meets this criteria, then another vertical mark is drawn. The height of each successive mark is proportional to the difference of the two angles. When the sign of the angle difference changes from positive to negative or vice versa, then the location of the reflection point is extrapolated between the last two points.



Changing the reflection angle tolerance to a higher value shows the location of potential reflection points

Click the Green check button to retain the reflection points on the display. Click the Cancel button to remove the reflection points.

Effective earth radius representation

For small distances relative to the earth radius, the parabolic representation of the earth given by Equation (1) is used.

$$h = \frac{\gamma}{2} \cdot d^2 \qquad \gamma = \frac{1}{a} \tag{1}$$

h elevation above sea level

d distance

γ earth curvature

a actual earth radius (6375 Km)

The path followed by a radio wave is governed by the vertical gradient of the index of refraction. Under normal propagation conditions, the density of the earth's atmosphere decreases uniformly with increasing elevation. Radio waves, in this case, will bend downwards toward the denser medium.

The earth radius in Equation (1) can be replaced by an effective earth radius (K·a) so that radio waves can be represented as straight lines. This transformation is valid only for a constant vertical gradient of the index of refraction. This assumption is valid for radio paths within one kilometer of the earth's surface.

This effective earth radius model simplifies the basic path geometry. Parameters such as grazing angles, and path clearance can be calculated using plane geometry.

The following paragraphs provide a basic derivation of the effective earth radius model. This representation is used in the Pathloss program.

Refraction

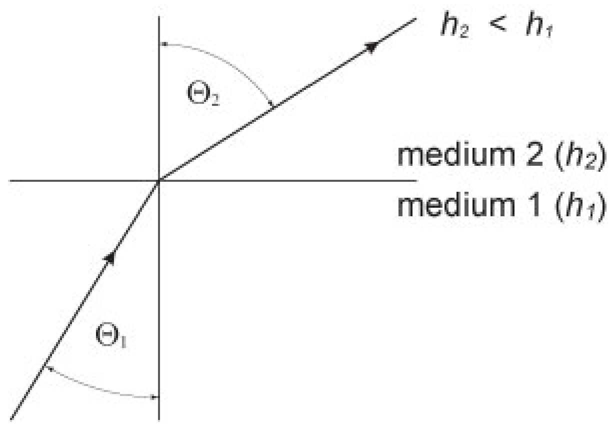


Figure (1): Refraction

When a ray passes through two mediums with different refractive indexes, the ray is bent in the direction of the medium with the larger refractive index, in accordance with Snell's law.

$$\eta_1 \cdot \sin(\theta_1) = \eta_2 \cdot \sin(\theta_2) \qquad (2)$$

The refractive index, η, of a medium is defined as the ratio of the velocity of light in a vacuum to the velocity of light in the medium. The index of refraction is a dimensionless number and does not exceed 1.00045 at sea level. For convenience, the refractive index is usually expressed as refractivity, *N*, defined as:

$$N-(\eta-1)\cdot 10^{6} N\text{-}units \qquad (3)$$

The radio refractivity of air for frequencies up to 30 GHz is given by:

$$N = 77.6 \cdot \frac{\rho}{T} + 3.73 \cdot 10^{5} \cdot \frac{\varepsilon}{T^{2}} \qquad (4)$$

ρ total atmospheric pressure in millibars
ε partial pressure due to water vapor in millibars
T absolute temperature in degrees Kelvin

T and ε normally decrease with elevation.

ρ always decreases with elevation.

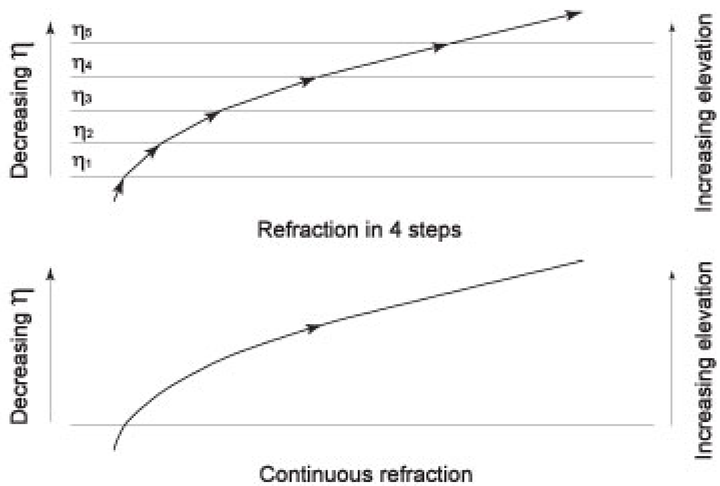


Figure (2): Flat Earth Refraction

The concept of radio wave bending is illustrated in Figure (2). In the upper diagram, the atmosphere is shown as discreet layers with refractive indexes η1...η5. In the lower diagram, the atmosphere has a continuous variation or the refractive index. The diagram represents propagation through a horizontally stratified atmosphere.

Refractivity gradient

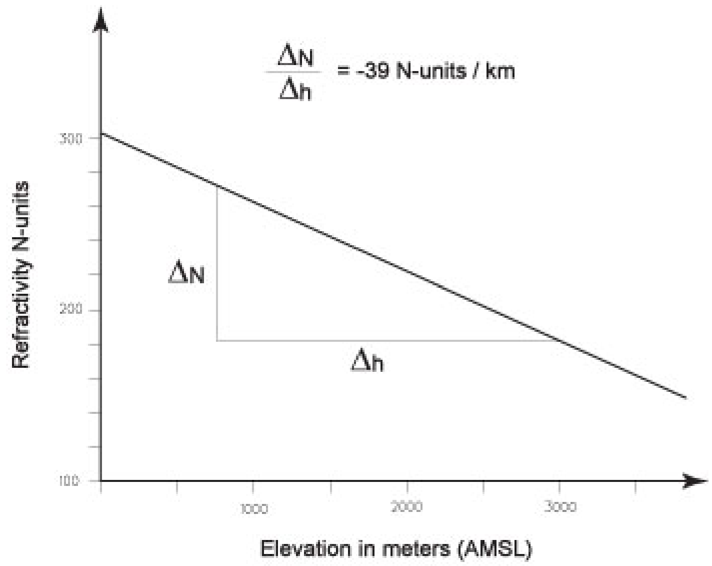


Figure (3): Refractivity gradient

The refractivity gradient is the slope of the refractivity versus elevation curve:

$$Refractivity\ Gradient = \frac{\Delta N}{\Delta h} \tag{5}$$

An example of a constant refractivity gradient which represents normal propagation conditions is shown in Figure (3).

Path profile formats

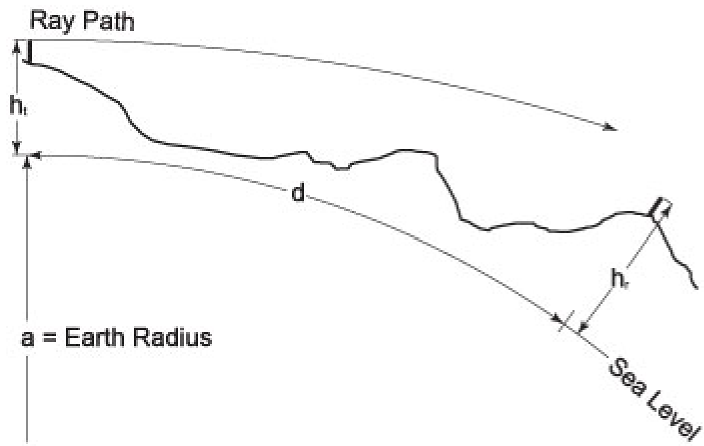


Figure (1): Physical path profile

Physical Earth Profile

Figure (1) shows a physical representation of a path profile using the representation given by Equation (1). The ray path curvature is based on the refractivity gradient shown in Figure (3) of the "Effective earth radius representation"section. The initial angle of the ray is assumed to be zero (horizontal).

Effective Earth Radius Profile

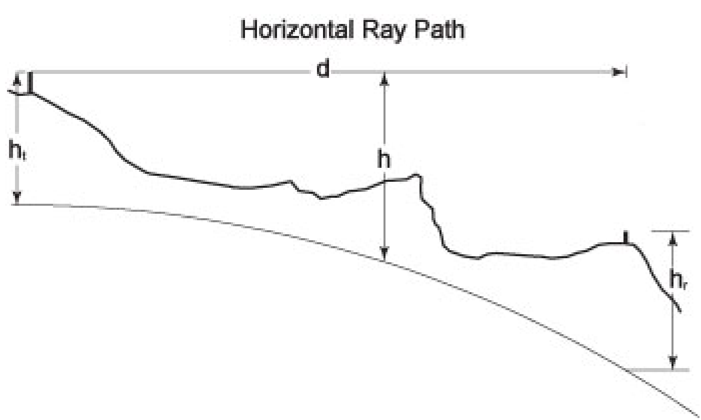


Figure (2): Effective earth radius profile

In Figure (2), the earth radius, *a*, is replaced by an effective earth radius, a_e, defined as:

$$a_e = K \cdot a$$
$$K = \left(1 + \frac{\frac{\Delta N}{\Delta h}}{157} \right)^{-1} \quad (1)$$

The ray is now represented as a straight horizontal line. The profile is drawn in a rectilinear format which implies the following assumptions:

- The distance along the ray path is equal to the great circle arc distance.
- Elevations perpendicular to the earth are equal to their rectilinear values.

The elevations with respect to the ray path are given by:

$$h - h_1 + \frac{d^2}{2 \cdot K \cdot a} \quad (2)$$

The usual terrain profile representation is obtained by applying a transformation to Equation (2) so that the display is relative to the end points of the profile. The final display is shown in Figure (3).

The elevation, *h*, is given by:

$$h = \frac{d_1 \cdot d_2}{2 \cdot a \cdot K}$$

$$h = \frac{d_1 \cdot d_2}{12.75 \cdot K}$$

$d_{1/2}$ in kilometers

h in meters (3)

$$h = \frac{d_1 \cdot d_2}{1.5 \cdot K}$$

$d_{1/2}$ in miles

h in feet

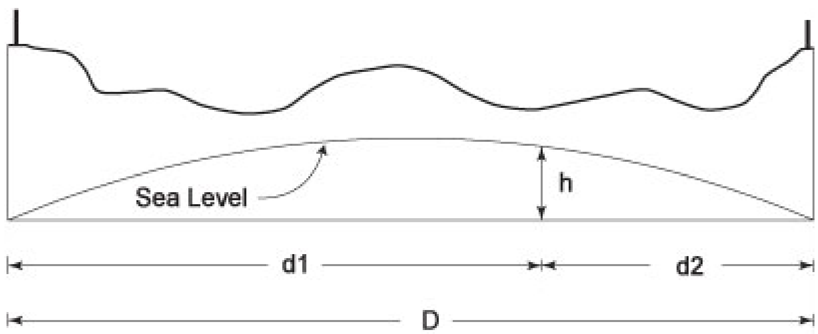


Figure (3): Path profile format

Ray tracing

In the previous section is was noted that if a path profile is modified to include the effective earth radius, then all rays can be represented with straight lines. The ray trace in this case would be a constant gradient ray trace and all rays will be straight lines.

If the change in refractivity with height (dN/dh) is not a constant, a ray will follow a curved path based on the value of dN/dh at the elevation of the ray. The ray bending will depend on its angle. If a ray passes through different refractivity layers at right angles will not bend. As the angle of incidence becomes shallower, the bending will be more noticeable until the wave is actually entirely reflected back. In the case of the earth's atmosphere, the refractivity changes smoothly with elevation, therefor the important angle is the vertical angle with respect to the local horizontal.

M Profiles

Modified refractivity or M profiles are used to describe this refractivity gradient in ducting analysis and are defined as: *M(h) = N(h) + 157h (M units) or*

dM/dh = dN/dh + 157

Figure (1) taken from ITU-R P.453-8 illustrates the modified refractivity above ground and the definition of duct types. Ducts are classed as: a) surface based, b) elevated-surface and c) elevated ducts. Due the rather few cases of elevated-surface ducts in comparison with surface ducts, the ITU statistics have combined these two types into one group designated surface ducts. Surface ducts are characterized by their strength S_s or E_s (M-units) and their thickness S_t or E_t (m). Two additional parameters are used to characterize elevated ducts, the base height of the duct E_b and E_m (m), the height within the duct of maximum Km.

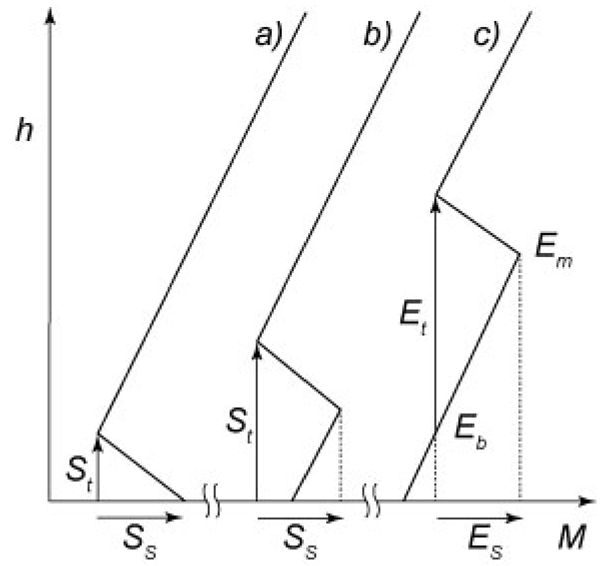


Figure (1): Ducting parameters

Algorithm

At site 1, the initial conditions are set by the antenna height and the antenna elevation angle. It is assumed that the antenna orientation was carried out under the median value of K as determined by the sea level refractivity: The initial value of dN/dh is read from the M profile which sets the initial curvature.

The ray trace proceed in uniform distance increments along the path. At the end of each increment, a new elevation and vertical angle is obtained. The new value of dN/dh is read from the M profile and the process continues. If ground contact occurs (the new elevation is below the profile), the location of the reflection point is extrapolated and a new ray is initiated from ground level at the reflected angle.

The ray tracing geometry is shown in Figure (2) Equations (1) to (6) show the formulas which effectively solve two related triangles using the sine and cosine laws twice each.

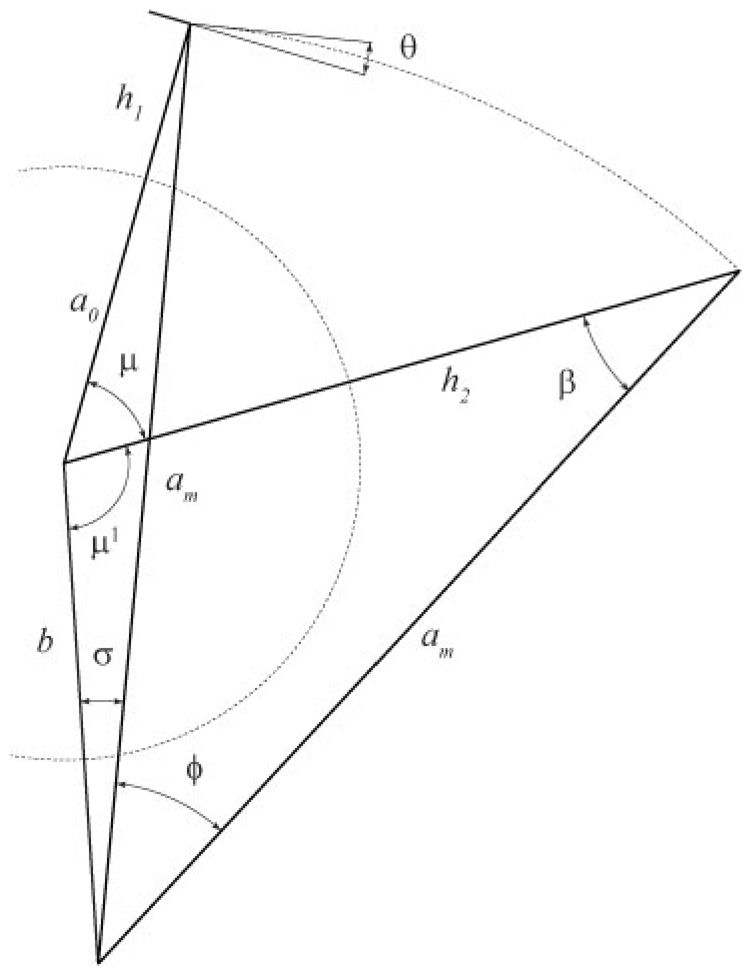


Figure (2): Ray tracing geometry

Given:

a_0 = earth radius
b = new take off angle
h_1 = initial elevation
h_2 = height above earth at end of arc
a_m = beam radius of curvature
θ = vertical angle
μ = angular distance

Where:

$$b = \sqrt{(a_0 = h_1)^2 + a_m{}^2 - 2(a_0 + h_1)\, a_m \cos(\theta)} \tag{1}$$

$$\sin(\sigma) = \frac{(a_0 + h_1)\sin(\theta)}{b} \tag{2}$$

$$\mu^1 = 180 - (\sigma + \theta + \mu) \tag{3}$$

$$\beta = \sin^{-1}\left(\frac{\sin(\mu^1)\cdot b}{a_m}\right) \tag{4}$$

$$\phi = 180 - (\beta + \mu^1 + \sigma) \tag{5}$$

$$(a0 + h2)^2 = b^2 + a_m{}^2 - 2b \cdot a_m \cos(\sigma + \phi) \tag{6}$$

Two ray optics

The reflective plane analysis is based on two ray optics and is limited to a single specular reflection. The receive signal is the vector addition of the direct signal and the reflected signal.

The amplitude of the reflected signal depends on:

- theoretical reflection coefficient
- terrain roughness
- divergence
- ground cover over the reflection surface
- additional loss due to lack of clearance between the reflection point and the antennas
- antenna discrimination
- the phase difference between the direct and reflected signals depends on:
- the difference in path lengths between the two signals
- the phase shift which occurs on reflection

The resultant signal is given by:

$$A = 10 \cdot \log\left[1 + R^2 - R\cos\left(\frac{2\pi\Delta r}{\lambda} - C_{v,h}\right)\right] \quad (1)$$

R	reflected signal amplitude
λ	wavelength
Δr	difference in path length between the main and reflected signal paths expressed in the same units as the wavelength
$\pi - C_{v,h}$	phase shift which occurs on reflection

The subscripts *v* and *h* refer to vertical and horizontal polarization.

Equation (1) is valid on line of sight paths for frequencies greater than 30 MHz. As the clearance approaches grazing, two ray optics results in an unrealistically high loss.

Theoretical Reflection Coefficient

The theoretical reflection coefficient is a complex number consisting of a magnitude and an angle and depends on:

- frequency
- polarization
- grazing angle (angle of incidence or angle of reflection)
- relative surface dielectric constant (ε)
- surface conductivity (σ mhos/meter)

The magnitude of the reflection coefficient R_h and R_v and the phase delay (π-$C_{v,h}$) for horizontal and vertical polarization is given by Equation (2). This is based on Technical Note 101 (III-3).

$$
\begin{aligned}
&x = 1.80 \cdot 10^{4} \cdot \frac{\sigma}{f_{MHZ}} \\
&q = \frac{x}{2p} \\
&2p^{2} = \sqrt{\varepsilon - \left(\cos^{2}\Psi\right)^{2} + x^{2} + \left(\varepsilon - \cos^{2}\Psi\right)} \\
&b_{v} = \frac{\varepsilon^{2} + x^{2}}{p^{2} + q^{2}} \\
&b_{h} = \frac{1}{p^{2} + q^{2}} \\
&m_{v} = \frac{2\left(p\varepsilon + qx\right)}{p^{2} + q^{2}} \\
&m_{h} = \frac{2p}{p^{2} + q^{2}} \\
&R_{v}^{2} = \frac{1 + b_{v}\sin^{2}\Psi - m_{v}\sin^{2}\Psi}{1 + b_{v}\sin^{2}\Psi + m_{v}\sin\Psi} \\
&R_{h}^{2} = \frac{1 + b_{h}\sin^{2}\Psi - m_{h}\sin^{2}\Psi}{1 + b_{h}\sin^{2}\Psi + m_{h}\sin\Psi} \\
&\pi - C_{v} = \tan^{1}\left(\frac{x\sin\Psi - q}{\varepsilon}\right) - \tan^{1}\left(\frac{x\sin\Psi - q}{\varepsilon\sin\Psi + p}\right) \\
&\pi - C_{h} = \tan^{1}\left(\frac{-q}{\sin\Psi = p}\right) - \tan^{1}\left(\frac{q}{\sin\Psi + p}\right)
\end{aligned}
\tag{2}
$$

ε relative dielectric constant
σ surface conductivity
Ψ grazing angle in radians (angle of incidence or angle of reflection)

The phase shift on reflection is very near 180 degrees (radians) on most radio paths. As the grazing angle approaches the Brewster angle in the range 5 to 11 degrees, the phase shift rapidly changes for π to $-\pi$ radians. This path geometry is rarely encountered in practice.

Table 1: Ground Characteristics

Ground Type	Conductivity (s) (mhos per meter)	Relative Dielectric Constant ()
Poor Ground	0.001	4
Average Ground	0.005	15
Good Ground	0.020	25
Salt Water	5.000	81
Fresh Water	0.010	81

The surface dielectric constant and the surface conductivity are determined by the ground types specified in the terrain profile as shown in Table 1.

Terrain Roughness

The magnitude of the theoretical reflection coefficient, $R_{h,v}$ in Equation (2) is based on a smooth surface over the area of the reflection. Typically, $R_{h,v}$ is in the range 0.9 to 0.99, which will result in receive signal nulls of 20 to 40 dB.

The reflection coefficient is modified to account for terrain roughness as shown in Equation (3) below.

$$R_e = R_{h,v} e^{-\left(0.6 \sin\Psi \frac{\Delta h}{\lambda}\right)} \quad (3)$$

R_e effective reflection coefficient

λ wavelength

Δ_h terrain roughness expressed in the same units as the wavelength

Ψ grazing angle in radians (angle of incidence or angle of reflection)

Note that the effect of terrain roughness depends on the sine of the grazing angle (Ψ). At very low values of Ψ, the sine is zero and terrain roughness has no effect. Even a very rough surface is reflective. This phenomenon is often observed while driving on paved roads. The road in the distance appears as a mirror reflecting light. The road surface is reflective to light at low grazing angles.

The terrain roughness is defined as the standard deviation of the terrain relative to a smooth curve within the limits of the reflection area. This is the same definition as used in the Microwave Worksheet; however, no limits are placed on the value of the terrain roughness. If the path is over water or salt flats, then a value of zero should be used for the terrain roughness which represents the worse case.

Note that the effective reflection coefficient is a function of frequency (λ). The effect will be greater at the higher frequencies. In estimating a value of the terrain roughness, only the terrain should be considered. Do not attempt to account for ground cover (trees or foliage) using terrain roughness. These effects are described under Ground Cover Effects.

Divergence

Divergence is defined as the scattering of a reflected ray due to the curvature of the earth. The effect is to slightly reduce the amplitude of the reflection coefficient for small values of K. Divergence has no effect at large values of K. If K is negative, divergence becomes convergence and the amplitude of the reflection coefficient increases.

The divergence factor is given by:

$$D = \frac{1}{\sqrt{1 + \frac{2 \cdot d_1 \cdot d_2}{K \cdot a \cdot d \cdot \tan(\Psi)}}} \quad (4)$$

d_1 distance from Site #1 to the reflection point

d_2 distance from Site #2 to the reflection point

d path length

a earth radius

K effective earth radius factor

Ψ grazing angle (angle of incidence or reflection)

The reflection coefficient is modified as $R = D\ R_e$.

Ground Cover Effects

Trees and foliage in the area of the reflected signal can significantly reduce the reflected signal amplitude and the subsequent variations in the receive signal. An estimate of the ground cover loss is critical in determining the requirement for space diversity to handle specular reflections.

Table 2 provides approximate values of the loss for several types of ground cover.

Table 2: Ground Cover Loss

Ground Cover	***Loss***
water, desert or salt flats	0 to 1 dB
fields with low vegetation and low grass	1 to 3 dB
sage brush, fields with high vegetation and high grass	3 to 6 dB

partially wooded areas including trees along roads which are perpendicular to the path	8 to 15 dB

Additional loss to the reflected path will occur if there is less than 60% first Fresnel zone clearance between an antenna and the reflection point. This analysis must be carried out separately in the Diffraction module.

Antenna Discrimination

Additional loss to the reflected signal will result from the antenna discrimination, provided that the angle difference between the orientation angle and the angle to the reflection point is sufficiently large. The antenna discrimination is calculated as:

$$u = \sqrt{\frac{1.0 + \cos\left(\frac{\pi \cdot \theta}{bw}\right)}{2}}$$

$$for \theta \le bw$$

$$u = \frac{\sin\left(\frac{bw}{2}\right)}{\sqrt{2} \cdot \sin(\theta)} \tag{5}$$

$$for \theta > bw$$

$$U_{db} = 20 \cdot \log(u)$$

u, U_{db} antenna discrimination
θ discrimination angle (radians)
bw total 3 dB beam width of the antenna (radians)

It is assumed that the vertical antenna orientation was carried out for an effective earth radius of K = 4/3. As K changes, the angle of arrival will also change resulting in an orientation loss. If the

Propagation in regions of non standard refractivity

The following section has been taken from Chapter 5 of:

The Physics of Microwave Propagation, D.C. Livingston
The Bayside Laboratory research center at
General Telephone & Electronics Laboratories Incorporated, Bayside New York
Technical Monograph 1967

5.1 Atmospheric Dynamics

In Chapter IV, we considered the properties of the well-mixed atmosphere, the 4/3-earth atmosphere, and, more generally, the class of standard atmospheres with which we associate the concept of an effective earth radius. We found that these atmospheres have microwave refraction characteristics describable in terms of Eqs. (4.22) and (4.25), with dn/dh varying negligibly with elevation in the former.

Although the properties of the actual atmosphere frequently conform quite closely to those of one or another of the above standard atmospheres, there are nevertheless many instances when its refractive properties do not conform to those of any standard atmosphere over the full range of elevations pertinent to a given application. Moreover, an atmosphere may appear at first sight to resemble a standard atmosphere, only to be found upon closer examination to contain slight irregularities in refractivity capable of seriously impairing the quality of microwave signals passing through it.

The present chapter considers the causes of these atmospheric conditions and their detailed effects on microwave transmission. At the same time, it reveals the mechanisms which lead to normal propagation when allowed to operate without interference from perturbing influences.

Hydrostatic equilibrium

In analyzing the mechanics of rigid bodies, we are accustomed to dealing with three types of equilibrium. A spherical ball at rest on a level surface is in neutral equilibrium. If left alone, it remains at rest; if placed at rest at a neighboring point, it again remains at rest since it is subject to no net force. The downward force of gravity on it is balanced by the upward reaction of the surface. If the ball rests at the lowest point of a concave surface, it is in stable equilibrium, for any displacement causes it to experience a restoring force tending to return it to its original position. If the ball rests at the highest point of a convex surface, it is in unstable equilibrium. Although it can remain in this initial position indefinitely without constraining forces to keep it there, the slightest displacement immediately causes it to experience a force tending to increase the displacement.

These same three types of equilibrium occur in air masses. In this case, the forces which come into balance with each other are those of gravitation and of buoyancy, the latter being the resultant force on any given air parcel due to the pressure exerted on it by the surrounding gases. Archimedes' Principle tells us that this condition of balance must exist whenever the air in a given parcel has the same density as the surrounding air. It is common experience that air masses can be very nearly if not completely stationary at times within a specified region. Inside a room which is not being heated or cooled artificially, this is particularly common. Anyone who has ever been becalmed in a sailboat knows that it also happens in the open air. Presumably, every air parcel in such a region must be in a state of mechanical equilibrium.

Whether the equilibrium state in a given case is neutral, stable, or unstable is less obvious. In the well-mixed atmosphere, every air parcel is in neutral equilibrium. This becomes evident when we consider that an air parcel in this atmosphere, when displaced upward from its initial position, expands at such a rate that its temperature and pressure remain at all times the same as those of the surrounding gases, thereby permitting it to remain in equilibrium throughout the displacement.

Situations in which the air is in stable or unstable equilibrium are also important to the study of microwave propagation phenomena, for they lead to various forms of abnormal propagation. We consider them next.

Heating from below

Suppose that a well-mixed atmosphere extends within a short distance of the ground and that air below the well-mixed region absorbs heat from the ground via radiation, the ground being warmer than the air. Let us suppose that mixing processes are active in the air layers nearest the ground as well as higher up and that the principal effect of these processes is to cause individual air parcels to continually move slowly in directions which are random except for the assumption that parcels shall flow over each other without merging. This assumption does not affect the argument but facilitates discussion. Suppose two air parcels with initially similar elevations, temperatures, pressures, and volumes to traverse different paths which eventually bring them to the same elevation after absorbing slightly different amounts of heat from the ground. The parcel which absorbed the greater amount of heat must have at this latter elevation a higher temperature and pressure than the other parcel. The former parcel, because of its greater pressure, expands at the expense of the latter parcel, thereby becoming less dense while the latter parcel becomes more dense.

The denser parcel, having become less buoyant than the surrounding air, now tends to drift lower while the less dense parcel drifts higher. The descending parcel approaches closer to the ground and absorbs more heat via radiation, thereby leading us to expect that it might eventually also share in the ultimate destiny of the lighter parcel. The ascending parcel, on the other hand, faces a new situation. As it rises past parcels with successively lower pressures, it expands so that its own pressure continues to decline. Since it is now surrounded by air parcels which tend on average to have absorbed less heat per unit mass than it did itself, its density continues to be less than that of the surrounding air even when its pressure is the same. Its temperature, incidentally, remains higher than that of the surrounding air, but this fact is irrelevant since air parcels with different temperatures do not tend to exchange heat via radiation because of their low radiation efficiencies.

There is a fundamental difference between the condition of this air parcel which has absorbed heat from the ground and the parcels which it encounters after it has ascended into the base of the well-mixed region. This difference is measured in meteorological literature in terms of a parameter called the potential temperature, which is defined as the temperature that an air parcel acquires at an arbitrary reference pressure when brought to that pressure by an adiabatic process. It follows that a well-mixed atmosphere has the same potential temperature at all elevations within its range and that a foreign air parcel which does not become integral with the well-mixed atmosphere through complete mixing cannot come into a state of neutral equilibrium with it no matter what elevation it rises or descends to. If the parcel has a higher potential temperature than the well-mixed atmosphere, it is less dense whatever its elevation. Once it enters the base of the well-mixed region, it must rise continually either until it reaches the top of the well-mixed region or until it has lost its identity through intimate mixing. The latter is what happens in practice, but, as is explained later in this section, intimate mixing is a relatively complicated process that takes place in several steps. An air parcel can rise a considerable distance before it loses its identity. This mechanism is, in fact, essential to the establishment of a well-mixed atmosphere. The continuous ascent of air parcels into the well-mixed region from the radiatively heated region near the ground provides the primary mechanical motive power for the mixing process.

Thus far in discussing heating from below, we have assumed a certain amount of random motion among the air parcels in the region heated by radiation from the ground. This is necessary to establish regions of predominantly rising air from the heated zone into the well-mixed zone and separate regions of predominantly descending air. Ordinarily, regions of ascending air and of descending air tend to be determined by geographical features of the terrain, although random factors are also important. During periods of hot weather, air tends to rise over types of terrain with high absorptivity to sunlight, low thermal conductivity, and low thermal capacity. Together, these properties lead to relatively high surface temperature under solar irradiation. Surfaces possessing these properties include barren ground, grassland, and paved roads. Descending air tends to be found where ground conditions do not favor the occurrence of rising air, namely, over terrain lacking any of the three previously identified attributes conducive to high surface temperature. Metallic surfaces tend to reflect incident radiation rather than absorb it; trees allow the incident radiation to filter through a considerable depth of leaves, thereby distributing the heat over a large volume with relatively small temperature increase; and water must absorb a large amount of heat for a relatively small rise in temperature. Thus, rivers, small ponds and lakes, and small clumps of trees tend to be associated with descending air.

In some areas, the terrain is extremely uniform, being flat, featureless, and uniform in composition. If, in addition, the sky is usually cloudless, so that the ground is subjected to uniform solar irradiation, there remain virtually no predisposing terrain influences to determine that one place is more likely than another to serve as a point over which ascending air will appear. Under such circumstances, heating of air parcels near the ground proceeds anyway, but each parcel finds that parcels above it do not move aside to allow it to rise. Each parcel thus remains where it is; it is thus in some sort of mechanical equilibrium. To ascertain whether this equilibrium is neutral, stable, Or unstable, we must examine conditions within the radiatively heated zone more closely, and we can do this by visualizing a hypothetical experiment.

Suppose a well-mixed atmosphere to extend all the way to the ground, even though it would be difficult to imagine a way for this to actually happen. Let us now modify this atmosphere by allowing heat to flow into its lowest layers via radiation from the ground, heat flowing upward through the surface of the ground at some given area rate, absorption taking place in successively higher layers of the air in accordance with the usual exponential attenuation law until the flux at some given height is negligibly small. The air temperature at each elevation will be increased by a definite amount due to heat absorption before a stable temperature distribution can again prevail, and air parcels experiencing these temperature increases will have to expand to keep their pressures constant as required in order that they may continue to support the unchanged weight of the air above them.

After the above changes have taken place, the well-mixed region is unchanged except that it has been lifted somewhat due to the expansion of the heated zone beneath it. Although any given air parcel in the well-mixed region is somewhat higher above the ground than it was previously, its temperature, pressure, volume, and position relative to neighboring parcels are unchanged. Parcels in the heated zone, on the other hand, have increased temperatures, volumes, and vertical separations, but their pressures and horizontal separations are unchanged. It is clear from the definition of potential temperature that the air parcels in the well-mixed region all have the same potential temperature while those in the heated zone have higher potential temperatures the closer they are to the ground. Consider now what happens if an air parcel in the heated zone is raised slightly through an adiabatic process. It expands and its temperature decreases as its pressure decreases to that of the surrounding air, but its temperature remains higher than that of the surrounding air because of its higher potential temperature. Its density is less than that of the surrounding air, so it experiences a buoyant force greater than its weight. Thus, it is driven further upward. A similar argument shows that displacing it downward leads to a loss of buoyancy with subsequent further spontaneous descent. In short, air in the heated zone is in unstable equilibrium.

This unstable situation cannot continue to develop indefinitely, for spontaneous irregularities eventually develop to start an upward movement of air from the unstable region into the neutral region above it. As was pointed out earlier, once an air parcel from the heated region enters the well-mixed region, it can rise a considerable distance. This explains the phenomena of "dust devils," which are familiar to those who have travelled on the deserts of the western United States. One typically begins as a small, whirling puff of dust close to the surface of the ground and represents visual evidence that a vent for an updraft has begun to penetrate the neutral region. Hot surface air has begun to rise through a space where the pressure has dropped momentarily due to random influences. As air rises into what has, in effect, become a chimney, other parcels of hot air flow in horizontally to take its place. The process builds up momentum, hot air flowing in from a considerable distance, gaining velocity, picking up loose sand from the dry ground, and rushing up the chimney, carrying the sand up with it. It is quite common to see such dust devils several hundred feet high and persisting for half an hour or more. As many as a dozen may be visible simultaneously from a single point. Desert mirages producing illusions of bodies of water are frequently seen in the same regions where dust devils occur. They are caused by abnormal refraction of light rays in the region of unstable air close to the ground.

Cooling from below

We shall consider next what happens when the ground beneath an initially well-mixed atmosphere is cooler than the lowest layers of air and induces cooling by absorbing radiation from the air. Whereas in heating from below we find an upward flow of heat with maximum flux density at the surface, we now find a downward flow with maximum flux density at the surface. The lowest layers of air are cooled the most, so the temperature gradient dT/dh becomes less negative than in the well-mixed atmosphere. The cooled air parcels must contract to maintain their pressures the same as previously in order that they may continue to support the overlying atmosphere, whose pressure remains unchanged. These air parcels are thus denser and therefore less buoyant than they would be in the absence of cooling. Moreover, their potential temperatures are lower than those of parcels higher up. It follows that an air parcel which is displaced upward from its equilibrium position and allowed to expand adiabatically to allow its pressure to become the same as that of its surroundings is more dense than other parcels in its new environment, so it is less buoyant than the surrounding air. It therefore experiences a net downward force tending to return it to its original level. If the parcel is displaced downward rather than upward, we again find that the net force acting on it in its new location tends to push it back to its previous position. The air in the cooled region is thus in stable equilibrium.

Temperature inversions

If cooling from below is sufficiently intense, the temperature gradient dT/dh near the surface may actually become positive so that the temperature itself actually increases with elevation instead of decreasing. Such a condition is known as a temperature inversion, a term which has become familiar to the general public through its association with such disagreeable atmospheric phenomena as "smogs." The existence of the temperature inversion is not actually a necessary condition for smog; but it is more than merely sufficient. The minimum sufficient condition is that there exist an air layer in stable mechanical equilibrium, for such a layer acts as a ceiling which air rising from the surface of the ground and carrying with it such obnoxious gases as industrial smoke and automotive exhaust cannot penetrate. These substances thus accumulate between the ground and the stable layer, or close to the ground itself if the stable layer is formed adjacent to the ground as described above.

Temperature inversions may be formed by mechanisms other than cooling from below. The mechanism responsible for the notorious Los Angeles smog is known as subsidence, and the corresponding inversion is known as a subsidence inversion. Subsidence is the name given to the adiabatic descent of an air mass. If only individual air parcels were descending through the action of mixing processes, there would be no change in the temperature distribution in the atmosphere, for we have seen that the temperatures of such parcels simply adjust through adiabatic compression to the same temperatures as those of other parcels at the same elevations. The difference in subsidence lies in the fact that the entire air mass, by descending, leaves room above for more air to move into through horizontal motion. The weight of this additional air is added to that already bearing down on the air in the subsiding mass with the result that the latter undergoes additional compression with accompanying additional temperature rise.

If the atmosphere was well-mixed before the onset of subsidence and if the pattern of surface winds combined with the contour of the terrain do not permit the surface layers of air to move aside to make way for the subsiding air, the latter cannot descend all the way to the ground but must start moving horizontally at some minimum altitude above the ground at which no obstruction to its flow exists. When this happens, the stage for subsidence inversion has been set, for the temperature of the air above the bottom of the subsiding air mass becomes higher than it had been before subsidence began, while that below remains the same. In the vicinity of the boundary between these zones, the temperature may therefore increase with elevation, and the subsidence inversion is established.

Mixing processes

Three processes are responsible for the mixing of air constituents from different sources to bring about the creation of a well- mixed atmosphere. When one or another of these mechanisms is inhibited, deviations from complete mixing follow. In order of descending gross effect but of increasing microscopic effect, these processes are convection, eddy turbulence, and molecular diffusion.

The distinctions between these processes are conveniently drawn through a simple example. Consider a room with a radiator near the base of one wall, and suppose that all doors and windows are closed. Let a smoker in the room blow a smoke ring. The latter consists of a hollow toroid with a sharply-defined surface within which the smoke circulates in closed paths encircling the central hole of the toroid. The smoke ring does not remain indefinitely near its point of origin, for the air in the room is in motion and carries the ring along with it. This motion is due to convection. The radiator heats air in its immediate vicinity by radiation and, to some extent, by conduction. The air thus affected rises in temperature and pressure, whereupon it expands and becomes less dense. It therefore develops buoyancy and rises toward the ceiling. Cooler air moves horizontally toward the radiator to take its place, and a circulating loop of air is established, encompassing the entire room. The smoke ring is carried along in this circulating air stream.

Because of eddy turbulence, the ring does not retain its regular shape for long. Turbulence develops in the moving air stream, causing random whirls and eddies to arise. These occur in a wide range of sizes, the smaller ones outnumbering the larger ones. The net effect of eddy turbulence is to change the shape of the smoke ring without breaking up the integrity of the closed paths around which the smoke flows. The boundary of the ring, although distorted, remains sharp insofar as effects due to eddy turbulence are concerned. Eventually, these effects nevertheless totally destroy virtually all evidence of the original shape of the ring.

Even the combined effects of convection and eddy turbulence do not really accomplish any mixing, however. These mechanisms have served thus far only to distribute the smoke allover the room by gross distortion and distension of the shape of its bounding surface, which still has the same topology as had the original toroid. Only through molecular diffusion does any penetration of the smoke through the surface of the former toroid take place, and, as the name implies, this mechanism operates at the molecular level. It is also relatively slow but eventually results in complete integration of the smoke from the smoke ring into the air of the room.

In the atmosphere, convection is responsible for causing the composition of large air parcels at different elevations to be essentially the same, while molecular diffusion assures that small parcels will have similar compositions no matter how small they are. Eddy turbulence plays an intermediate role, requiring less molecular diffusion than would otherwise be required in order to achieve complete mixing. In particular, these processes are responsible for distributing uniformly throughout a well-mixed atmosphere whatever moisture and heat are acquired from the ground.

Diurnal cycle of ground influence

We shall close this section by tracing out the sequence of events which may take place in the course of a single day in an air mass due to the influences of the ground beneath it. Let us begin in the early evening as the convective mixing driven by heating from below is about to cease with setting of the sun. Vigorous convection has led to the establishment of a well-mixed atmosphere to an elevation of the order of 2000 feet or more. Moisture from the ground has been mixed uniformly to the height at which condensation begins to take place. Adjacent to the ground is a heated region in which temperature falls more rapidly with elevation than in the well-mixed region. A plot of temperature as a function of elevation thus appears as shown by curve A in Fig. 5-1. This curve indicates that the temperature of the ground at this time is slightly above 80oF.

After the sun sets, the ground is no longer heated by absorption of sunlight, but it continues to radiate. Thus, it cools. As its temperature falls below that of the low-lying air layers, the latter lose heat by radiation to the ground, so the vertical temperature gradient in the air becomes less negative, eventually becoming actually positive if the ground temperature falls sufficiently. In Fig. 5-1, curves B, C, and D indicate successive temperature distributions as cooling from below progresses.

Since the air in the cooled region has become stable, convection ceases, thereby preventing further communication of moisture from the ground to the well-mixed region above the inversion layer. The conditions conducive to the greatest temperature gradient in the region of stable equilibrium are those which favor the greatest drop in ground temperature. These include a dry soil, since a large moisture content implies large heat capacity and therefore slow cooling. Also, since clouds tend to reflect back toward the ground any heat radiated from the ground, a clear sky is conducive to rapid cooling of the ground. Such conditions are particularly likely to occur in deserts and other arid places.

When the sun rises in the morning and begins to heat the ground again, heating from below resumes and a sequence of temperature distributions like those in Fig. 5-2 ensues. Let us suppose that the temperature distribution in the air at sunrise is that shown by curve D, which represents the same curve as that denoted by the same symbol in Fig. 5-1. These curves indicate that the ground temperature had fallen during the night to a minimum value of somewhat less than 50oF. As the ground temperature rises, a thin unstable region is formed in the air immediately above it, and convection begins to take place. Convection cannot penetrate very deeply into the stable region at first, however, for the potential temperature of an air parcel starting from the surface is high enough to allow it to rise only a short distance before it finds itself surrounded by air at a higher potential temperature. Between the ground and the elevation at which this condition is reached, however, mixing proceeds at an efficient rate and leads to the formation of a well-mixed region which gradually penetrates higher into the stable region as the potential temperature of its air parcels rises. The temperature as a function of elevation thus passes through a sequence of configurations such as shown by curves E, F, and G in Fig. 5-2.

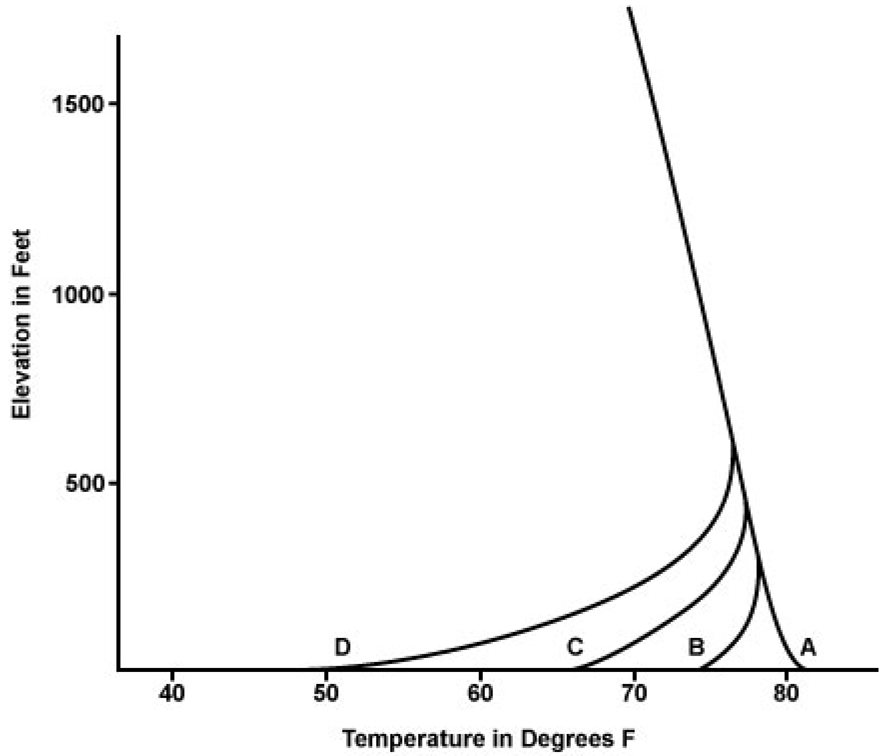


Figure (5-1): Growth of ground-based nocturnal temperature inversion due to cooling from below

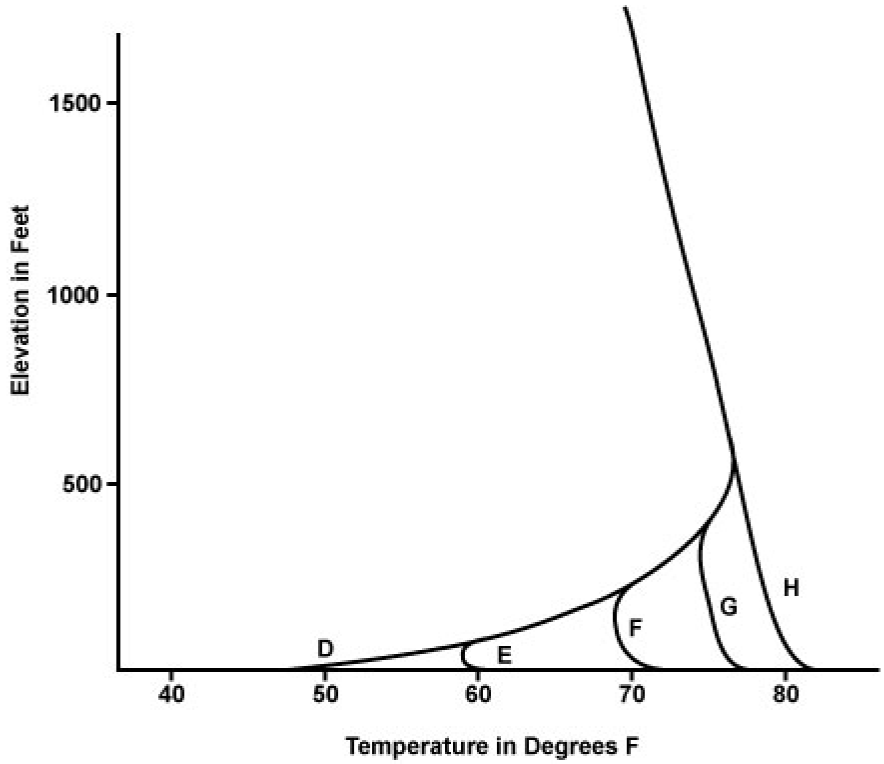


Figure (5-2): Growth of elevated daytime temperature inversion due to heating from above

Let us briefly note the principal features of curves F and G, which are typical early-morning temperature distributions. Close to the ground is a thin unstable region in which heating from below is taking place. Some distance higher up is an elevated stable region in which exists a zone of temperature inversion. There are two regions of well-mixed atmosphere, one on either side of the inversion zone. They are characterized by different potential temperatures which, however, are coming together as heating continues. Finally, we reach the configuration in curve H, which is the same as curve A in Fig. 5-1. We have thus come full circle, and the diurnal cycle is complete.

5.2 Microwave Propagation in Nonstandard Atmosphere

In this section, we consider the effects of the dynamic situations described in the previous section on the propagation of microwaves through the regions in which they occur. We shall do this through the use of Eqs. (4.5) and (4.22). In Section 4.2, we found the normal variations of the partial pressures of dry air and water vapor and of temperature with elevation in the atmosphere to be such as to cause the microwave refractivity to decrease with elevation. Through Eq. (4.22), we found the radius of curvature of a microwave ray path to normally be of the order of magnitude of four times the radius of the earth. It has, in fact, become customary to define standard refraction as that for which the ray path curvature is exactly four times the radius of the earth. Evidently, changing the variations of pi, e, and T in Eq. (4.5) with elevation can lead to conditions of refraction in which the ray is either more curved or less curved than for standard refraction. If the ray path is more curved, it can more nearly follow the curvature of the earth, thereby increasing the maximum spacing between a pair of antennas of specified heights which permits them to be connected by a ray path not intercepting the surface of the smooth earth. For given antennas with given separation, increasing the curvature of the ray path between them increases the Fresnel-zone clearance of that path over the terrain. Clearly, such propagation conditions are superior to those associated with standard refraction, so refraction under these conditions has been appropriately described as superstandard refraction.

Conversely, less than standard refraction leads to reduced maximum permissible separation between a given pair of antennas and to reduced Fresnel zone clearance for the path between a given pair of antennas with given separation. Such refraction is known as substandard refraction.

The present section explores how the parameters p', e, and T in Eq. (4.5) must vary with elevation to give rise to superstandard and substandard refraction.

Superstandard refraction

Equation (4.5) indicates that reducing the rate of decrease of temperature with elevation, all other things being the same, results in a more gradual decrease of refractivity N or refractive index n with elevation, whereupon it follows from Eq. (4.22) that the radius of curvature p of the ray path becomes smaller. It then becomes natural to inquire whether p can become equal to or smaller than the earth's radius and under what condition this can happen. If we suppose that p' and e remain as for the standard atmosphere, we find from Eq. (4.5) that the temperature gradient must be +9.3°F per 100 ft for this to happen. A temperature inversion of this magnitude seems so large that we cannot reasonably expect it to occur in practice, so we must conclude that the condition p = a can occur only through the combination of a temperature inversion with an unusual distribution of another parameter. Because the coefficient of e in Eq. (4.5) is so much larger than that of p', the refractivity is much more sensitive to e than to p'. In fact, when we consider that the water vapor concentration in the atmosphere becomes saturated at all reasonable temperatures while e is still small compared to p', we are left with the conclusion that the distribution of e is the only other parameter which might contribute appreciably to the production of the condition p = a.

In the case of the nocturnal ground-based temperature inversion illustrated in Fig. 5-1, the magnitude of the accompanying humidity gradient will depend in large measure upon the state of motion of the air and upon the character of the underlying surface. Since the air is in stable equilibrium, convective transfer of moisture in the vertical direction will be at a minimum. If the air is currently over dry land and had been moving over dry land for the past several hours, the specific humidity at all levels will be low, and the gradient of e will be negligible. The microwave path curvature will remain large in spite of the temperature inversion. This condition is common during the night over extensive desert areas. On the other hand, if the air mass moves over a body of water after an extensive passage over dry land, it may be expected to develop a considerable e gradient close to the surface. At the surface itself, the relative humidity will be close to 100 percent; because of the lack of convection, moisture will be carried upward only through the less efficient processes of diffusion and turbulence. This is conducive to an e distribution decreasing exponentially with elevation. The e gradient in this case can be and often is large enough so that, in combination with the temperature inversion, the path curvature p can become equal to or less than the earth's radius. This situation is frequently encountered off the eastern coast of the United States.

The situation depicted in Fig. 5-2, caused by heating from below, frequently leads to short-term disturbances to propagation within narrow ranges of elevation up to several hundred feet above the ground. For this to occur, the underlying ground must be moist. The well-mixed region with adiabatic temperature gradient lying under the zone of temperature inversion can then contain a high water-vapor concentration all the way up to the base of the inversion. Because of the stability of the air within the inversion zone, penetration of moisture into this zone is blocked, and a large gradient of e results. It thus becomes possible for the microwave path curvature p to become equal to or smaller than that of the earth's surface.

Subsidence inversions are almost always accompanied by strong refraction effects.* The subsiding air, having been originally quite cool, contains very little moisture. The underlying air, on the other hand, is usually well mixed by convection, so the specific humidity near the base of the inversion is likely to be not much different from that near the ground. The e gradient is thus likely to be large through the temperature inversion zone. As was noted earlier, this type of inversion occurs frequently and lasts for considerable periods of time in the Los Angeles area. Although the presence of subsidence inversion is less likely to he detected by the casual observer when it is not accompanied by air pollution, its effects on radio transmission may still be severe.

* Ref. 1, page 261.

Substandard refraction

Thus far, we have considered only the possibility that temperature inversion could cause the radius of curvature of a microwave ray path to decrease from the standard value 4a to a. This corresponds to an increase in the effective earth radius factor K from 4/3 to 00, at least over a very restricted range of elevations. From Fig. 4-5, it would appear that the average value of K through the first 1000 feet of the atmosphere can range considerably above and appreciably below this value. It remains to inquire what atmospheric conditions are conducive to extremely low values for K. For the answer, we may consider the situation discussed under "heating from below" in Section 5.1, in which a considerable mass of air in unstable equilibrium lay next to the ground. We found this region to be characterized by an unusually rapid decrease in temperature with elevation. Upon inspection of Eq. (4.5), we find that a sufficiently rapid decrease in T might actually cause N to increase with elevation. This would require that p' and e decrease slowly enough with elevation to permit T to dominate the variation of N. As a matter of fact, we can expect p' and e to decrease more slowly in a region in unstable equilibrium than in one in neutral equilibrium. To see that this is true, we may perform a hypothetical experiment. Let us begin with an atmosphere which is well-mixed all the way to the ground. It is in neutral equilibrium at all elevations. Through a succession of steps, we may now set up a condition of unstable equilibrium in the layer of air nearest to the surface without disturbing the state of neutral equilibrium in the air above it. First, while forcibly constraining each air parcel against expansion, we may supply heat to the parcels near the surface in such a way as to obtain the desired temperature distribution. Each air parcel thus heated not only rises in temperature but also exerts increased pressure against the surrounding air. Normally, this increase in pressure would cause the air to expand until a pressure balance was again established. Air parcels nearer to the ground, because they had received more heating, would have increased more in pressure than parcels higher up and would therefore have to expand by a greater amount to restore their original pressures. Rather than allow expansion to take place, which would complicate comparison between the initial state and the final state, however, we may bring the pressure distribution back into balance by removing an appropriate amount of air from each parcel. It is now evident that, although the pressure at the boundary between the regions of neutral and unstable equilibrium has not been affected, an entirely, new pressure distribution must exist throughout the region of unstable equilibrium between this boundary and the ground. This follows directly from the hydrostatic pressure relation, Eq. (4.7), when we note that the quantity ml/v, representing the density of the air in any given parcel, has been reduced below its original value as a result of the withdrawal of air from the parcel. In short, we see that the pressure gradient dp'/ dh in the region of unstable equilibrium is smaller than it was in that same region when it was in neutral equilibrium. We have thus established that replacing a surface layer in neutral equilibrium by one in unstable equilibrium increases the temperature gradient and at the same time decreases the pressure gradient. It then follows that this causes Eq. (4.5) to lead to a slower decrease of N with elevation than in the case of a well-mixed atmosphere.

In the special case of vanishing dN/dh, no refraction occurs at all, and the ray travels in a straight line. K is then unity. When dN/dh actually becomes positive, the ray travels along a path which is concave upward rather than downward. This situation is known as inverse bending.

Reflection from atmospheric inhomogeneities

Ordinarily, we regard reflection as arising only at surfaces of discontinuity between dissimilar media. Actually, under appropriate circumstances, it can take place from the interior of a medium whose properties vary continuously from point to point. To understand how this can happen, we may refer to Fig. 4-2 and consider first the configuration of a large number of very thin air layers, each having a refractive index ni differing only slightly from those of its nearest neighbors and then the limiting configuration shown in Fig. 4-2(c). In the former case, we note that a reflected wave arises at each interface in accordance with Snell's law for reflection, its amplitude being governed by Fresnel's formulas, Eqs. (3.6) and (3.7). Because of the slight differences in refractive index between adjacent layers, each reflected wave has much smaller amplitude than does the incident wave, and we incur only minor error by ignoring secondary reflections, that is, subsequent reflections of reflected waves. To a reasgnable approximation then, we can regard each interface as giving rise to a reflected wave which returns eventually to region no. We may readily verify through Snell's laws that all such reflected waves are parallel in region no. If the interfaces are equally spaced, the waves arising from reflection at successively higher interfaces have phase lags which form a linear sequence. If, in addition, the refractive indexes of successive layers form a monotone sequence, then these waves can yield an appreciable resultant only if the total range of phase lags is small compared to 2W. The same conclusion remains valid when we pass from the case of many close-spaced reflecting interfaces to a continuous refractive-index gradient. It follows that a region of continuous refractive irregularity can give rise to a reflected wave of significant magnitude if the region is narrow enough and the angle of incidence of the incident wave large enough so that the path differences of rays via reflection points at extreme positions within the region cannot differ by an appreciable fraction of 2W. In this context, "appreciable" means any fraction larger than about 0.3 or 0.4. It seems reasonable to expect that these conditions would sometimes be satisfied at microwave frequencies when a narrow region of rapid refractive index variation lies only a short distance above or below the line- of-sight path joining a pair of antennas. Such effects might be observed when an elevated inversion zone exists close to the propagation path.

5.3 Propagation Ducts and the Modified Refractive Index

In the previous section, it was shown that a microwave ray path could be refracted strongly enough to enable the ray to follow the curved surface of the earth. When this happens, the ray can evidently traverse an indefinite distance at a fixed distance above the ground. Such a transmission path is said to lie in a ~. This section explores in detail the mechanism which produces ducts and determines their properties.

In discussing propagation in the presence of ducts, it proves useful to introduce a new quantity in terms of which to describe the refractive properties of the atmosphere. It is currently customary to denote this quantity by the symbol M and to refer to it as the modified refractive index.* It is defined in a manner which seeks to accomplish two aims: (1) Its vertical gradient should vanish at any elevation for which the path of a ray launched horizontally is a circular arc concentric with the surface of the earth; and (2) it should be readily calculable from refractivity N. To satisfy the first aim, we can define M so that

$$\frac{dM}{dh} = \frac{dN}{dH} + \frac{10^6}{a+h} \tag{5.1}$$

in which a and h are the radius of the earth and the height of the ray path above the ground, respectively, for setting n = 1 in Eq. (4.22) reveals that dN/dh = -ld3/(a + h) at any elevation at which a ray path is a circular arc concentric with the surface of the earth.

Integrating Eq. (5.1) yields

$$M = N + 10^6 \ln(a+h) + N_1 \tag{5.2}$$

in which Dl is an arbitrary constant which we can set equal to -lOS ln a to make M and D coincide at h = 0. Equation (5.2) then becomes

$$M = N + 10^6 \ln\left(1 + \frac{h}{d}\right) \tag{5.3}$$

Although this result satisfies the first aim above, it does not satisfy the second because of the presence of the logarithm. However, since h « a on all reasonable line-of-sight microwave links, we can replace the logarithmic term in Eq. (5.3) by the first term in its series expansion with only negligible error. Equation (5.3) then becomes

$$M = N + 10^6 \frac{h}{d} \tag{5.4}$$

which readily satisfies the second aim above. It no longer satisfies the first aim precisely, but the error is of negligible magnitude as long as h « a. It is thus customary to use Eq. (5.4) as the definition for M.

For insight into the physical significance of the quantity M, we may note that the foregoing method for defining it would cause dM/dh to vanish identically at all elevations in a homogeneous atmosphere over a flat earth. M, itself, would then be a constant, having at all elevations the same numerical value which it had at ground level. For this reason, a procedure based on the use of M rather than of N is frequently called an earth-flattening procedure.

Because of the approximation we introduced in passing from Eq. (5.3) to Eq. (5.4), M as defined by the latter does not yield vanishing dMldh at precisely the same elevation at which a microwave beam launched horizontally remains parallel to the earth. However, the approximation remains close as long as h « a, so we may consider that the two elevations coincide for all practical purposes. Throughout the remainder of our discussion, we shall regard the vanishing of dM/ah as precisely locating an elevation at which a wave launched horizontally remains parallel to the surface of the earth. A plot of M against h therefore provides a convenient means for revealing the presence of ducts. Moreover, as will be seen shortly, the shape of the M-profil~, as such a curve is customarily called, yields useful information on the properties of any duct that may be present.

In a standard atmosphere with p = 4a at all elevations, we found earlier that dN/dh was of magnitude -106/4a. Upon substituting this value into Eq. (5.1) and replacing the denominator of the final term by simply a in view of the condition h « a, we find for dM/dh at all elevations the value loP(3/4a) ft-l. With the appropriate numerical value substituted for a, this becomes 0.036 ft-l. The M-profile for this standard atmosphere is thus a straight line with positive slope at all elevations.

Ground-based ducts

We have seen that a duct is characterized by propagation conditions which allow an initially horizontal ray path to remain parallel to the earth over an indefinite distance. Moreover, we have defined M so that dM/dh practically vanishes along such a path. We may therefore use the vanishing of dM/dh to locate a duct. This is illustrated in Fig. 5-3, which depicts an M-profile for a typical ground-based duct. On this profile, dM/dh vanishes at point 0, a height OP above the ground. This height is typically of the order of a few hundred feet or less. To determine the properties of this duct, we shall examine a bundle of initially parallel rays launched horizontally at various elevations. In order to do this, we shall need to know how the radius of curvature of the microwave path varies with dM/dh. Substituting Eq. (4.2) into Eq. (4.22) and replacing dN/dh in accordance with Eq. (5.1) yields

$$p - \frac{1}{\frac{1}{a+h} - 10^{6}\frac{dM}{dH}} \tag{5.5}$$

as the desired relation. This expression reveals, as we had surmised earlier, that p becomes equal to a + h when dM/dh vanishes. We see further that positive values of dM/dh lead to smaller values for p, and vice versa. The effect of the ground-based duct shown in Fig. 5-3 on rays launched horizontally at various elevations must thus be generally as indicated in Fig. 5-4. This is a ~lattened-earth diag~, in which rays traveling horizontally with radius of curvature a + h appear as horizontal straight lines. One such ray appears at the elevation for which dM/dh vanishes on the M-profile shown at left. Since dM/dh is negative below this elevation, p is smaller than a +h in this region in accordance with Eq. (5.5) and must therefore appear concave downward in Fig. 5-4. By the same token, rays above this level must appear concave upward. If the duct is uniform in the horizontal direction, that is, if its M-profile is the same at all locations over a geographical region of considerable size, the path of any ray must be symmetrical about the point at which it is parallel to the ground.

We can gain additional insight into the behavior of a ground-based duct by studying Fig. 5-5. This figure shows the various paths a ray may follow when launched at various angles above the horizontal from a transmitting antenna on the ground at point T. Study of these paths reveals that there is a critical angle at which a ray must be launched in order to enter the dM/dh = O level without passing through it and escaping from the duct. Even when the ray is launched at this angle, however, it approaches the dM/dh = O level asymptotically; thus, it never actually reaches it. Two other cases are of greater practical importance: (1) When the launch angle exceeds the critical angle, the ray escapes from the duct; (2) when the angle is less than the critical angle, the ray reaches a maximum height which is closer to the dM/dh = O height the nearer the launch angle is to the critical angle, and the ray returns to the ground from its point of maximum height via a path which is symmetrical about its path up to that point with respect to a vertical through it. If the ground is horizontal and specularly reflecting, a reflected ray traverses a path symmetrical with respect to the incident ray, reaching the same height as the incident ray and returning to the ground for a possible second reflection. At microwave frequencies, it seems reasonable to expect the ground to generally be sufficiently irregular that a reflected field would be dissipated by diffuse reflection and escape through the top of the duct if it required more than a single reflection in order to reach the receiving antenna. These observations justify our designating the elevation at which dM/dh vanishes as the top of the duct and regarding the duct as extending from the ground up to this elevation. Rays which are unable to penetrate the upper boundary of the ground-based duct are said to be trapped in it. We can draw several significant conclusions concerning the performance of a line-of-sight microwave link in which the transmitting antenna is below the top of a groundbased duct: (1) There will always exist one and only one direct ray path between the transmitting and receiving antennas, and its Fresnel-zone clearance will exceed that of the path prevailing in the absence of the duct. (2) If both antennas are below the top of the duct, there may also be one significant reflection path. Barring interference between rays traversing the direct path and such a reflection path, transmission between antennas beneath the top of a ground-based duct generally leads to improved reception as compared with transmission in the absence of the duct.

If the transmitting antenna is located above the top of the duct, the paths followed by rays launched at various angles above or below the horizontal become as shown in Fig. 5-6. We see that trapping is again possible, the launch angle for trapping again being critical. Launch angles above the critical angle enable the rays to remain always above the top of the duct; those below the critical angle cause the rays to penetrate the top of the duct and reach the ground. As described above, the latter rays may be reflected. If the ground is horizontal and specularly reflecting, the reflected rays penetrate the top of the duct. We may draw an important conclusion concerning the performance of a line-of-sight microwave link operating between antennas at least one of which is above the top of a groundbased duct; Ther~ will always be one and only one direct path connecting the two antennas, and there may be one significant reflecting path. The presence of a ground-based duct should evidently lead to improved reception even when the antennas are above the top of the duct, provided that the ground surface is such as to not lead to reception of a strong reflected signal by the receiving antenna.

Elevated ducts

Just as a ground-based duct arises when a ground-based temperature inversion occurs simultaneously with a steep negative gradient of water-vapor pressure in the same range of elevations, an elevated duct can occur some distance above the ground when the appropriate temperature inversion and humidity gradient are present. As in the case of the ground-based duct, the occurrence of an elevated duct is predicated upon the condition that dN/di1 be negative through some range of elevations. The typical situation is illustrated in Fig. 5-7. The range of negative dN/di1 in this case lies between points O and P, dN/di1 vanishing at both of these points. To determine the behavior of microwaves in the presence of such an M-profile, we may use Snell's law. Since M is analogous in a flattened-earth diagram to n in the actual atmosphere, we may use

$$M_0 \sin\theta_0 = M_1 \sin\theta_1 \tag{5.6}$$

as the analog of Eq. (4.20). eo represents the angle between the ray and the vertical at an elevation for which M has the value Mo. Similarly, ~ is the same angle at the elevation where M has the value M1. In particular, Eq. (5.6) tells us that a ray passing between two elevations makes the same angle with the horizontal at each elevation if M has the same value at both. A ray launched horizontally at any elevation between points S and I in Fig. 5-7, M having the same value at point S as at point I, thus always remains within the limiting elevations bounded by these points. Such a ray is said to be trapped in the elevated duct. The limiting elevations between which trapping can occur are marked by points O and Q, and they are defined as the elevations of the top and the bottom of the duct, respectively. Similar reasoning leads us directly to the conclusion that rays launched horizontally at elevations above point O or below point Q follow paths which are concave upward. In the former case, the ray diverges from the duct from the beginning; in the latter case, it first penetrates the base of the duct, passes through it, and then emerges through the top at the same angle with the vertical at which it had entered the base. It immediately follows that a ray cannot be trapped within an elevated duct in the above manner unless the transmitting antenna from which it was launched was itself located within the duct. On the other hand, the type of trapping that occurs in a ground-based duct can also occur in an elevated duct, for the refractivity profile in the vicinity of the top of an elevated duct has the same general shape as that in the vicinity of the top of a ground-based duct. Thus, a ray launched horizontally at a point at the top of the elevated duct will remain at that elevation, while rays launched horizontally at points just above or below the top will diverge away from their initial elevations in a manner similar to that shown in Fig. 5-4.

By analogy with the types of mechanical equilibrium described in Section 5.1, we may conveniently distinguish between the two types of trapping exemplified by Figs. 5-4 and 5-6. In the former, a horizontal ray at precisely the top of the duct will remain there indefinitely while one displaced slightly above or below the top will become displaced progressively further. This behavior is reminiscent of unstable equilibrium, so it would be meaningful to refer to such trapping as unstable trapping. Similar reasoning suggests for the type of trapping shown in Fig. 5-6 the name stable trapping. In principle, at least, there could exist a form of trapping for which the name neutral trapping would be applicable. Evidently, however, this would require that the modified refractive index M be constant over a significant interval of elevation, a rather stringent condition that we should not expect to find satisfied very often if ever at all.

It is of interest to note how the power density in a wave is affected by each of these types of trapping. This requires that we examine whether trapping causes a bundle of rays from the transmitting antenna to become more divergent or less divergent than it would be in the absence of trapping, and we should be cognizant of the limitations of ray optics in comparison with wave optics.

To ascertain these properties of waves subjected to unstable trapping, we need consider merely the basic fact that rays slightly above or below the unstable trapping level diverge increasingly from that level. Thus, the divergence of a bundle of rays whose central ray was approaching the unstable trapping level asymptotically must increase as the bundle progresses along the duct. In other words, energy leaks out of the trapping level continuously. Through this mechanism alone, we find that the power density in the unstably trapped wave must decrease with distance more rapidly than would be given by an inverse square law. On the other hand, this attenuation rate remains smaller than it would be for a diffraction path of similar length beyond the horizon. It remains to consider the effect of the approximation inherent in ray optics. If the refractivity gradient varies rapidly enough with elevation in the vicinity of the unstable trapping level so that an appreciable change in refractivity gradient takes place within a vertical interval of the same order of magnitude as the radiation wavelength, diffraction effects will not be negligible and will cause additional leakage of power to take place from the unstable trapping level. We would not ordinarily expect this to be an important consideration at frequencies in the microwave range.

In a stable trapping level, reasoning similar to the above leads us to the conclusion that the divergence of a bundle of rays is decreased by the duct, so that the attenuation rate of the wave is less than that given by the inverse square law. We thus conclude that stable trapping should be considerably more effective than unstable trapping in promoting the appearance of abnormally strong signals at extreme distances from the transmitting antenna.

To gain further insight into the effect of an elevated duct on microwaves, we can examine diagrams corresponding to Figs. 5-5 and 5-6. Thus, Fig. 5-7 indicates qualitatively the behavior of rays launched horizontally at various elevations above, within, and below an elevated duct. The follow~ ing noteworthy facts may be deduced from the diagram: (1) A ray launched horizontally at the top of the duct remains trapped at that elevation indefinitely. (2) A ray launched horizontally at the dM/dh = a level intermediate between the top and bottom of the duct remains trapped at that level indefinitely. (3) A ray launched horizontally at the bottom of the duct ascends through the duct and asymptotically approaches a trapped state in the top of the duct. The above three rays are shown in Fig. 5-7 by extra heavy lines. (4) Rays launched horizontally from points outside the duct cannot become trapped in the duct. (5) No ray launched horizontally from any point within the duct can escape from the duct.

Figure 5-8 shows, again qualitatively, the behavior of rays launched at various angles from points above and below an elevated duct.

Significant facts that can be deduced from this diagram are the following: (I) A ray launched at a critical angle below the horizontal from a point above the top of an elevated duct can become trapped in the unstable trapping level at the top of the duct. (2) No other ray launched from outside the duct can become trapped within the duct. (3) If a transmitting antenna above an elevated duct is connected to a receiving antenna by a line-of-sight path in the absence of the duct, that path being intercepted by the duct when the latter is present, there may exist two paths not involving reflection when the duct is present, one penetrating below the bottom of the duct while the other does not. If the receiving antenna is above the duct, the higher path lies entirely outside the duct.

Figure 5-9 shows the behavior of rays launched from an antenna located within an elevated duct. It reveals the following significant facts: (1) When a transmitting antenna is located within an elevated duct, rays over a broad range of launching angles above and below the horizontal are trapped within the duct. (2) Radiation from each such antenna has a critical launching angle for which a ray approaches the top of the duct asymptotically. (3) There are generally a number of paths by which radiation from a transmitting antenna within an elevated duct can reach a receiving antenna within the same duct. (4) There are at most two paths by which such radiation can reach a receiving antenna above the duct. (5) There is only one path by which such radiation can reach an antenna below the duct.

5.4 Multipath Propagation due to Atmospheric Inhomogeneity

In Sections 3.1,3.2, and 3.4, we considered multipath effects due to reflection from the ground. We now consider situations in which multipath propagation can arise directly from the state of the atmosphere itself without in any way involving reflection from the underlying terrain. These types of multipath interference can occur in a line-of-sight microwave link even when the antennas have been so located as to provide more than adequate Fresnel-zone clearance and to fully avoid all possibility of reflection from the ground. They are caused not by reflection from the ground but by refraction in the air and possibly by reflection within the atmosphere itself. We may recognize two distinct forms of multipath interference attributable to atmospheric inhomogeneity. One is most likely to be observed when the atmosphere is in a quiescent state. It is due to the presence of ducts.*

* Particularly lucid accounts of the multipath effects attributable to elevated ducts are given in Refs. 4 and 6, which describe two exhaustive series of experiments on microwave paths in New Jersey.

As explained in the previous section, elevated ducts may cause two or more propagation paths not involving reflection to exist, the specific number of paths in any given case depending upon the positions of the antennas with respect to the duct. In addition, there may be reflection paths due to glancing incidence of radiation upon narrow regions in which exist exceptionally large refractivity gradients. The mechanism underlying such reflection is discussed in Section 5.2.

Although a ground-based duct was shown in Section 5.3 to be incapable of supporting more than a single path between two antennas without involving reflection, the possibility that reflection might take place at the narrow region of large refractivity gradient that sometimes marks the top of a duct raises the possibility that both refractive and reflective paths may occur via the top of the duct when both antennas lie on the same side of the top of the duct.

Finally, there is a form of multipath propagation that can occur even when there are no ducts present. Moreover, unlike the multipath conditions induced by ducts, which occur in still air, the form of multipath propagation now to be discussed occurs principally in turbulent air. Its mechanism is identical with that which causes stars to appear to twinkle. Although it is most pronounced on long paths, especially on transhorizon paths, its extent is by no means negligible on shorter ones. An oversimplified illustration will clarify the mechanism involved. Suppose the atmosphere to have a normal refractivity gradient everywhere except within a small region lying slightly above the midpoint of the nominal line-of-sight path joining a pair of antennas. Suppose the refractivity gradient within this region to be larger than usual, so that a microwave beam passing through it is deflected downward through a larger angle than it would under normal conditions. The possibility thus arises that two different rays from the same transmitting antenna may both reach the receiving antenna, one by the nominal line-of-sight path and the other by a path through the region of abnormal refractivity. If instead of one small region with perturbed refractivity gradient there are many such regions distributed at random throughout the entire atmosphere along the line-of-sight path, there may exist many separate paths by which radiation from the transmitting antenna may reach the receiving antenna.

Multipath propagation might be of relatively minor practical importance in radio technology if each of the separate paths was stable in time. The response of the receiving antenna would be simply the resultant of its responses to the individual signals, and this would be a steady signal whose only possible objectionable feature attributable to multipath propagation would be the presence of echoes or envelope distortion resulting from the superposition of multiple replicas of the same signal with different time delays. By using antennas with sufficiently narrow directivity patterns, thereby eliminating all paths except those with propagation times lying within a sufficiently narrow range about the value for the nominal line-of-sight path, we could suppress this effect to any desired extent.

In practicet of courset the situation is not this simple. Even though the range of time delays is brought within acceptable limits by using highly directive antennas, it is found that the amplitude of the resultant signal is unstable in the presence of multipath conditions. This is due to the fact that path length variations between different component signals are large compared with the radiation wavelength and therefore give rise to rapid alternations between constructive and destructive interference among the carriers. In the case of multipath propagation induced by the presence of ducts, the variation in path lengths is due to the fact that the ducts are not absolutely stationary, their vertical refractivity profiles generally varying slowly. Several experimental studies carried out on microwave paths on which this type of propagation was taking place are noteworthy for the clarity with which they reveal the mechanisms responsible for the variability of the received signal strengths. In three of these, measurements were made of the angles of arrival of microwaves on line-of-sight routes.4,7,B These revealed that signal components occasionally arrived at angles as much as 0.75 degrees above the nominal line-of-sight plane and that as many as four separate signal components arriving from different directions in the vertical plane could be observed simultaneously. Delay-time measurements with pulsed signals clearly revealed that signals arriving via different paths varied continuously in relative delay time.6

In the case of multipath propagation associated with refractivity inhomogeneities distributed irregularly throughout an entire air mass, the propagation path lengths vary since the air parcels with different refractivities are in constant movement due to turbulence in the atmosphere. Although a turbulent air mass which is exchanging neither heat nor moisture with its surroundings must eventually reach the well-mixed state characterized by normal propagation, we cannot safely assume merely because the air is turbulent that it is well-mixed and will yield normal propagation. In the first place, we have seen that the atmosphere can develop ducts and other stratified refractivity irregularities through the mechanisms of heating and cooling from below. Even if thermal exchange with the ground ceases simultaneously with the onset of turbulent mixing, it will take some time for the mixing processes to bring about the well-mixed state. During this time, we may expect to observe multipath propagation due to irregularly distributed atmospheric inhomogeneities. In the second place, it is not reasonable to suppose that heat and moisture exchange with the ground will cease with the onset of 'turbulence. More likely, the turbulence is directly attributable to heating from below. The theory behind multipath interference associated with turbulent motion of inhomogeneous air is developed in one classical paper which, although pertaining directly to scatter propagation, is also applicable to line-of-sight propagation.[9] Further discussion of this theory with specific application to propagation on line-of-sight paths appears in a number of other papers.[lO,11,12,13,14] Direct experimental measurements of short-range spatial fluctuations of atmospheric refractivity are presented in two other papers,[15,16] and recordings of received microwave signal levels exhibiting fluctuations attributable to this mechanism may be found in a number of papers.[ll,17,lB]

References for Chapter V

1. Kerr, Propagation of Short Radio Waves, McGraw-Hi11, New York (1951).

2. Humphreys, Physics of the Air, third edition, McGraw-Hi11, New (1940).

3. Zemansky, Heat and Thermodynamics, third edition, McGraw-Hi11, New York (1951).

4. Crawford and Jakes, Selective Fading of Microwaves, BSTJ, .n, 68-90 (1952).

5. Friis, Microwave Repeater Research, BSTJ, 12, 183-246 (1948).

6. De Lange, Propagation Studies at Microwave Frequencies bv Means of Very Short Pulses, BSTJ, 31, 91-103 (1952).

7. Sharpless, Measurement of Angle of Arrival of Microwaves, Proc. 34, 837-845 (1946).

8. Crawford and Sharpless, Further Observations of Angle of Arrival of Microwaves, Proc. IRE, 34, 845-848 (1946).

9. Booker and Gordon, Theory of Radio Scattering in Troposphere, Proc. IRE, 38, 401-412 (1950).

10. URSI, Commission 2 of U.S.A., Report on Tropospheric Radio Propagation, Section 2.4, "Line-of-Sight Scintillation", Jour. Res. NBS, 64D, 613- 614 (1960). -

11. Bogle, Some Aspects of Microwave Fading on Optical Path over Sea, Proc. IEE III, 22, 236-240 (1952).

12. Englund, Crawford, and Mumford, Ultra-Short-Wave Transmission and Atmospheric Irregularities, BSTJ, 12,489-519 (1938).

13. Austin, Effect of Multiple Scattering on Line-of-Sight Propagation, Trans. IEEE, AP-13, 737-742 (1965).

14. Wheelon, Radio-Wave Scattering by Tropospheric Irregularities, Res. NBS, 63D, 205-234 (1959).

15. Essen, Highly Stable Microwave Oscillator and Its Application to Measurement of Spatial Variations of Refractive Index in Atmosphere, Proc. IEE III, !QQ, 19-24 (1953).

16. Busseyand Birnbaum, Measurement of Variations in Atmospheric Refractive Index with Airborne Microwave Refractometer, Jour. Res. NBS, 21, 171-178 (1953).

17. Durkee, Results of Microwave Propagation Tests on 40-Mile Overland Path, Proc. IRE, J§, 197-205 (1948).

18. Barsis, Barghausen, and Kirby, Studies of Within-the-Horizon Propagation at 9300 Mc, Trans. IEEE, AF-ll, 24-38 (1963).

Historical perspective

Calculating the diffraction loss of a radio wave propagating over irregular terrain is not an exact science. The uncertainty becomes more serious when one attempts to account for the surface cover of the terrain. The effects of trees, buildings and street alignment in an urban environment can lead to large discrepancies between measured and predicted results. It is worthwhile to review diffraction loss calculations from a historical perspective to understand the present day state of the art.

The term diffraction, was first coined by Grimaldi in the year 1665 to describe the complex transition pattern between the illuminated and shadow regions, formed when light strikes an opaque object.

In the year 1818, Fresnel developed the mathematical theory of diffraction. Fresnel's model incorporated most of the physical principles in modern diffraction theory including Fresnel zones and Fresnel integrals. A subsequent refinement, known as the Fresnel-Kirchhoff theory forms the basis of modern day diffraction theory.

An exact calculation of diffraction loss for a simple obstacle geometry was now possible; the most notable of these being a simple knife edge.

The first successful application of knife edge diffraction theory at radio frequencies was carried out in 1933, over a mountain range by ATT (Schelling et. al) in the VHF frequency band.

When the Fresnel - Kirchhoff theory was first applied to radio propagation, it became apparent that a closed form solution to irregular terrain was not possible. The problem was described as one of the most difficult facing the mathematical physical sciences. This was attributed to the extremely small wavelengths in comparison to the radius of the earth.

The case of propagation over a smooth spherical earth became the major objective as the range of radio transmission increased. The special case of propagation over flat earth had been previously solved by Sommerfeld.

One of the first solutions to the smooth spherical earth is credited to Bremmer for work carried out during the years 1944-45 at the Philips Research Laboratory in Holland. The solution is in the form of an infinite series known as the residue series. The series converged rapidly for paths well beyond the horizon, but very slowly for path lengths near the horizon distance.

At this point, solutions were available for the two limiting cases: knife edge and smooth earth diffraction. Unfortunately, the majority of practical terrain profiles fall in between these two extremes. Two approaches have been taken to handle the intermediate cases.

The first was the use of numerical methods to solve the Fresnel-Kirchhoff equations over irregular terrain using high speed computers. Numerous papers were published describing the methods and the results; however, it is generally accepted that this approach is not practical for general design purposes.

In the second approach, hybrid propagation models were developed which characterize the earth as a series of knife edge obstacles and combinations of smooth earth and knife edge diffraction. The major work in this area was carried out in the years 1950 to 1970 under the auspices of the US National of Bureau of Standards. The results are embodied in the publication:

> Transmission Loss Predictions for Tropospheric Communication Circuits
>
> Technical Note 101
>
> Longley, Rice, Norton and Baris

The diffraction algorithms used in the Pathloss program are based on this document. Significant errors can occur when the terrain does not fit the diffraction model for which it was developed. Diffraction loss calculations consider a terrain profile as a slice through a section of the earth. The terrain across or perpendicular to the path is assumed to be constant. The effects of reflections and scatter from terrain and structures which are not on the direct path are ignored.

In recent years, ray tracing and rendering techniques have been applied to propagation over three dimensional surfaces; and in particular, digital models of cities. This approach is expected to become more commonplace as computer speeds increase and the cost of digital models of cities become more affordable.

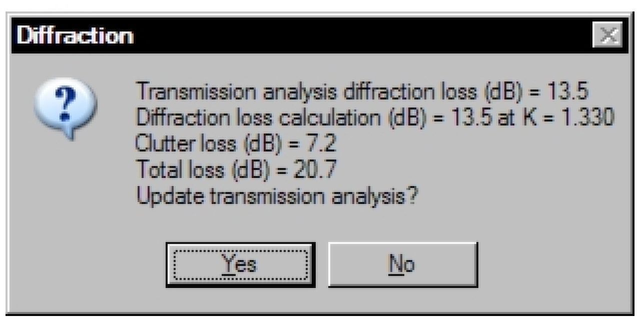
Overview

All diffraction algorithms are deterministic. A terrain profile is required and the calculations are based on the profile geometry. An accurate representation of the effective earth radius is achieved by adding temporary points to the profile using linear interpolation so that the minimum spacing between points is one percent of the profile length.

All calculations are inhibited if either antenna height is zero.

Diffraction loss calculation is saved in the Pathloss data file; however, the results are automatically erased whenever a parameter is changed, which would invalidate these results. These parameters include:

- terrain profile elevations path length
- structures (locations and heights) frequency
- polarization antenna heights
- earth radius factor K the diffraction algorithm



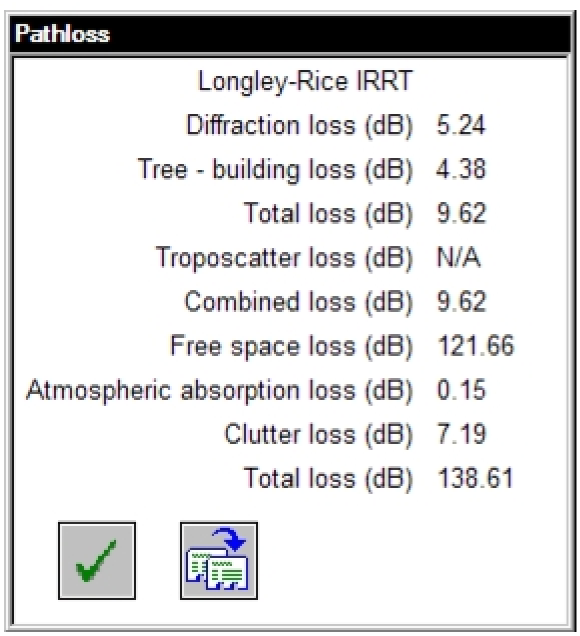
The diffraction loss is <u>not</u> automatically transferred to the transmission analysis design section. Many operations are carried out in the diffraction section which are not applicable to the transmission path. These include the calculation of diffraction loss as a function of the earth radius factor (K) and analysing the loss from a reflection point to an antenna. If the transmission analysis diffraction loss entry is different than the current diffraction loss calculation, you will be prompted to use the calculated value.

Diffraction algorithms

The following diffraction algorithm selections are available on the control bar.

Knife Edge	Average
Isolated Obstacle	Height Gain
Longley & Rice Irregular Terrain	Two Ray Optics
Pathloss	TIREM (Terrain Integrated Rough Earth Model)
NSMA (National Spectrum Managers Association)	

Automatic diffraction algorithms



The algorithms Pathloss, TIREM and NSMA are referred to as the automatic algorithms. When one of these have been selected, just click the Calculate button or press F9 to carry out the calculation. These algorithms analyse the terrain profile in accordance with a set of rules, and determine which algorithm, or combination of algorithms to use. Note that the pathloss algorithm can be configured for special cases. The choice of diffraction algorithm depends on your application. The following are some general guide lines:

- The NSMA algorithm is intended for interference calculations. This is the current standard of the North American frequency coordination industry.
- The TIREM algorithm has been used as the base algorithm for the design of most cellular radio networks.
- The Pathloss algorithm (using the default configuration) is recommended for transmission applications.

Manual diffraction algorithms

The remaining algorithms are referred to as manual calculations. The user analyses the profile and decides which algorithm(s) to use on which segment of the profile. Manual calculations are used to validate the automatic algorithms in critical applications.

Knife edge - isolated obstacle - average

These algorithms all depend on the clearance to first Fresnel zone ratio (C/F1) at the selected point on the profile. The results are cumulative. This allows a path to be analysed as a succession of discreet calculations, by selecting different profile segments and calculating the loss of each segment.

Height gain

This is only used with the above C/F1 type algorithms and represents the additional loss which occurs when there is less than 60% first Fresnel zone clearance between an antenna and its horizon. The calculation is made for both ends of the path and is automatic in the sense that it is not necessary to select a profile segment. The Height Gain is valid only on obstructed paths. The height - gain algorithm is used in all three automatic algorithms.

Longley & Rice Irregular Terrain

This algorithm is applicable to both line of sight and obstructed paths and can only be used over the complete profile. Previous versions of the Pathloss program used the Longley & Rice algorithm as an alternative to the height gain calculation, using the profile segment between an antenna and its horizon. This approach really over extends the use of the Longley & Rice algorithm and has been discontinued.

On obstructed paths the Longley & Rice algorithm will automatically calculate the diffraction loss. On line of sight paths, a reflective plane definition is required.

Two ray optics

Two ray optics is valid on line of sight paths over the complete profile. This has been included primarily to assess the effects of a specular reflection and is not intended as a diffraction loss algorithm. This algorithm requires a reflective plane to be defined.

Tree - building loss

The additional loss of trees and buildings on the profile or ranges of trees and buildings is calculated with any of the automatic diffraction algorithms

Clutter loss

Clutter represents the additional loss produced by trees and buildings in the immediate foreground of a site. The clutter loss calculation is used when it is not practical to enter these structures on the path profile. Instead, a clutter loss calculation is made independently and is shown as a separate term in a total loss display.

Variable parameters

Diffraction loss can be calculated as a function of antenna heights, earth radius factor, frequency or distance along the path. The selected automatic diffraction algorithm will be used for the calculations. If any of the manual diffraction algorithms have been selected, then the Pathloss automatic diffraction algorithm will be used.

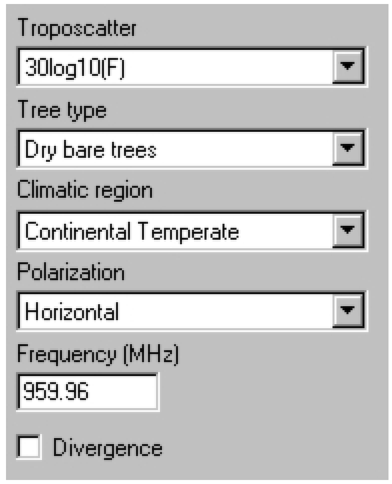
Tropospheric scatter loss

Scatter loss is automatically calculated on obstructed paths and displayed on the status bar. The calculation is valid for an earth radius factor (K) in the range 1.2 to 1.5. Scatter loss is not calculated for paths close to grazing. Two methods of calculating scatter loss are available. The selection is made in the Diffraction Options dialog box.

Diffraction loss configuration

The Pathloss diffraction algorithm and the parameters use in a diffraction loss calculation are set under Configure - Set PL50L options.

Diffraction parameters



Select Configure - Set PL50L options and then select Diffraction - diffraction parameters. Alternately click the frequency box on the status bar.

Tropospheric scatter loss

Tropospheric scatter loss can be calculated using either of the following relationships:

30 * log10(Frequency)

36 + 20 * log10(Frequency)

The latter relationship effectively removes the frequency dependence in tropospheric scatter loss. The cross over frequencies of these two definitions is 3981 MHz. If the scatter loss method is set to Auto, then the program will use the correct method, based on the specified frequency.

If the NSMA automatic diffraction algorithm is selected, then the 36 + 20·log(f) relationship will always be used.

Tree type

If trees have been entered in the terrain profile, then the tree loss will be calculated using the parameters of the specified tree type.

Climatic region

The climatic region determines the time variability of the combined diffraction and tropospheric scatter loss. This is used in an ONHLOSS calculation.

Frequency

This is the design frequency and is global to all modules in the program.

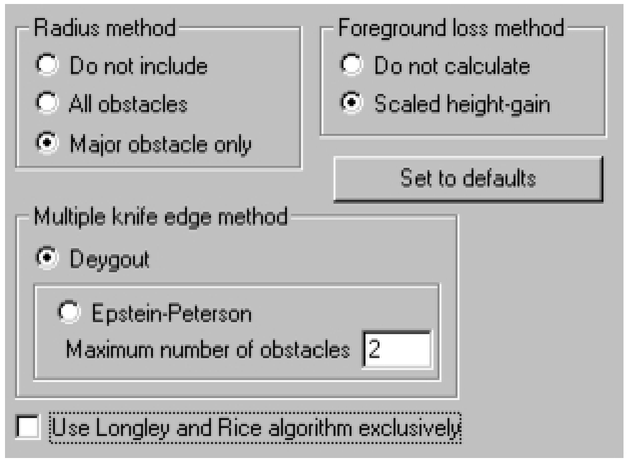
Polarization

This is the design polarization and is global to all modules in the program. With the exception of the two ray optics algorithm, polarization does not significantly affect the diffraction loss calculations.

Divergence

Divergence is the scattering of a reflected wave due to the curvature of the earth. This applies to the two ray optics algorithm only. The option is global and its primary use is in the Multipath - reflections design section.

Pathloss algorithm



The default settings are recommended for transmission applications. The algorithm can be configured for special applications or to compare the results with those of other programs.

Radius Method

This setting refers to the radius calculation used by the isolated obstacle algorithm when the terrain is characterized as a single or multiple knife edge. The isolated obstacle algorithm is equivalent to a knife edge if the radius is not used.

No radius

The loss is always calculated as a single knife edge for single or multiple knife edge paths. The results are usually lower than the measured value.

All obstacles

A radius will be used for all obstacles. On multiple knife edge paths, this setting usually results in higher than measured value.

Major obstacle only

If the path contains a single obstacle, the radius will be used. In the case of multiple obstacles, the radius will only be applied to the major obstacle. The major obstacle is the one with the minimum clearance to first Fresnel zone ratio (C /F1). Note that the reference end points are different in the Deygout and Epstein & Peterson multiple knife edge models. In the Deygout model, the C /F1 is referenced to the end points of the profile. In the Epstein & Peterson model, the C/F1 is referenced to the horizons of the obstacle under test.

Multiple knife edge method

Deygout (default)

This model is limited to a double knife edge path. The clearance to first Fresnel zone ratio is calculated for each obstacle, with respect to the end points of the profile, to determine the major obstacle.

The loss of the major obstacle is calculated as a knife edge or isolated obstacle referenced to the end points of the profile, as if the second obstacle did not exist. The loss of the minor obstacle is then calculated with respect to its horizons. The resultant loss is the total of the two calculations.

Epstein & Peterson

In this model, there is no theoretical limit to the number of knife edges; however, the program has an internal limit of 10. The user can set an upper limit in the range 2 to 10. If this limit is exceeded, the Longley & Rice irregular terrain algorithm will be used.

The Epstein & Peterson model treats the terrain as a succession of knife edges. The loss of each knife edge is calculated using the horizons of the knife edge as the end points. The resultant loss is the sum of the individual knife edge calculations.

The results of the Deygout model will always be higher than the Epstein & Peterson model, and therefore, provides a conservative design approach. When the obstacles are widely separated, the Epstein & Peterson model is more accurate. When the obstacles are close together, the Epstein & Peterson model will seriously under-predict the loss.

Foreground loss method

When the terrain is characterized as a single or multiple knife edge, it is necessary to examine the terrain between an antenna and its horizon. If the clearance to first Fresnel zone ratio in this region is less than 60%, additional loss will occur and must be taken into account. This is referred to as the foreground loss.

This calculation is carried out using the height - gain algorithm and should always be used. An option to not calculate this loss is provided primarily as a means to compare the results with other programs.

Use Longley and Rice algorithm exclusively

If this option is selected, all diffraction loss calculations for line of sight and obstructed paths will use the Longley and Rice algorithm.

General operation

General operations for diffraction section display area described in the following paragraphs.

Cursor Control

A cursor is used for the following operations:

- to select a segment of the profile
- to identify the peak of an obstacle using the knife edge, average and isolated obstacle algorithms
- to define a reflective plane
- to obtain additional information on a profile point

Cursor Style

The default cursor is a vertical arrow. This can be changed to lines from the antennas. Press the letter 'A' to toggle between the two formats. Alternately, click on the Cursor Style box on the status bar.

Cursor movement

There are three cursor movement modes:

- P - the cursor can be located on all profile points
- S - the cursor can be located on profile peaks only
- C - the cursor movement is continuous and is not constrained to the profile

These modes are set with the letters P, S or C as indicated above. Alternately, you can click on the cursor movement box on the status bar. The cursor is moved with either the keyboard cursor keys or with the mouse. The movement depends on which cursor movement mode has been selected as described below:

Cursor on All Profile Points

The left and right cursor keys move the cursor to the next profile point in that direction. The left mouse button moves the cursor to the first profile point past the mouse cursor location. The home and end keys move the cursor to the left and right ends of the display.

Cursor on Profile Peaks Only

The left and right cursor keys move the cursor to the next profile peak, or to the end of the display if no peaks are found. The left mouse button moves the cursor to the first peak past the mouse cursor location, or to the end of the display, if a peak is not found in this direction.

Continuous Cursor

The cursor can be positioned anywhere on the display. The left, right, up and down cursor keys move the cursor one increment. The increment is an arbitrary number of pixels established by the screen resolution at start up. The + and - keys increase and decrease this increment. There is no visible indication of the magnitude of the increment.

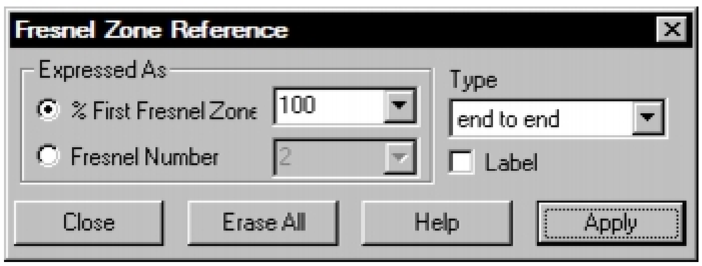
If the cursor is moved above the top of the display, the display will be rescaled by 80%. This may be required to calculate effective knife edge diffraction.

If the cursor is moved below the display and the display has been rescaled, it will be reset to the initial state.

Clicking the left mouse button moves the cursor to the mouse cursor location. The cursor can be moved by holding down the left mouse button and dragging the cursor to its new location.

Fresnel zone reference

Fresnel zone references are used to analyse the clearance on a profile. Select Operations - Fresnel Zones or press the F2 key to bring up the Fresnel Zone Reference dialog box. The Fresnel zone can be expressed as either a percentage of the first Fresnel zone or a Fresnel number. The drop down lists contain commonly used values. New values can be added to the lists.



Three types of Fresnel zone formats are available. The selection will be limited by the path geometry and the calculation state.

End to end

A single Fresnel zone reference is drawn between the end points of the display. This format always available and is the main indicator of path clearance.

Between horizons

A series of Fresnel zones are drawn between the horizons on the profile. This format is limited to obstructed paths.

To reflection point

The Fresnel zone is drawn from the antennas to the reflection point. Both the upper and lower Fresnel zones are drawn. This format is only available if a reflective plane exists.

The Fresnel zone can be labelled. The label is drawn in the center of the display.

Keyboard control

The following list summarizes all keyboard commands used in the Diffraction

module.

- P - set cursor movement to all profile points
- S - limit the cursor movement to peaks of the profile
- C - allow continuous cursor movement
- A - change between an arrow cursor and lines to the antennas
- Home - moves the cursor to the left side display limit
- End - moves the cursor to the right side display limit
- + key - increases the cursor movement increment in the continuous

  cursor mode and increases the radius increment in the isolated obstacle

  diffraction option

- - key - decreases the cursor movement increment in the continuous

  cursor mode and decreases the radius increment in the isolated obstacle

  diffraction option

- F1 - select the point at the cursor location in a select profile

  segment or define reflective plane operation

- F2 - display the Fresnel zone reference dialog box
- F3 - erase all diffraction loss calculations
- F6 - define a reflective plane
- Ctrl F6 - erase a reflective plane

- F7 - switch the radius calculation on or off in the isolated obstacle

  diffraction algorithm

- F8 - reset a profile segment to the complete profile, or cancel

  a select segment operation.

- F9 - calculate the diffraction loss
- Ctrl F9 - calculate the loss of a single tree or building on the

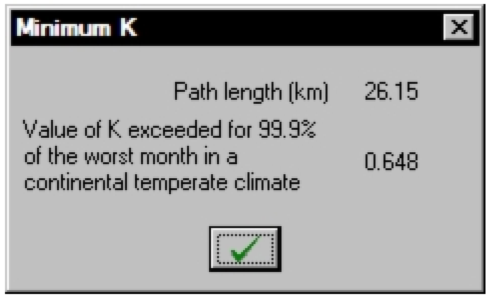
  profile

- Tab - move the cursor from the top of a tree or building to ground

  level

- D - display a summary of the diffraction loss calculations
- Ins - display the data of the profile point at the cursor location

Minimum K



The minimum earth radius factor (K) is defined as the value which will be exceeded for 99.9% of the time in the worst month for a continental temperate climate. This is a function of path length and is used to test the link operation for the additional diffraction loss resulting from this minimum K.

Staus bar

The status bar provides general information on the status and parameters of the calculation and also provides access to certain options in the program. The site names are always at the end of the status bar. Click on either the Site 1 or Site 2 name to access the site data entry form. A description of the remaining items follows:

Frequency

This is the global design frequency. Click on this box to access the diffraction parameters options in which the frequency can be changed

Diffraction loss

This box (D) shows the diffraction loss calculation summary. If a question mark is displayed, then the calculation has not been made. Click on this box to display the total loss summary.

Scatter Loss

This box (S) shows the scatter loss. If "N/A" is displayed, then the scatter loss is not applicable for any of the following reasons:

- the path is line of sight
- the earth radius factor (K) is outside the range 1.2 to 1.5
- the path is close to grazing and the scatter loss calculation is not valid

Click on this box to access the Diffraction Parameters dialog box in which the method of calculating scatter loss can be changed.

Cursor Style and Movement

The letters A and P in the above status bar display represent the cursor style (arrow or lines) and the movement (on profile, peaks or continuous). These can be changed by clicking the left mouse button on the associated box. Cursor control is described in detail in a following paragraph.

Antenna Combination

The current antenna combination is displayed. If the antenna configuration supports more than a single combination, click on this box to change the antenna combination.

Measurement System

The measurement system status box displays the current units of measurement. Click on this box to change between kilometers - metes and miles - feet.

Cursor Location Status Box

This box shows the current location of the cursor. Click on this box or press the Ins key for an information display on the selected point.

Display zoom feature

Any portion of the diffraction display can be selected and displayed as a full screen. This zoom feature is only implemented in the Antenna Heights and Diffraction modules. This is particularly useful on profiles with near in obstructions or buildings.

Position the mouse cursor at one corner of the area to be selected. Hold down the Ctrl key and then hold down the left mouse button and drag the cursor to the opposite corner. Release the mouse button and the selected area will be scaled to fill the window.

To reset the display, hold down the Ctrl key and click the right mouse button.

Manual diffraction loss algorithms procedure

The following paragraphs describe the procedures for the manual diffraction loss calculations in which the user defines the specific point on the profile and the section of the profile to use the specified algorithm.

Two ray optics

The two ray optics algorithm calculates the vector sum of a direct and

a reflected signal. This algorithm can only be used on a line of sight path. If the clearance at the reflection point is less than 0.57 first Fresnel zone radius, the result is always a loss and is referred to as plane earth loss. For a clearance above this value, the result can be

a loss or a signal enhancement (gain). At clearances close to grazing, the algorithm produces an unrealistically high loss.

The two ray optics algorithm requires a reflective plane to be defined.

The plane establishes location of the reflection point and the grazing angles. Terrain roughness is automatically calculated over the defined end points of the plane.

The plane can be predefined before the calculation; otherwise, you will be prompted to define the plane when the calculation starts. Refer to

the Reflective Plane Definition later in this section for additional details.

The following steps predefine the reflective plane before using two ray optics:

- Press the F6 key to begin the reflective plane definition.
- Move the cursor to one end of the plane and press the F1 key or

  click the right mouse button.

- Move the cursor to the opposite end of the plane and press the

  F1 key again or click the right mouse button.

- If the plane definition is not satisfactory, repeat the above steps. The new reflective plane will replace the existing one.
- Select the two ray optics algorithm from the drop down list box on the status bar.
- Click the calculate button or press the F9 key.
- Click the OK button on the diffraction loss display to accept the calculation or the Cancel button to discard the calculation.

Average diffraction

Recognizing that an ideal knife edge rarely occurs in practice, the average diffraction algorithm was formulated by AT&T. This is the same algorithm used in ITU - 530. The algorithm is a linear relationship between loss and the clearance to the first Fresnel zone ratio and is based on empirical data. The primary application was to estimate the fading produced by low values of K on microwave radio paths.

The clearance and the average diffraction loss is calculated at the cursor location, with respect to the end points of the display. If the complete profile is displayed, the clearance and loss are referenced to the end points of the profile. If a segment of the profile has been selected, the clearance and loss are referenced to the end points of this segment.

The basic procedure is described below:

- Select the average diffraction algorithm

  from the drop down list box on the control bar.

- Place the arrow on the peak of the obstruction.
- Click the calculate button or press the F9

  key.

- Click the OK button on the diffraction loss

  display to accept the calculation or the Cancel button to discard the calculation.

Height - gain algorithm

If the path is being analysed as a single or multiple knife edge, then it is necessary to examine the terrain between each site and its horizon. If there is less than 60% first Fresnel zone clearance in this region, then additional loss will occur and must be taken into account. This can be calculated with the height - gain algorithm.

Select the height - gain algorithm on the control bar and click the Calculate button of press F9. Click OK to accept the result or Cancel to discard the calculation.

Isolated obstacle diffraction

The isolated obstacle algorithm extends the ideal knife edge algorithm to include the effects of the breadth of obstacle along the path. This is accounted for by the radius of the obstacle; and therefore, an estimate of the radius of the obstacle must be made. This algorithm produces the most realistic prediction of diffraction loss on a path with a single obstruction. The algorithm is valid when the obstacle is isolated from both sites.

The clearance and diffraction loss are calculated at the cursor location, with respect to the end points of the display. If the complete profile is displayed, the clearance and loss are referenced to the end points of the profile. If a segment of the profile has been selected, the clearance and loss are referenced to the end points of this segment. The procedure for the isolated obstacle calculation is described below:

- Select the isolated obstacle diffraction

  algorithm from the drop down list box on the control bar.

- Place the arrow at the peak of the obstruction

  and press the F7 key to initiate the radius calculation. The screen

  display shows an arc of a circle below the arrow. The radius is shown on the control bar prompt box. Note that the circular arc appears

  parabolic due to the differences in the horizontal and vertical scales.

  If the arrow was located on a peak when the F7 key was pressed, the program will calculate the radius based on the slope of the terrain

on either side of the peak; otherwise, a default radius of 250 km

will be displayed.

- To change the radius, move the mouse cursor

  to one of the grip boxes at the ends of the arc. Hold down the left

  button and drag the mouse to change the radius. Alternately, hold

  down the Ctrl key and use the left, right, up or down cursor keys

  to change the radius. The radius is changed in increments. The size

  of the increment is changed with the + and -keys. There is no visible display of the increment.

- Change the radius to match the shape of the

  obstacle. This is best accomplished by selecting a continuous cursor movement. In this mode, the radius can be dragged by holding down

  the right mouse button or with any of the cursor keys.

- Note that the radius may be greater than

  the path length. An extreme example of a radius calculation is a smooth earth profile where the obstruction is formed by the bulge of the

  earth. The radius of the obstruction, in this case, is the earth radius factor, (K) times the earth radius. For the median value of K, the radius of the obstruction is 1.33 x 6375 = 8478 km.

- When the radius of the obstacle has been

  determined, click the calculate button or press the F9 key to calculate the diffraction loss.

- Click the OK button on the diffraction loss

  display to accept the calculation or the Cancel button to discard

  the calculation.

This procedure can be extended to multiple obstacle paths by selecting the appropriate segments of the profile and repeating the calculation for each segment. If the radius is calculated for all of the obstacles, the results tend to produce a somewhat high loss.

Knife edge diffraction

The knife edge diffraction algorithm is used for single, multiple and

effective knife edge diffraction loss calculations. A knife edge produces the lowest loss of any algorithm and can be considered as a lower limit.

The clearance and diffraction loss are calculated at the cursor location, with respect to the end points of the display. If the complete profile is displayed, the clearance and loss are referenced to the profile end points. If a segment of the profile has been selected, the clearance and loss are referenced to the end points of this segment. The basic procedure for knife edge calculations is described below:

- Select the knife edge diffraction algorithm from the drop down

  list box on the control bar.

- Place the arrow on the peak of the obstruction.
- Click the calculate button or press the F9 key.
- Click the OK button on the diffraction loss display to accept the

  calculation or the Cancel button to discard the calculation.

This procedure can be extended to multiple knife edges by selecting

the appropriate segments of the profile.

Longley & Rice irregular terrain - line of sight paths

On line of sight paths, the Longley - Rice irregular terrain algorithm interpolates the diffraction loss from three separate calculations at distances d0, d1 and d2.

The distances d0 and d1 are chosen within the horizon and the loss at these distances is calculated using two ray optics. The distance, d2

is beyond the horizon and the loss is calculated using the irregular terrain algorithm for obstructed paths. A smooth curve is fitted to the three points and the loss at the path length is interpolated.

This algorithm requires a reflective plane to be defined. The plane can be predefined before the calculation; otherwise, you will be prompted to define the plane when the calculation starts. Refer to the Reflective Plane Definition later in this section for additional details. The following steps predefine the reflective plane before calculating the diffraction loss:

- Press F6 to begin the reflective plane definition. Move the cursor to one end of the plane and press the F1 key or click the right mouse button.
- Move the cursor to the opposite end of the plane and press the F1 key again or click the right mouse button.
- If the plane definition is not satisfactory, repeat the above steps.

  The new reflective plane will replace the existing one.

- Select the irregular terrain algorithm from the drop down list box on the status bar.
- Click the calculate button or press the F9 key.
- Click the OK button on the diffraction loss display to accept the calculation or the Cancel button to discard the calculation.

Longley & Rice irregular terrain - obstructed paths

On obstructed paths, the Longley-Rice irregular terrain algorithm estimates the loss using the weighted average of the smooth earth loss and the loss of a double knife edge. The weighting factor is based on empirical data and considers the following parameters:

- terrain roughness effective antenna heights
- frequency horizon angles

For smooth paths, the loss approaches the smooth earth value. For very

rough paths the loss approaches the double knife edge value. The Pathloss automatic diffraction algorithm defaults to irregular terrain when the

path cannot be characterized as a single or multiple isolated obstacle(s).

- Select the irregular terrain algorithm from the drop down list

  box on the control bar.

- Click the calculate button or press the F9 key to calculate the

  diffraction loss.

- Click the OK button on the diffraction loss display to accept the

  calculation or the Cancel button to discard the calculation.

Selecting a profile segment

Any section of the profile can be selected when using the knife edge, average or isolated obstacle manual diffraction algorithms. The clearance and C /F1 ratio are referenced to the end points of the selected segment.

This feature is required to calculate multiple knife edge diffraction.

The following steps describe how to select a profile segment:

- Move the cursor to one end of the segment

  and press the F1 key or click the right mouse button to select the first end point. Note that the arrow will be above the antenna if it is positioned on one of the sites. The reset button is now enabled and the point selection can be cancelled by clicking this button or pressing the F8 key.

- Move the cursor to the other end of the segment

  and press the F1 key again or click the right mouse button.

The display is reformatted for the selected segment.

All diffraction loss calculations are referenced to the end points of this segment.

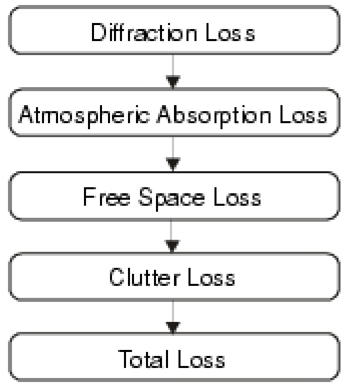
To reset the display back to the complete profile,

click the reset button or press the F8 key.

Total loss concept

All losses are relative to free space loss. The concept of total loss is described below for line of sight paths and obstructed paths.

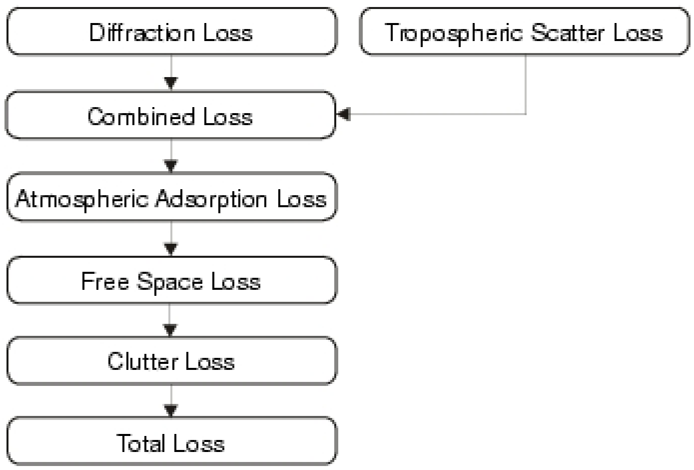
Line of sight paths



The total loss on a line of sight path consists of the components shown on the right. Note that diffraction loss will occur on a line of sight path if there is less than 60% first Fresnel zone clearance on the path.

Obstructed paths

On an obstructed path, the total loss concept is somewhat more complicated in that the loss is time variant. When a diffraction loss calculation is carried out, the results are displayed as the total loss as shown below.



Tropospheric scatter loss is combined with the diffraction loss using the formula below:

$$L_c = 10 \cdot \log_{10}\left[10^{-\frac{L_d}{10}} + 10^{-\frac{L_s}{10}}\right]$$

where:

L_c is the combined loss

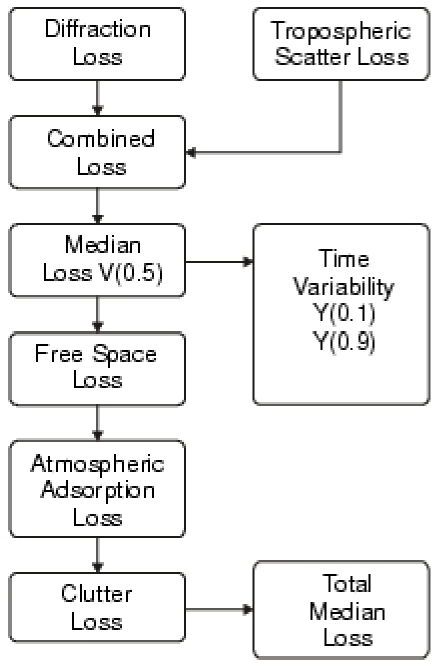
L_d is the diffraction loss

L_s is the tropospheric scatter loss

Diffraction and scatter loss are two independent propagation mechanisms and can be considered as two resistors in parallel. If the diffraction loss is much greater than the scatter loss, the combined result is effectively equal to the scatter loss. Conversely, if the scatter loss is much greater than the diffraction loss, the result is equal to the diffraction loss. If the results are equal, then the combined loss will be 3 dB less than either value. The combined loss is always less than either the diffraction or scatter loss.

OHLOSS format

The OHLOSS (Over the Horizon Loss) format considers the time variability of the loss due to changes in the atmospheric conditions. The combined loss is subjected to a empirical analysis using data for a specific climatic region to determine the time variability.

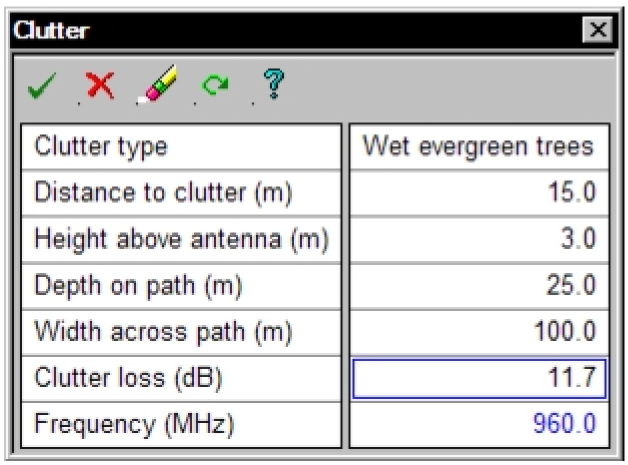


The median loss is first calculated by adding a correction factor to the combined loss. This accounts for differences between the long term measured and calculated values.

The median loss is then subjected to a time variability analysis for a range of time percentages. These are divided into 50% and 95% confidence factors. A 95% confidence factor means that if 100 measurements were taken over a long time period, then 95% of the measurements would be within the specified ranges.

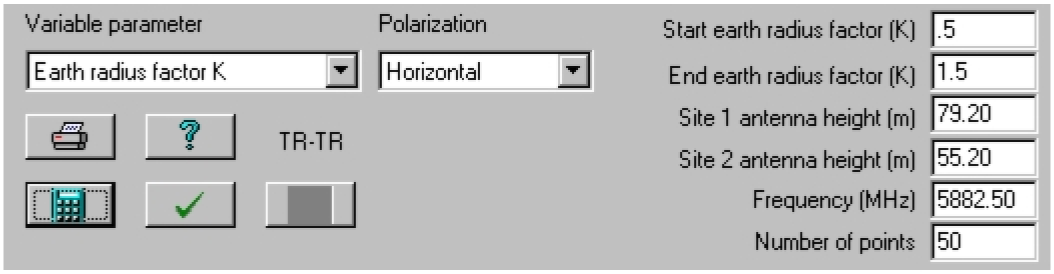
Clutter

Select *Operations - Clutter* from the Diffraction menu to access the clutter data entry form. Clutter accounts for trees and buildings in the immediate vicinity of the site where it is impractical to enter these on the path profile. The analysis considers the depth of the trees / buildings along the path and the width across the path. All measurements are in feet or meters as determined by the program setting. Enter the values in accordance with the prompts. Note that the clutter loss can be directly entered. Click OK to accept the clutter loss. This will be included as an additional loss in all diffraction loss reports.



To erase or remove a clutter calculation, select Operations - Erase Clutter from the Diffraction menu bar or hold down the Ctrl key and press F3.

Variable parameters



Diffraction loss can be calculated as a function of antenna heights, earth radius factor, frequency and path length. In microwave applications, the diffraction loss versus K, is used to verify the link operation at the minimum expected value of the earth radius factor (K). Select Variable from the Diffraction menu bar.

Select the variable parameter and then set the start and end values.

If the antenna configuration supports multiple antenna combinations, click the Antenna Combination button to select a specific combination. Set the values for the constant parameters and click the calculate button to display the results. On some paths, discontinuities will occur in the curve as a result of the diffraction algorithm changing as the path geometry changes.

Repeat the calculation with a greater number of points to isolate the point where the algorithm switches and used the average value at this location.

All parameters used in variable calculations except polarization are local variables and do not change the corresponding values outside of this calculation.

When the earth radius factor (K) is the variable parameter, note the following points.

- the start earth radius factor should be lower than the minimum expected value of K.

- the end earth radius factor should be slightly greater that the point at which free space loss occurs
- the horizontal scale is formatted as arctangent(K). Several common K values are also displayed on the graph. The following examples illustrate the format:

K = 1 arctangent(K) = 45?

K = 4 arctangent(K) = 90?

K = 4/3 arctangent(K) = 53.1?

Transhorizon path geometry

Figure (1) shows the basic geometry of a transhorizon path. By convention, the transmit site is on the left and the receive site is on the right side of the display. The terminology is defined below and is used throughout this section.

h_{ts}	transmit antenna height above sea level
h_{rs}	receive antenna height above sea level
d_{lt}	distance from the transmit site to its horizon
h_{lt}	transmit horizon elevation above sea level
Θ_{et}	transmit horizon elevation angle
d_{lr}	distance from the receive site to its horizon
h_{lr}	receive horizon elevation above sea level
Θ_{er}	receive horizon elevation angle
d	great circle arc path length
Θ	cross over angle of the horizon rays
d_1	distance from the transmit site to the cross over point of the horizon rays
d_2	distance from the receiver site to the cross over point of the horizon rays
d_s	distance between the transmit and receive horizons

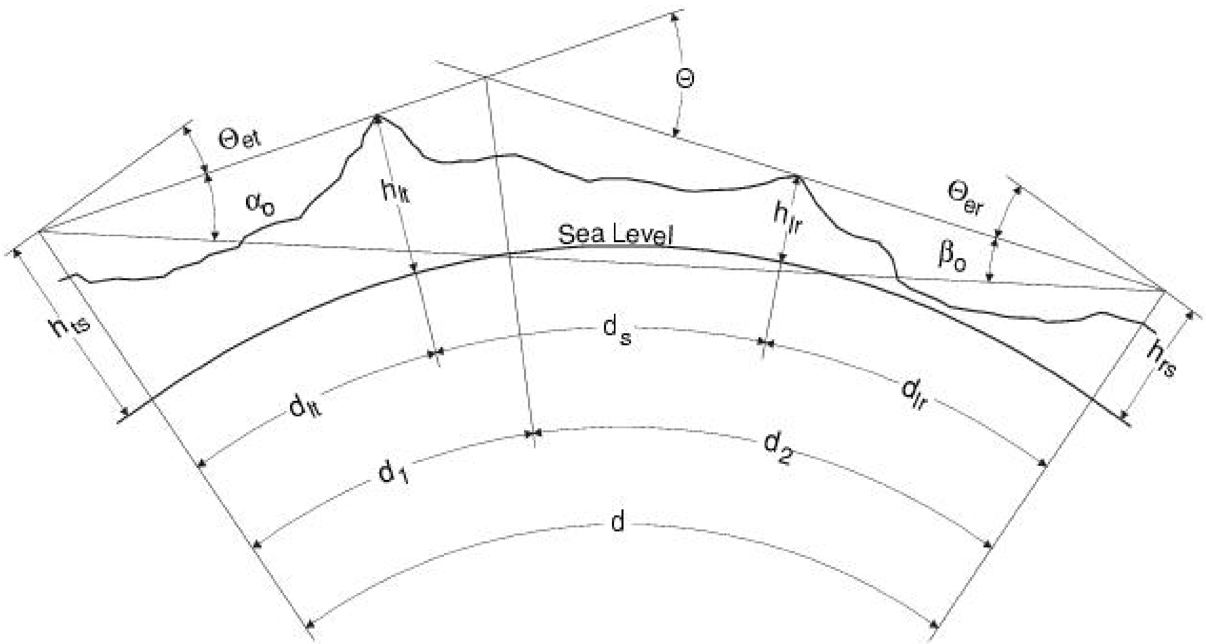


Figure (1): Transhorizon path geometry

The following formulas are taken from Reference (1). All distances and elevations are expressed in the same units. It is assumed that all angles are small and that tan (Θ) ≈ Θ. In the Pathloss program, all angles are calculated using the arctangent of the specific expressions.

Horizon Elevation Angles

The transmit and receive elevation angles, Θ_{et} and Θ_{er}, are calculated by:

$$\Theta_{et} = \frac{h_{lt} - h_{ts}}{d_{lt}} - \frac{d_{lt}}{2 \cdot a} radians$$

$$\Theta_{er} = \frac{h_{lr} - h_{rs}}{d_{lr}} - \frac{d_{lr}}{2 \cdot a} radians \qquad \textbf{(1)}$$

In Equation (1), the effective earth radius *a*, is calculated as the actual earth radius, (a_o = 6370 km) times the earth radius factor K (*a*

$= K \cdot a_o$). Alternately, a, can be expressed in terms of the surface refractivity, N_s, as:

$$a = \frac{a_o}{1 - 0.04665 \cdot e^{0.005577 \cdot N_s}} \quad \textbf{(2)}$$

The angles, α and β, are calculated as:

$$\alpha_o = \Theta_{et} + \frac{d}{2 \cdot a} + \frac{h_{ts} - h_{rs}}{d}$$
$$\beta_o = \Theta_{er} + \frac{d}{2 \cdot a} + \frac{h_{rs} - h_{ts}}{d} \quad \textbf{(3)}$$

Angular Distance

The angular distance, Θ, is the cross over angle of the horizon rays. This is sometimes referred to as the scatter angle and is always positive for a transhorizon path.

$$\Theta = \Theta_{et} + \Theta_{er} + \frac{d}{a}$$
$$Or$$
$$\Theta = a_o + \beta_o \quad \textbf{(4)}$$

The distances, d_1 and d_2, from the cross over point of the horizon rays to the transmit and receive sites are given by:

$$d_1 = \frac{d \cdot \beta}{\Theta} \quad d_2 = \frac{d \cdot a}{\Theta} \quad \textbf{(5)}$$

Path clearance

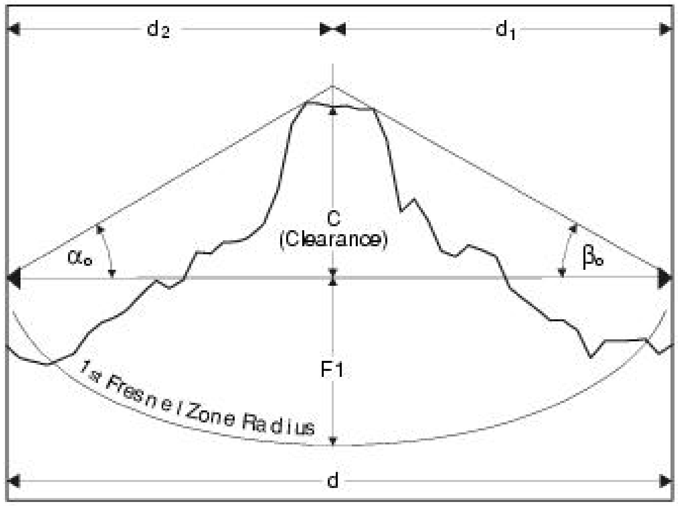


Figure (2): Path clearance

Path clearance, *C*, is defined in Figure (2).*C* is positive for line of sight paths and negative for an obstructed path. The normalized path clearance is expressed as the ratio of the clearance to the first Fresnel zone radius and is defined by:

$$\frac{C}{F1} = \frac{C}{17.3}\sqrt{\frac{f_{GHz} \cdot d}{d_1 \cdot d_2}} \quad \textbf{(6)}$$

where d, d_1 and d_2 are defined in Figure (2) and are expressed in kilometers. The clearance *C*, is expressed in meters.

The parameter, *V*,is used as an alternate definition of path clearance and is defined by Equation (7) using the terminology in Figure (2).

$$V = \sqrt{\frac{2 \cdot d \cdot \tan(a_o) \cdot \tan(\beta_o)}{\lambda}} \quad \textbf{(7)}$$

λ wavelength

d path length

λ and *d* are expressed in the same units.

V is positive for obstructed paths and negative for line of sight paths. The two normalized clearance parameters are related by:

$$V = -\frac{C}{F1} \cdot \sqrt{2} \quad \textbf{(8)}$$

Note that *V* is defined at the intersection of the horizon rays; and therefore, Equation (8) is true only if the transmit and receive horizons are located at the same point.

Effective antenna heights

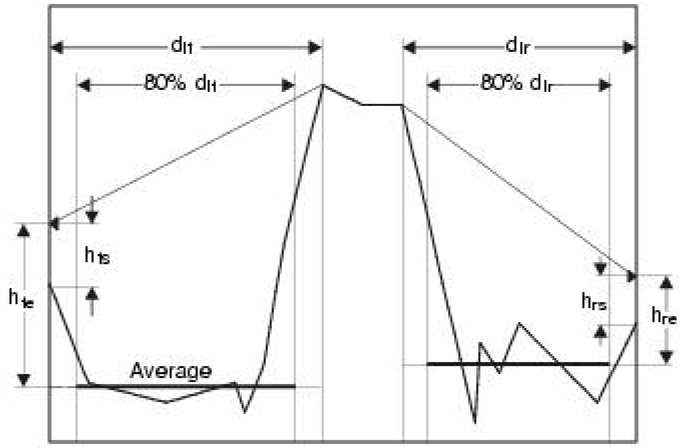


Figure (3): Effective antenna heights - average

Two methods of calculating effective antenna heights on obstructed paths are used in the program. The Tirem and NSMA algorithms use the height above average terrain. The Pathloss algorithm uses a least squares fit.

Height above average terrain

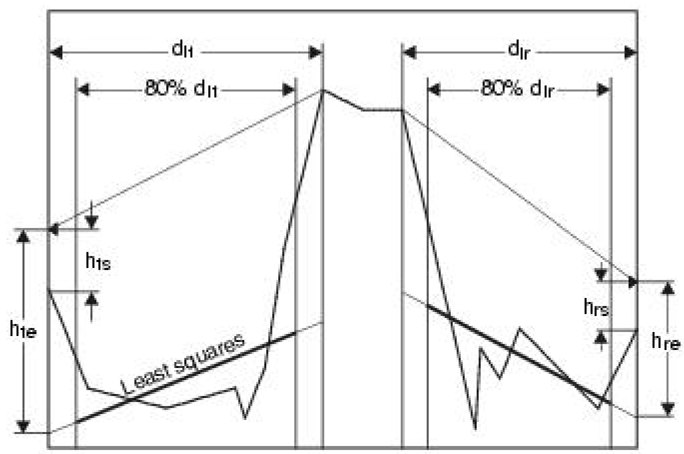


Figure (4): Effective antenna heights - LSQ

The effective antenna heights, h_{te} and h_{re}, at the transmit and receive site are calculated as shown in Figure (3). The average elevation in the central 80% of the terrain between an antenna and its horizon is calculated.

The effective antenna height is defined as the height of the antenna above this average elevation.

Height Above Least Squares Fit

Construct a two term least squares fit to the central 80% portion of the terrain between an antenna and its horizon. Extend this least squares fit line to the sites. The effective antenna heights are defined in Figure (4). The terminology used in Figure (3) and Figure (4) is given below:

d_{lt} distance to the transmitter horizon

d_{lr} distance to the receiver horizon

h_{ts} structural transmitter antenna height

h_{rs} structural receiver antenna height

h_{te} transmitter effective antenna height

h_{re} receiver effective antenna height

The effective antenna heights cannot be less than the structural antenna heights.

Single knife edge diffraction loss (SKE)

The Fresnel-Kirchhoff knife edge diffraction loss, *A(v,θ)*, is defined in Reference (1), and is given by:

$$
\begin{aligned}
&A(v,\theta) \;=\; 6.02 + 9.0v + 1.65 \cdot v^2 \\
&for -0.8 \le v \le \theta \\
&A(v,\theta) \;=\; 6.02 + 9.11 \cdot v - 1.27 \cdot v^2 \\
&for\ \theta < v \le 2.4 \\
&A(v,\theta) \;=\; 12.953 + 20 \cdot \log(v) \\
&for\ v > 2.4
\end{aligned} \qquad \textbf{(9)}
$$

Note that for values of *v*, less than -0.8, the knife edge diffraction loss is zero. The corresponding value of *C/F1* from Equation (8), is 56.57% of the first Fresnel zone radius. In practice, the value has been rounded to 60% and represents the minimum clearance criteria for free space loss conditions.

Effective knife edge (EFFKE)

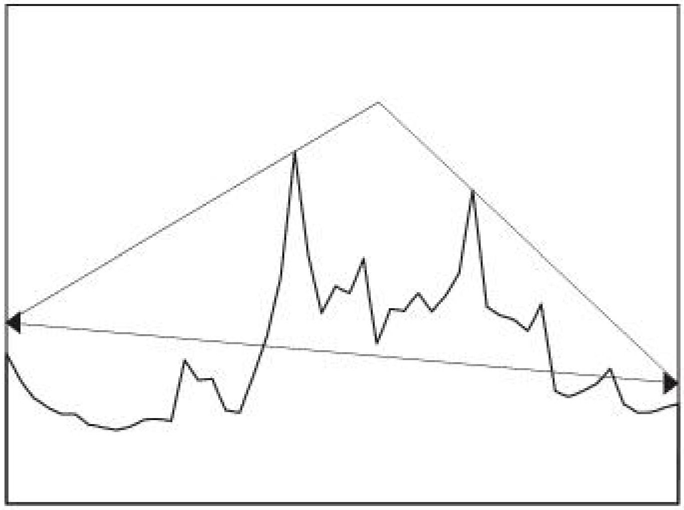


Figure (8): Effective knife edge

In the effective knife edge method, the diffraction loss of irregular terrain is calculated as a single knife edge located at the intersection of the horizon rays. The method is described in Reference (11) and shown in Figure (8).

Note that the definition of the parameter V, in Equation (7) and Figure (2), will inherently calculate the effective knife edge diffraction. Effective knife edge and single knife edge diffraction are equal if the transmit and receive horizons are located at the same point.

Multiple knife edge diffraction loss (MKE, DKE)

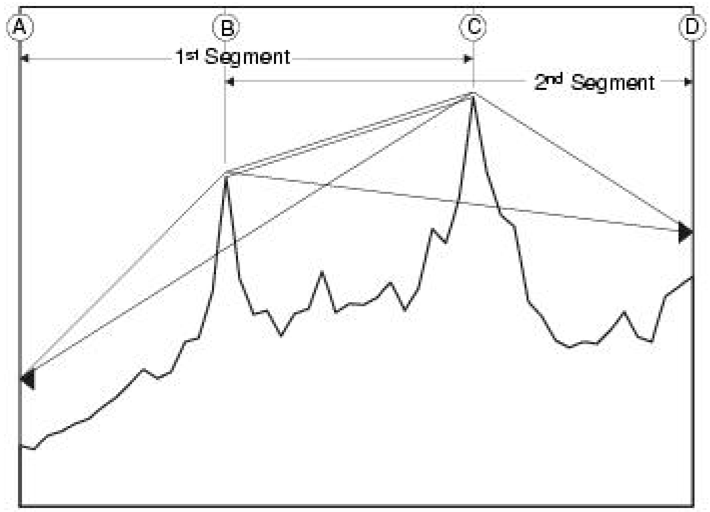


Figure (6): Double knife edge - Epstein-Peterson

An irregular terrain path can be analyzed as a series of knife edges. The total diffraction loss is taken as the sum of the individual knife edges. There are two methods of calculating multiple knife edge diffraction loss (MKE).

Epstein-Peterson

The Epstein-Peterson method is described in Reference (9). A double knife edge (DKE) example of this method is shown in Figure (6). The diffraction loss of each knife edge is calculated over the profile segment formed by the horizons of the knife edge. In Figure (6), the knife edge located at B, is calculated over the profile segment from A to C. The knife edge located at C, is calculated over the segment from B to D. There is no limit to the number of knife edges on the path using this method. Best results are obtained when the individual knife edges are widely separated.

Deygout

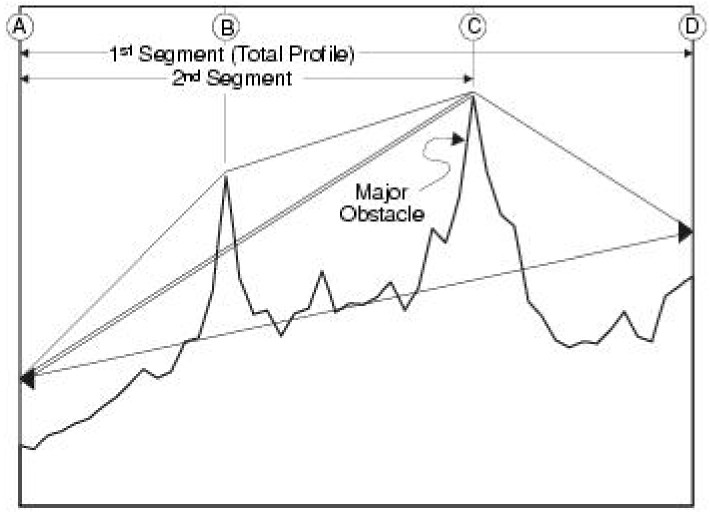


Figure (7): Double knife edge - Deygout

The Deygout method is described in Reference (8) and Reference (10) and is limited to a double knife path. An example of the Deygout method is shown in Figure (7). The parameter V, is first calculated for both of the knife edges located at B and C over the entire profile from A to D. The major obstacle is defined as the knife edge with the maximum value of V.

In Figure (7), the major knife edge located at C, is calculated over the complete profile from A to D. The second knife edge, located at B, is calculated over the profile segment A to C. Best accuracy is obtained when the knife edges are relatively close together.

A discussion and comparison of the two methods is given in Reference (12).

Isolated obstacle diffraction loss (ISOL)

An ideal knife edge rarely occurs in practice. The isolated obstacle algorithm adds additional terms to the basic knife edge diffraction formula in Equation (9) to account for the finite radius of the obstruction. From Reference (1), the isolated obstacle diffraction loss is given by:

$$A(v,\rho) = A(v,\theta) + A(\theta,\rho) + U(v\cdot\rho)$$

$$A(\theta,\rho) = 6.02 + 5.556\cdot\rho + 3.148\cdot\rho^2 + 0.256\cdot\rho^3$$

$$U(v\cdot\rho) = 11.45\cdot v\cdot\rho + 2.19\cdot(v\cdot\rho)^2 - 0.206\cdot(v\cdot\rho)^3 - 6.02$$

$$for\ v\cdot\rho \le 3$$

$$U(v\cdot\rho) = 13.47\cdot v\cdot\rho + 1.058\cdot(v\cdot\rho)^2 - 0.048\cdot(v\cdot\rho)^3 - 6.02$$

$$for\ 3 < v\cdot\rho \le 5$$

$$U(v\cdot\rho) = 20\cdot v\cdot\rho - 18.2$$

$$for\ v\cdot\rho > 5$$

$$\rho = 0.676\cdot R^{\frac{1}{3}}\cdot f_{MHz}^{-\frac{1}{6}}\cdot\sqrt{\frac{d}{d_1\cdot d_2}} \qquad \textbf{(10)}$$

R radius of the obstacle in kilometers

Obstacle radius

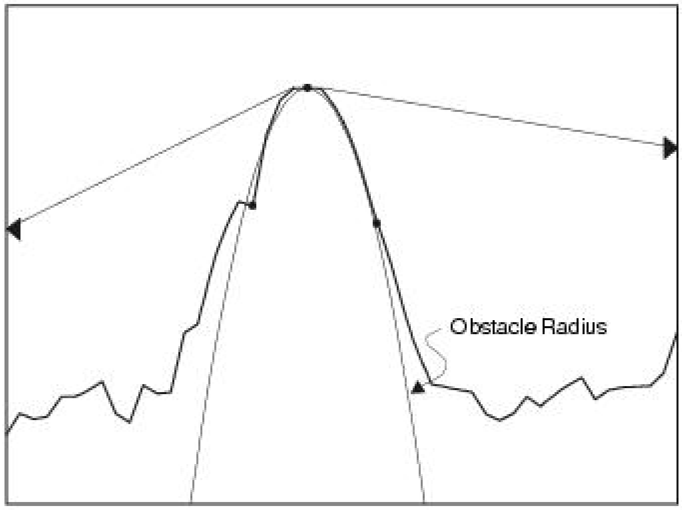


Figure (5): Isolated obstacle radius

The radius of the obstacle is calculated by locating three points on the obstruction as shown in Figure (5). The central point is taken at the crossover of the horizon rays. The two adjacent points are determined by the slope of the terrain from the horizon points.

Far Field

The following condition is used to determine if an isolated obstacle is in the far field of the transmit and receive sites.

$$h \cdot \frac{2 \cdot \pi}{\lambda} \cdot \left(\frac{\lambda}{\pi \cdot R}\right)^{\frac{1}{3}} \ll 1$$

$$h = \sqrt{d_1^2 + R^2} - R \qquad \textbf{(11)}$$

d_l is the transmitter or receiver horizon distance d_{lt} or d_{lr}

Irregular terrain (IRRT)

Reference (3) describes the irregular terrain prediction algorithm. It is outside the scope of this manual to provide a complete listing of all equations used in the algorithm. A basic description of the methodology is presented here.

Interdecile terrain elevation range

This term is used to characterize the terrain roughness and is calculated as follows:

- create an array of the elevations at 60 uniformly spaced points along the terrain profile.
- sort the array in terms of increasing elevation.
- the interdecile terrain elevation range is then given by array[54] - array[6].

On line of sight paths, the interdecile terrain elevation range is calculated over the defined end points of the dominant reflective plane and all elevations are referenced to the reflective plane.

On non line of sight paths, the interdecile terrain elevation range is calculated over the entire profile.

Obstructed Paths

Diffraction loss for non line of sight paths is calculated by combining estimates of knife edge diffraction, A_k and diffraction over smooth terrain A_r.

The knife edge diffraction, A_k, is calculated considering the path to be a double knife edge using the Epstein - Peterson method.

The diffraction loss, A_d, is calculated as a weighted average of the two estimates A_k and A_r: $A_d = (1 - w) \cdot A_k + w \cdot A_r$ **(13)**

where the weighting factor, w, is determined empirically as a function of frequency, path geometry and the interdecile terrain elevation range. For very rough terrain, A_d, approaches the knife edge value, A_k, For smooth terrain, A_d approaches the smooth earth value, A_r.

Two values of diffraction loss, A_3 and A_4, are calculated at distances d_3 and d_4 in the far diffraction region. A straight line through these points, (A_3, d_3) and (A_4, d_4) is then defined by the intercept (A_{ed}) and slope (m) as follows :

$$m = \left(\frac{A_4 - A_3}{d_4 - d_3}\right)\frac{dB}{km}$$

$$A_{ed} = A_4 - m \cdot d_4 \quad \textbf{(14)}$$

The diffraction loss, A_{cr}, at any distance d, which is greater than the smooth earth horizon distance, is given by: $A_{cr} = A_{ed} + m \cdot d$ **(15)**

Line of sight paths

Distances, d_0 and d_1, are chosen well within the horizon. Distance, d_0, represents the greatest distance at which free space conditions apply. The distance, d_1, is greater than d_0, but well within the range for which two ray optics formulas are valid. The diffraction loss, A_0 and A_1, at distances, d_0 and d_1, is calculated using two ray optics.

The diffraction loss, A_{ls}, is calculated at the smooth earth horizon distance, d_{ls}, using the obstructed path method described above.

The three values of diffraction loss, A_0, A_1 and A_{ls}, calculated at distances, d_0, d_1 and d_{ls}, respectively, are used to determine the slopes, k_1 and k_2, of a smooth curve of loss versus distance.

The attenuation, A_{cr}, at any distance, d, less than d_{ls}, is then given by:

$$A_{cr} = A_o + k_1 \cdot (d - d_o) + k_2 \cdot log\left(\frac{d}{d_o}\right) \quad \textbf{(16)}$$

Average diffraction

The average diffraction algorithm represents the diffraction loss of a typical wooded hill and is based on Figure (9) shows the characteristics of the average diffraction curve in comparison to the limiting cases of knife edge and smooth earth diffraction.

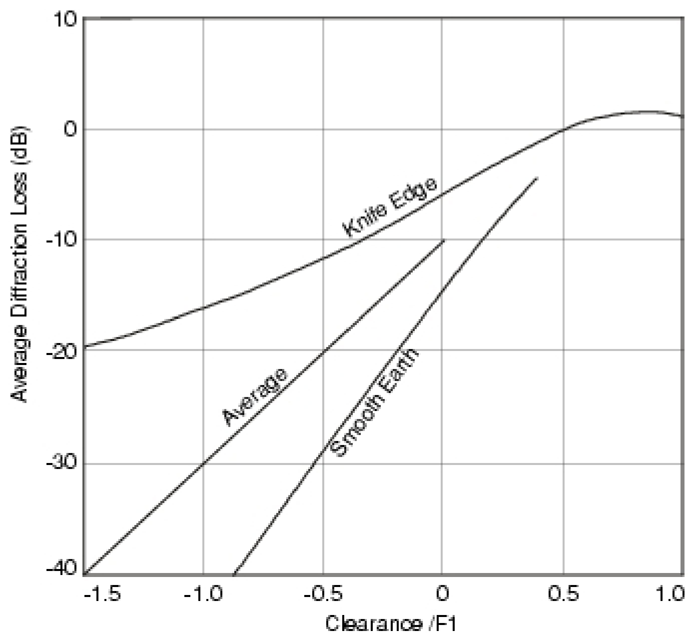


Figure (9): Average diffraction

Average diffraction is dependant only on the ratio of clearance to the first Fresnel zone radius and uses a linear relationship between *C/F1* and diffraction loss defined by the following equation:

$$A = 90 - 19.7 \cdot \left(\frac{C}{F1} + 4\right)$$

Height gain terms

In the region between an antenna and its horizon, additional diffraction loss may occur due to lack of clearance. A clearance test must be made at the transmit and receive sites when using any of the knife edge diffraction algorithms. This includes single knife edge, multiple knife edge and effective knife edge diffraction models. One method of calculating this additional loss, is a sub set of the rough earth diffraction model described above. In this case, a smooth curve is fitted to the terrain between an antenna and its horizon and smooth earth diffraction is applied to this section of the profile. The term, height gain, is used to denote the resulting loss. The term is a misnomer as the result is always a loss.

Tirem algorithm

Background

The TIREM (Terrain Integrated Rough Earth Model) algorithm was originally developed as part of the Master Propagation System by the Institute for Telecommunication Sciences (ITS), a Department of Commerce agency in Boulder, Colorado. The original version ran on a UNISYS 1100 and 2200 series main frame computer in batch mode. A second version, MPSII, was implemented on the PDP-11 series of minicomputers in an interactive mode. The Pathloss implementation of the TIREM algorithm is based on the MPSII version. The TIREM program is currently maintained by the Electromagnetic Compatibility Analysis Center (ECAC), a department of Defense Agency in Annapolis, Maryland. Certain revisions to the program have been made which are presented later in this section.

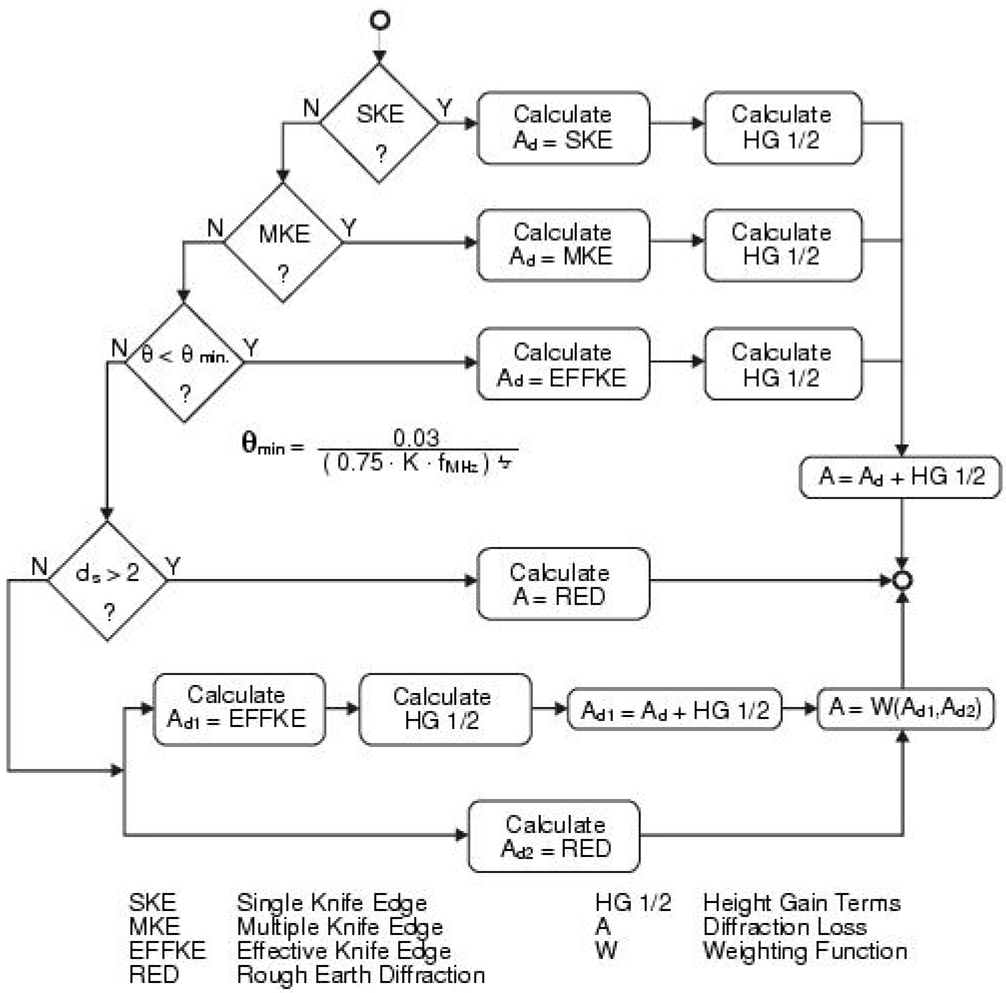


Figure (1): TIREM obstructed path model selection

Obstructed Model

The path profile is analyzed as shown in Figure (10) to determine the appropriate propagation model.

The criteria for each model selection is given below:

- Single knife edge diffraction loss is calculated if the transmit and receive horizons are at the same point on the profile.

- Multiple knife edge diffraction loss using the Epstein-Peterson method is calculated if the conditions listed below are satisfied. There is no limit to the allowable number of knife edges
  - all of the horizon points correspond to the peaks of the knife edges
  - the clearance between knife edges must be at least 50% of the first Fresnel zone radius
- If the path is close to line of sight, as determined by Equation (17), then the path is calculated as an effective knife edge.

$$\theta < \frac{0.03}{(0.75 \cdot K \cdot f_{MHz})^{\frac{1}{3}}} \quad \textbf{(17)}$$

θ cross over angle of the horizon rays

K earth radius factor

- If the distance between the transmit and receive horizons is greater than 2 miles, the rough earth diffraction loss algorithm is used.
- In all other cases, a weighted average of the effective knife edge diffraction and rough earth diffraction is calculated as shown below:

$$A_{d1} = EFFKE + HG1/2$$

$$A_{d2} = RED$$

$$A = \left(1 - \frac{d_s}{2}\right) \cdot A_{d1} + \left(\frac{d_s}{2}\right) \cdot A_{d2} \quad \textbf{(18)}$$

The requirement for the height gain terms are determined by the minimum value of the clearance, C_{min}, between an antenna and its horizon as follows:

- If C_{min} is greater than 150% of the first Fresnel zone radius, the height gain term is not calculated.
- If the clearance is less than 50% of the first Fresnel zone radius, the height gain term is calculated.
- For clearances between 50% and 150% of the first Fresnel zone radius, the height gain term is calculated and weighted in accordance with the following equation:

$$HG_C = HG \cdot (1.5 - C_{min}) \quad \textbf{(19)}$$

Line of Sight Model

The path is first tested for clearance. If the clearance at each point on the profile is greater than 150% of the first Fresnel zone radius, then free space conditions apply and diffraction loss is not calculated.

At frequencies greater than 200 MHz, the empirical Longley - Reasoner formula of Reference (2) is used to calculate the diffraction loss as shown in Equation (20) below:

$$\Delta h = \frac{I_e}{1 - 0.8 \cdot e^{-0.03 \cdot d}}$$

$$A = 9 \cdot (1 + e^{-0.01 \cdot \Delta h}) - 3.5 log\left(\frac{h_{min}}{\lambda}\right) + 0.113 \cdot d \quad \textbf{(20)}$$

I_e	interdecile terrain elevation range
Δh	terrain roughness
h_{min}	is the smaller value of the transmit and receive effective antenna heights
d	path length

At frequencies less than 150 MHz, the line of sight irregular terrain model of Reference (3) is used to calculate the diffraction loss.

At frequencies between 150 and 200 MHz, a weighted average of the Longley-Reasoner and irregular terrain is used according to the following equation: $$A = \frac{A_{d1} \cdot (200 - f_{MHz}) + A_{d2} \cdot (f_{MHz} - 150)}{50}$$ **(21)**

A_{d1} Longley Reasoner diffraction loss

A_{d2} irregular terrain diffraction loss

If the minimum path clearance, C/F1 is greater than 0.5, the diffraction loss value is weighted as follows: $$A = A \cdot \left(1.5 - \frac{C}{F1}\right)$$ **(22)**

Note that the TIREM algorithm employs an extremely conservative clearance criteria on line of sight paths. The clearance to first Fresnel zone ratio must be greater than 1.5 to achieve free space loss conditions. Due to the empirical nature of the diffraction loss calculations, a path with a *C/F1* ratio of 0.6 will produce a diffraction loss.

ECAC changes

The TIREM algorithm, as currently implemented by the Electromagnetic Compatibility Analysis Center is significantly different than the above description for obstructed paths. Diffraction loss is always calculated as a multiple knife edge using the Epstein Peterson method. If the obstructed portion of the path is over water, the loss is calculated as smooth earth diffraction.

This ECAC version is not specifically implemented in the Pathloss program; however, it can be simulated by the following switch settings in the Pathloss diffraction algorithm.

- Multiple Knife Edge Method Epstein-Peterson
- Maximum Number of Obstacles 10
- Include Obstacle Radius No
- Foreground Loss Scaled Height Gain

NSMA algorithm

The NSMA algorithm has been proposed by the US National Spectrum Managers Association as a reference diffraction loss calculation for interference analysis. The results provide conservative estimates of the diffraction loss. The algorithm is shown in Figure (11).

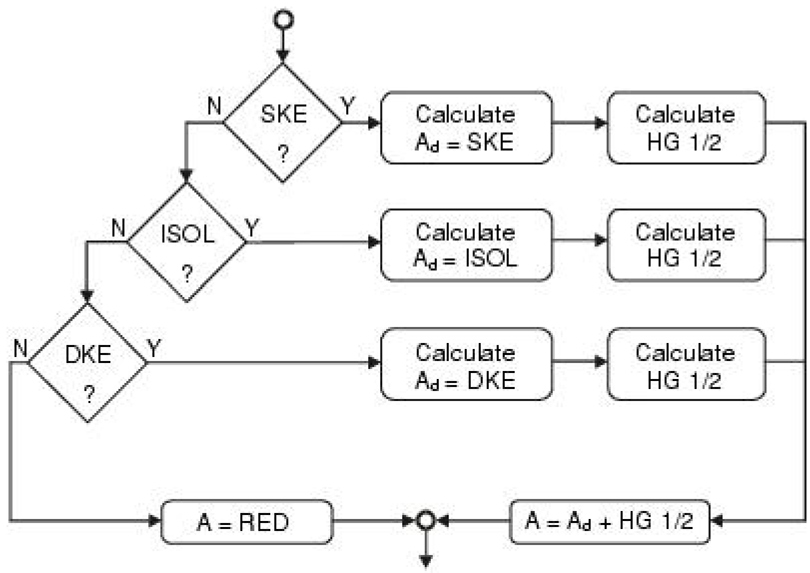


Figure (11): NSMA diffraction algorithm

The following criteria are used to select the diffraction loss method:

- The height gain term is calculated if more than 50% of the terrain between an antenna and its horizon has less than 100% first Fresnel zone clearance.
- Single knife edge diffraction is calculated if the transmit and receive horizons are located at the same point.
- Isolated obstacle diffraction loss is calculated if the distance between the transmit and receive horizons is less than 0.3 miles.
- Double knife edge diffraction loss is calculated, according to Epstein-Peterson, if a line of sight condition exists between the transmit and receive horizon points.

Line of sight

The NSMA algorithm is intended for obstructed paths and does not contain recommendations for line of sight paths. In this implementation, the TIREM line of sight algorithm is used.

Pathloss algorithm

The Pathloss algorithm is based on the premise that an ideal knife edge rarely occurs in practice. An obstacle always has a finite radius. A knife edge is simply the limiting case of an obstacle with zero radius. The TIREM and NSMA algorithms treat a path as an ideal knife edge whenever the transmit and receive horizons correspond to the same point on the profile. This criteria is very dependant on the specific points in the terrain profile.

Obstructed path algorithm

The basic algorithm is shown in Figure (12).

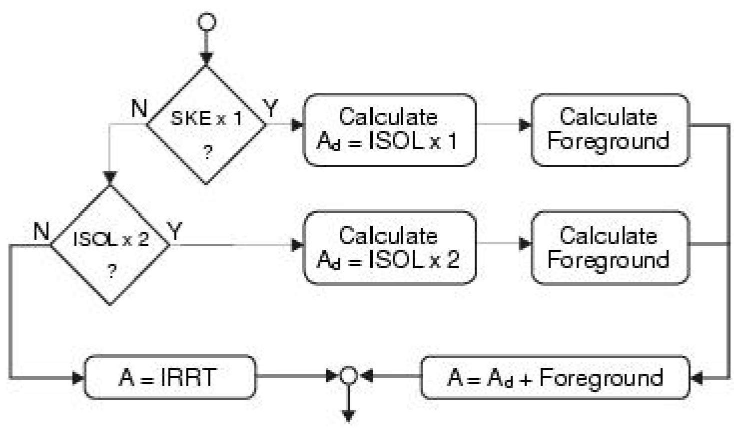


Figure (12): Pathloss diffraction algorithm

The following criteria are used for obstructed paths:

- If the path geometry consists of two horizon rays, single isolated obstacle diffraction loss is calculated provided that obstacle radius is less than 80% of the effective earth radius.
- If path geometry consists of three horizon rays, double isolated obstacle diffraction loss using the Deygout method is calculated, provided that each obstacle radius is less than 80% of the effective earth radius.

- If a radius calculation point is located at either the transmit or receive sites, foreground loss is not calculated. In this case, the obstacle of the radius is assumed to allow for the additional loss. Similarly, if the obstacle is in the near field of the transmitter or receiver site, as determined by Equation (11), the foreground loss is not calculated.
- In all other cases, the height gain algorithm is used to calculate the foreground loss.

Line of sight algorithm

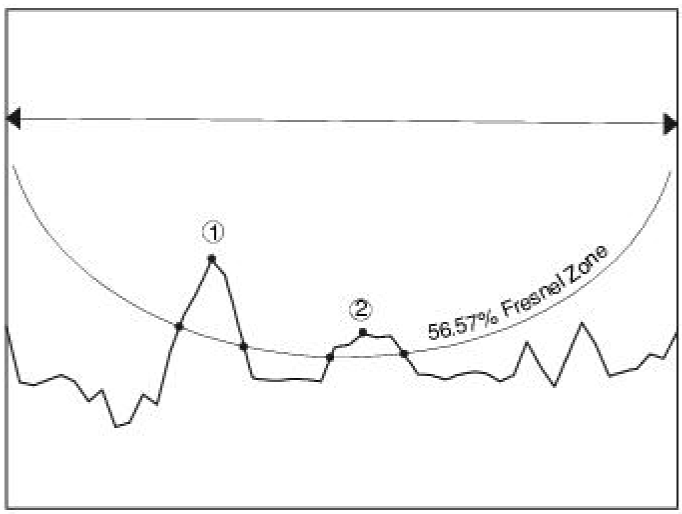


Figure (13): Isolated obstacles - LOS

If the clearance at each point is greater than 56.57% of the first Fresnel zone radius, the path is considered to be free space.

The intersections of the 56.57% first Fresnel zone reference and the terrain are first calculated. The path is analyzed as a series of isolated obstacles providing the following criteria are met:

- less than 60% of the path exceeds the Fresnel zone reference
- the number of obstacles does not exceed three

- the radius of any obstacle does not exceed 80% of the effective radius
- Fresnel zone reference clearance exists at each site

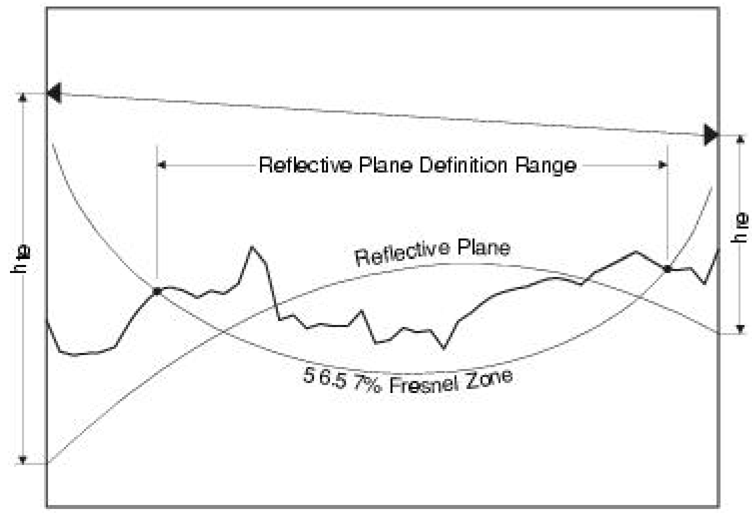


Figure (14): Irregular terrain - LOS

The radius of each obstacle is calculated using the peak and the intersection with the Fresnel zone reference, as shown in Figure (13).

If the above criteria are not met the path is analyzed using the irregular terrain algorithm. A reflective plane is defined between the first and last intersections of the terrain with the Fresnel zone reference, as shown in Figure (14). A two term least squares fit is use to generate the plane. The transmit and receive effective antenna heights, h_{te} and h_{re}, are determined from this reflective plane.

Rough earth diffraction (RED)

Rough earth diffraction is based on Reference (1) and Reference (4). The single effective earth radius is replaced with four different radii for the following regions of the path:

- transmit site to the transmit horizon
- transmit horizon to the cross over point of the horizon rays
- receive site to the receive horizon
- receive horizon to the cross over point of the horizon rays

The diffraction loss is calculated using smooth earth diffraction theory modified to accommodate the four different effective earth radii. A complete discussion of the algorithm is outside the scope of this manual.

Clutter

Clutter loss is defined as the loss produced by trees or buildings in the immediate foreground of an antenna and is calculated in accordance with Reference (13). Due to the proximity of these local obstructions to the antenna, it is not practical to enter these in the terrain profile. Instead, the clutter loss is calculated separately in the clutter module and added to the combined diffraction and tropospheric scatter loss.

Clutter loss is a function of the type of clutter and the following parameters:

d_c distance from the antenna to the clutter

h_c height of the clutter above the antenna

d_p depth of the clutter along the path

w_c width of the clutter across the path

The clutter parameters are specified in feet or meters, depending on the measurement system selected. Do not use miles or kilometers.

Tree Clutter

Tree clutter is calculated as the minimum value of the following three propagation mechanisms:

- Attenuation through the trees
- Lateral wave propagation along the tree tops
- Knife edge diffraction over the tree tops

Each propagation mechanism is discussed in the following paragraphs using the metric system of measurements.

Attenuation through trees

Table 1: Constants

Tree type	***σ***
Dry Bare Trees	7.0e-6
Dry Full Leaf Trees	1.0e-5
Dry Evergreen Trees	3.0e-5
Dry Rain Forest	2.0e-4
Wet Bare Trees	1.4e-6
Wet Full Leaf Trees	2.0e-5
Wet Evergreen Trees	6.0e-5
Wet Rain Forest	4.0e-4

The conductivity, σ, for various types of trees is given in Table 1

The attenuation through the trees, L_a, is given by:

$$\gamma = 1637 \cdot \sigma + 0.334 \cdot exp\left(-\frac{90}{f_{MHz}}\right) \cdot log \tag{25}$$

for vertical polarization

$$\gamma = 1637 \cdot \sigma + 0.427 \cdot exp\left(-\frac{210}{f_{MHz}}\right) \cdot log \tag{26}$$

for horizontal polarization

$$L_a = \gamma \cdot d_p \tag{27}$$

For thin screens of trees, the depth of the trees along the path, d_p, is increased by the following factor:

$$\text{EffectiveDepth} = \sqrt{d_p^2 + (7 \cdot \log(f_{MHz}))^2} \tag{29}$$

Lateral wave along tree tops

The attenuation of a lateral wave travelling across the tree tops is given by:

$$\begin{aligned} &\text{if } \sigma < 0.0002 \; dB_{lat} = 30 \\ &\text{if } \sigma < 0.00001 \; dB_{lat} = 12 \\ &\text{otherwise } dB_{lat} = 40 \\ &L_l = 6 + (dB_{lat} - 6) \cdot \left(1 - e^{-\frac{h_c}{10}}\right) \end{aligned} \tag{29}$$

Diffraction over tree tops

The knife edge diffraction algorithm, described in the Diffraction Algorithms section of the manual, is used to calculate the diffraction over tree tops. The parameter *V*, is calculated as follows:

$$V = 0.082 \sqrt{\frac{h_c^2 \cdot f_{MHz}}{d_c}} \tag{30}$$

Building clutter

Building clutter is calculated as the minimum value of the following three propagation mechanisms:

- Attenuation through the building
- Building multipath propagation loss
- Knife edge diffraction over the top of the building

Attenuation through buildings

Table 2: Building attenuation

Building type	***Attenuation E_m***
Wood buildings	15 dB
Brick buildings	30 dB
Concrete buildings	30 dB
Metal buildings	45 dB

The attenuation through a 15 meter thick building for various types of construction is given in the following table.

Building attenuation, L_a, as a function of the depth of buildings along the path, d_p, is given by:

$$L_a = \frac{d_p \cdot E_m}{15} \quad (31)$$

Building multipath propagation loss

The multipath transmission loss due to buildings, L_m, is given by:

$L_m = 20 \cdot log(f_{MHz})$ **(32)**

Diffraction over the top of buildings

Diffraction over the top of buildings is calculated in the same manner as trees.

Diffraction around buildings and trees

Due to the finite width of the clutter across the path, energy will be transmitted around the trees and buildings. The reduction in loss due to this propagation mechanism is given by: $L_1 = L \cdot \left(1 - e^{-\frac{2 \cdot w_c}{d_c}} \right)$ **(33)**

Tropospheric scatter loss

Tropospheric scatter loss, L_{sr}, is based on Reference (5) and is given by:

$$
\begin{aligned}
&L_{sr} = 30 \cdot log(f_{MHz}) - 20 \cdot log(d) + F(\theta \cdot d)\\
&for N_S = 301\\
&where\\
&F(\theta \cdot d) = 135.82 + 0.33\,\theta d + 30 log(\theta d)\\
&for\ 0.01 < \theta d < 10\\
&F(\theta \cdot d) = 129.5 + 0.212 \cdot \theta D + 37.5 \cdot log(\theta \cdot d)\\
&for\ 10 < \theta \cdot d < 70\\
&F(\theta \cdot d) = 119.2 + 0.157 \cdot \theta \cdot D + 45 \cdot log(\theta \cdot d)\\
&for\ \theta \cdot d > 70\\
&F(\theta \cdot d, N_s) = F(\theta \cdot D) - \left[0.1 \cdot (N_s - 301) e^{\frac{-\theta \cdot d}{40}}\right]
\end{aligned}
\quad \textbf{(23)}
$$

N_s surface refractivity

d path length in kilometers

G_t transmit antenna gain (dB)

G_r receiver antenna gain (dB)

Note that Equation (23) represents the total transmission loss between the transmit and receive sites due to tropospheric scatter. In the Pathloss program, tropospheric scatter loss is expressed relative to the free space loss. As stated in Reference (6), Equation (23) has not been validated for frequencies above 4 GHz. Theoretical calculations suggest that at frequencies between 2000 and 6000 MHz, the frequency dependence of tropospheric scatter loss will change from *30 log(f)* to *20 log(f)*. Accordingly, Equation (23) is modified as shown below.

$$L_s = 36 + 20 \cdot log(f_{MHz}) - 20 \cdot log(d) + F(\theta \cdot d) \quad \textbf{(24)}$$

The transition frequency between Equation (23) and Equation (24) is 3981 MHz. The Pathloss program provides the following three options to calculate scatter loss:

- *30 log(f)*
- *36 + 20 log(f)*
- *30 log(f) for f ≤ 3981 MHz*
  or
  36 + 20 log(f) for f > 3981 MHz

OHLOSS (Over the horizon loss)

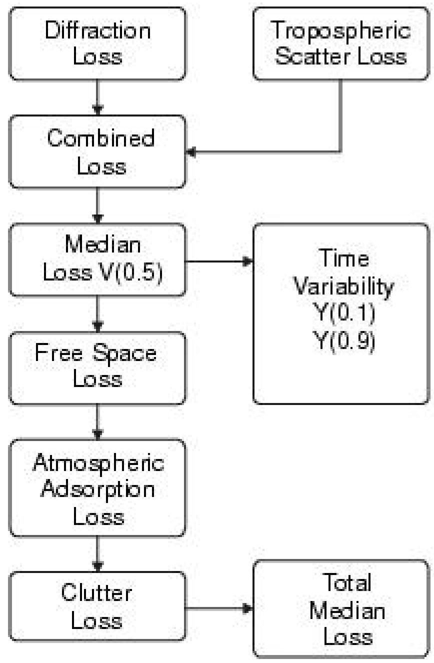


Figure (17): Transhorizon path loss

Transhorizon path loss components

Figure (17) shows the components of a transhorizon path loss calculation.

The diffraction and tropospheric scatter loss are combined and adjusted for regional geographic effects to produce a median value of the transhorizon path loss.

The time variability is calculated as the cumulative probability distribution of loss as a function of time, using 50% and 95% confidence factors.

Options are provided for both interference and transmission applications.

The probability distributions are not the same for the two cases. In the interference case, the minimum value of the path loss is given as a function of time. In the transmission case, the maximum value is calculated.

The total loss is calculated as the sum of the median loss, free space loss, atmospheric absorption loss and clutter loss, (if separately calculated).

OHLOSS report terminology

Loss summary

The OHLOSS report loss summary below represents the components shown in Figure (17).

Diffraction loss (dB)	34.75
Tree - building loss (dB)	0.00
Troposcatter loss (dB)	41.65
Combined loss (dB)	33.94
Median loss (dB)	33.51
Free Space loss (dB)	119.21
Atmospheric Absorption loss (dB)	0.14
Clutter Loss (dB)	Note (1)
Total loss (dB)	152.85

Note (1) Clutter loss must be separately calculated to be included in the OHLOSS report.

Cumulative loss distribution

This section of the OHLOSS report presents a cumulative probability distribution of the combined median loss for both interference and transmission applications as shown below. The values of loss in the column P=0.5, represents the median or average value of the expected loss as a function of time.

The values in the column (P=0.95) are adjusted for a 95% confidence level.

The 50% values for P=0.5 are the same for both interference and transmission applications.

Median Loss Time Variability

Time (%)	***Minimum Loss***		***Maximum Loss***	
	(P=50%)	(P=95%)	(P=50%)	(P=95%)
50.0000	33.51	27.66	33.51	39.36
80.0000	30.45	24.34	36.14	42.18
90.0000	28.85	22.42	37.26	43.49
99.0000	24.19	16.29	40.34	47.37
99.9000	20.78	11.48	42.56	50.35
99.9900	17.99	7.40	44.40	52.92
99.9950	17.43	6.58		
99.9975	16.68	5.47		

All loss values are artificially limited to -6.0 dB in interference applications. No limits are imposed on the values of loss in the transmission option.

Terrain profile listing

The OHLOSS report includes an optional listing of the terrain profile.

The following terminology is used:

DIST The cumulative path distance measured

from Site 1.

GND The ground elevation corresponding to

DIST measured above mean sea level.

OBST The height of any obstruction (tree

or building) measured above ground level.

CLR The absolute clearance measured from

the top of an obstruction to the line between antennas. The effects of the earth radius factor (K) are included in the clearance.

Path characteristics

The following conditions are tested and printed if true:

- Path is line of sight (LOS) for flat earth.
- Path has a common horizon.
- Path has separate horizons.
- Path is blocked between horizons.
- Path is blocked by __ obstacle(s).

Combined loss

Diffraction and tropospheric scatter are treated as two independent transmission mechanisms. Tropospheric scatter loss represents the limiting value of the transmission loss. The combined loss, *L*c, is calculated as:

$$L_c = 10 \cdot \log\left[10^{\left(-\frac{L_d}{10}\right)} + 10^{-\frac{L_s}{10}}\right] \quad \textbf{(34)}$$

L_d calculated diffraction loss

L_s calculated tropospheric scatter loss

Median transmission loss

The median transmission loss, $L_n(0.5)$, is obtained by applying a climatic adjustment factor to the basic combined loss. The climatic adjustment factor is defined as:

$$L_n(0.5) = L_c - V_n(0.5, d_e) \quad \textbf{(35)}$$

n denotes a particular climatic region.

d_e effective distance

The effective distance is given by:

$$d_{sl} = 65 \cdot \left(\frac{100}{f_{MHz}}\right)^{\frac{1}{3}}$$

$$d_L = 3\sqrt{2 \cdot h_{te}} + 3\sqrt{2 \cdot h_{re}}$$

$$for\ d \leq d_L + d_{sl}$$

$$d_e = 130 \cdot \frac{d}{d_L + d_{sl}}$$

$$for\ d > d_L + d_{sl}$$

$$d_e = 130 + d - (d_L + d_{sl}) \qquad \textbf{(36)}$$

h_{te} transmit effective antenna height in meters

h_{re} receive effective antenna height in meters

d path length in kilometers

$V_n(0.5)$ is given by the

following general analytic expression. The constants to evaluate V_n are given in Table 3.

$$\begin{pmatrix} V(0.5) \\ Y(0.1) \\ Y(0.9) \end{pmatrix} = [c_1 \cdot d_e^{n_1} - f_2(d_e)]e^{-(c_3 \cdot d_e^{n_3})} + f_2(d_e)$$

$$f_2(d_e) = f_\infty + (f_m - f_\infty) \cdot e^{-(c_2 \cdot d_e^{n_2})}$$

(37)

Time variability factors

The time variability factor is defined as:

$$L_n(q) = L_n(0.5) - Y_n(q, d_e) \quad \textbf{(38)}$$

n denotes a particular climatic region

q percent of time that the predicted loss will be different than the median transmission loss

The procedure used in Pathloss Version 3.0, calculated the time variability factor using the general analytic expression given in Equation (37). In interference calculations, Y(0.1) was calculated using the constants in Table 4. This results in the value of transmission loss which will be exceeded for 90% of the time. Values for other time percentages were determined by the following multipliers:

50.0000 $L_n(0.5)$

80.0000 $L_n(0.5)$ - 0.6567?Y(0.1)

90.0000 $L_n(0.5)$ - Y(0.1)

99.0000 $L_n(0.5)$ - 2.0?Y(0.1)

90.9000 $L_n(0.5)$ - 2.73?Y(0.1)

99.9900 $L_n(0.5)$ - 3.33?Y(0.1)
99.9950 $L_n(0.5)$ - 3.45?Y(0.1)
99.9975 $L_n(0.5)$ - 3.61?Y(0.1)

In transmission applications, the parameters in Table 5 were used to calculate Y(0.9). This represents the value of transmission loss that will be exceeded for 10% of the time. Values for other time percentages were determined by the following multipliers:

50.0000 $L_n(0.5)$
20.0000 $L_n(0.5)$ + 0.7?Y(0.9)
10.0000 $L_n(0.5)$ + Y(0.9)
01.0000 $L_n(0.5)$ + 1.82?Y(0.9)
00.1000 $L_n(0.5)$ + 2.41?Y(0.9)
00.0100 $L_n(0.5)$ + 2.9?Y(0.9)

This approach produced a reasonable approximation of the curves in Technical Note 101 for the 0.1 and 0.9 time percentages. For other time percentages, the above scaling factors only produced good agreement with the Continental Temperate climatic region. In Version 4.0, all of the time variability curves in Technical Note 101 have been digitized. The value at any time percentage is determined by interpolating the specific curves.

95 percent confidence factor adjustment

The adjustment for a 95 percent confidence level is given by:

$$L_n(q) \pm 1.64\sqrt{12.73 + 0.12Y^2(q)} \quad \textbf{(39)}$$

The adjustment is negative for the interference elimination option and positive for the transmission option.

Table 3: $V_n(0.5)$ Evaluation constants

Region	C_1	C_2	C_3	n_1	n_2	n_3	f_m	f_∞
Continental Temperate	1.59e-05	1.56e-11	2.77e-08	2.32	4.08	3.25	3.90	0.00
Maritime Temperate Overland	1.12e-04	1.26e-20	1.17e-11	1.68	7.30	4.41	1.70	0.00
Maritime Temperate Overseas	1.18e-04	3.33e-13	3.82e-09	2.06	4.60	3.75	7.00	3.20
Maritime Subtropical Overland	1.09e-04	5.89e-18	2.21e-07	2.06	6.81	2.97	5.80	2.20
Desert (Sahara)**	8.85e-07	2.76e-14	2.25e-12	2.80	4.82	4.78	8.40	8.20
Equatorial	3.45e-07	3.74e-12	6.97e-08	2.97	4.43	3.14	1.20	-8.40

Table 4: Y(0.1) Evaluation Constants

Region	C_1	C_2	C_3	n_1	n_2	n_3	f_m	f_∞
Continental Temperate	3.56e-02	9.85e-08	1.50e-11	1.13	2.80	4.85	10.50	5.40
Maritime Temperate Overland	6-28e-04	3.19e-08	6.06e-12	1.92	2.96	5.05	13.00	12.50

Maritime Temperate Overseas	182e-02	2.40e+00	6.92e-15	1.29	0.00	5.78	19.00	14.00
Maritime Subtropical Overland	4.33e-02	7.13e-11	1.19e-12	1.09	3.89	4.93	17.50	13.60
Desert (Sahara)	6.09e-02	1.36e-05	3.18e-11	1.08	1.84	4.60	15.10	6.00
Equatorial	5.22e-03	1.57e-04	5.22e-17	1.39	1.46	6.78	8.50	3.20
Continental Subtropical	1.01e-02	2.26e-07	3.90e-09	1.46	2.67	3.78	16.00	9.10

Table 5: Y(0.9) Evaluation Constants

Region	C_1	C_2	C_3	n_1	n_2	n_3	f_m	f_∞
Continental Temperate	9.48e-03	5.70e-11	5.56e-06	1.33	3.96	2.44	8.20	3.00
Maritime Temperate Overland	1.29e-04	1.93e-15	2.81e-04	2.14	5.80	1.65	10.00	4.50
Maritime Temperate Overseas	1.25e-03	6.57e-16	1.49e-09	1.72	5.96	3.84	12.00	4.00
Maritime Subtropical Overland	7.24e-03	4.26e-15	1.12e-06	1.35	5.41	2.56	12.70	8.40
Desert (Sahara)	3.19e-02	5.66e-08	7.39e-11	1.14	2.76	4.40	11.40	3.30
Equatorial	6.51e-03	2.53e-04	2.61e-16	1.36	1.36	6.55	8.40	2.70
Continental Subtropical	3.49e-03	1.08e-09	9.15e-11	1.55	3.49	4.48	10.10	3.50

** The constants shown for the Desert (Sahara) climatic region calculate the value for $-V_n(0.5)$

Time variability curves

The remainder of this section contains the time variability curves actually used in the program. These have been digitized from Technical Note 101

and form the basis of all time variability calculations.

The upper set of curves (0.1 to 0.0001) represents the up fade probability and are used in the interference calculations.

The lower set of curves (0.9 to 0.9999) represents the down fade probability and are used in transmission applications.

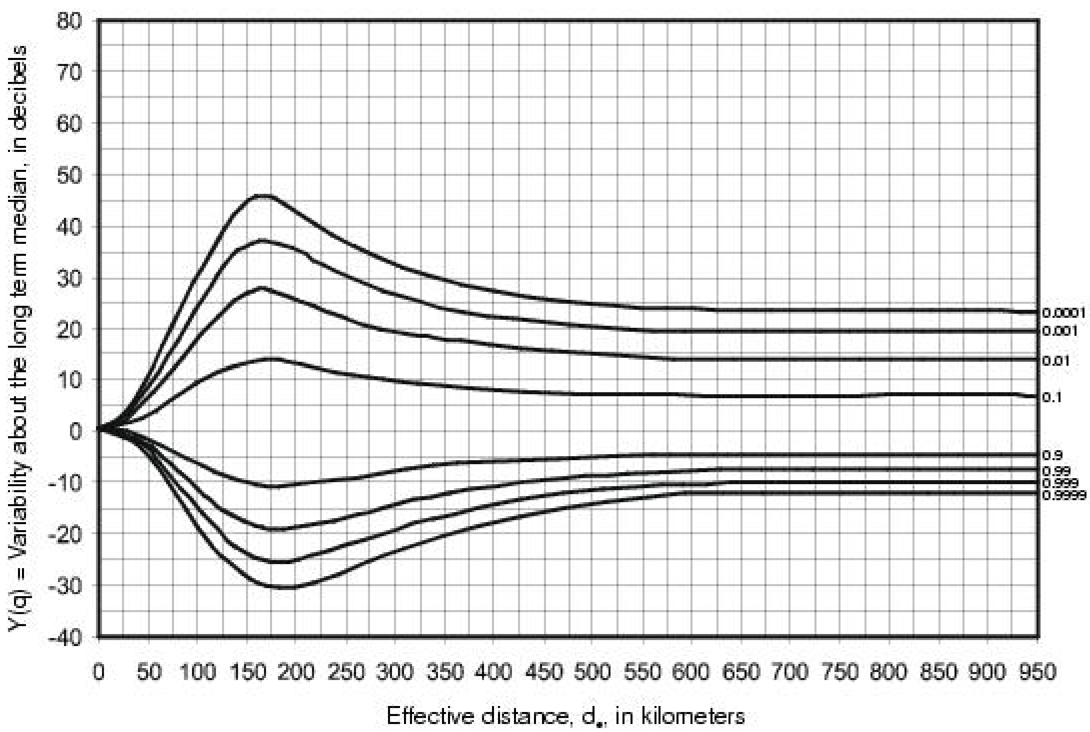


Figure (18): Continental Temperate

Climate 88 - 108 MHz

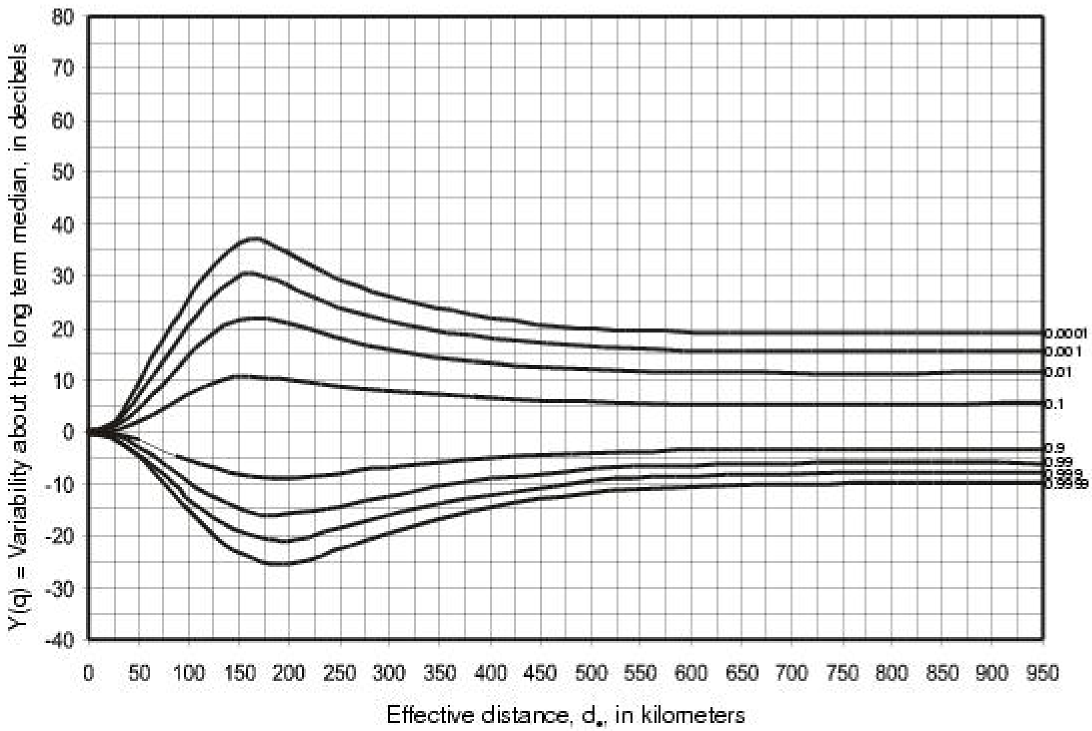


Figure (19): Continental Temperate

Climate 40 - 88 MHz

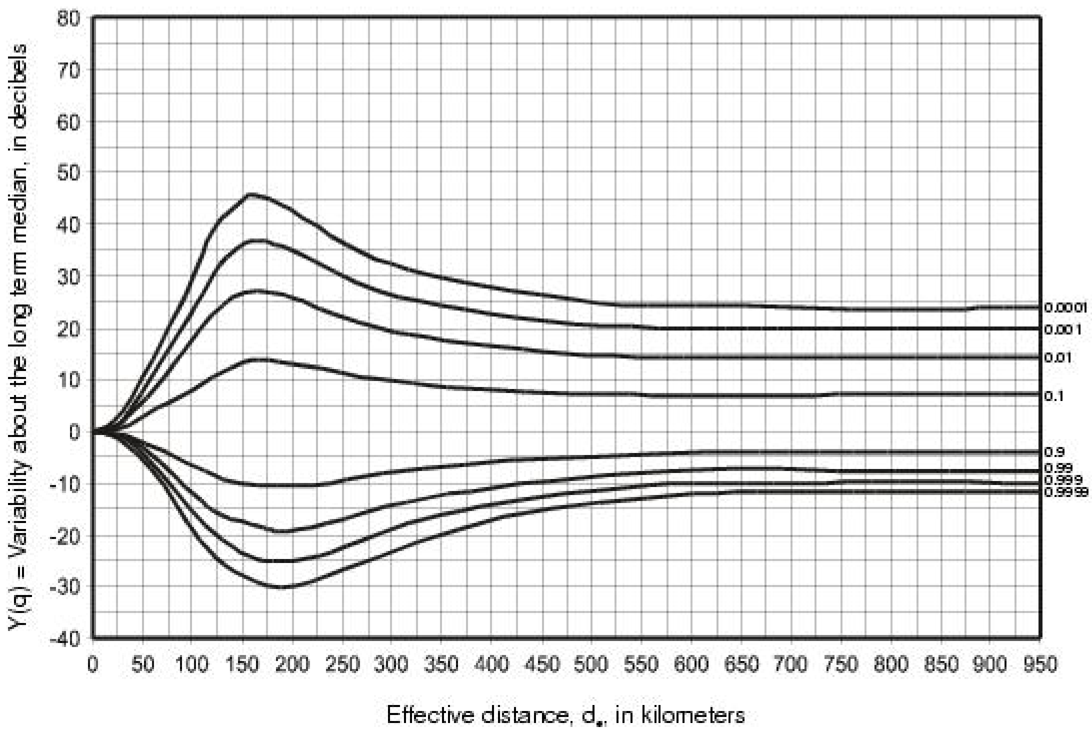


Figure (20): Continental Temperate

Climate 108 - 250 MHz

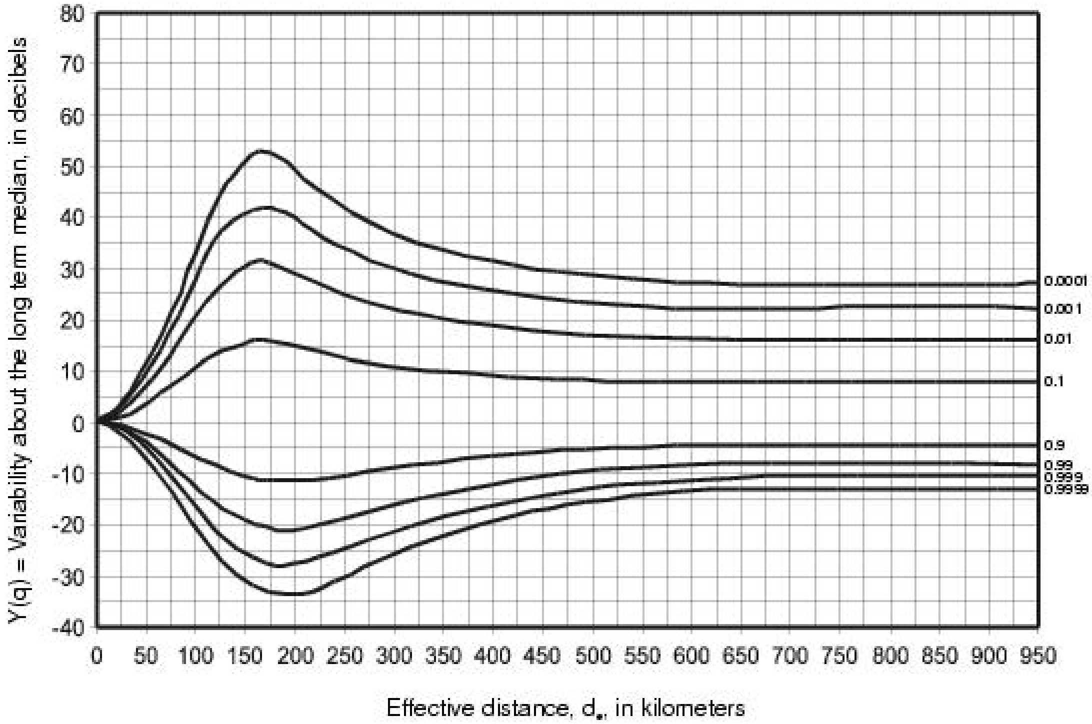


Figure (21): Continental Temperate

Climate 250 - 450 MHz

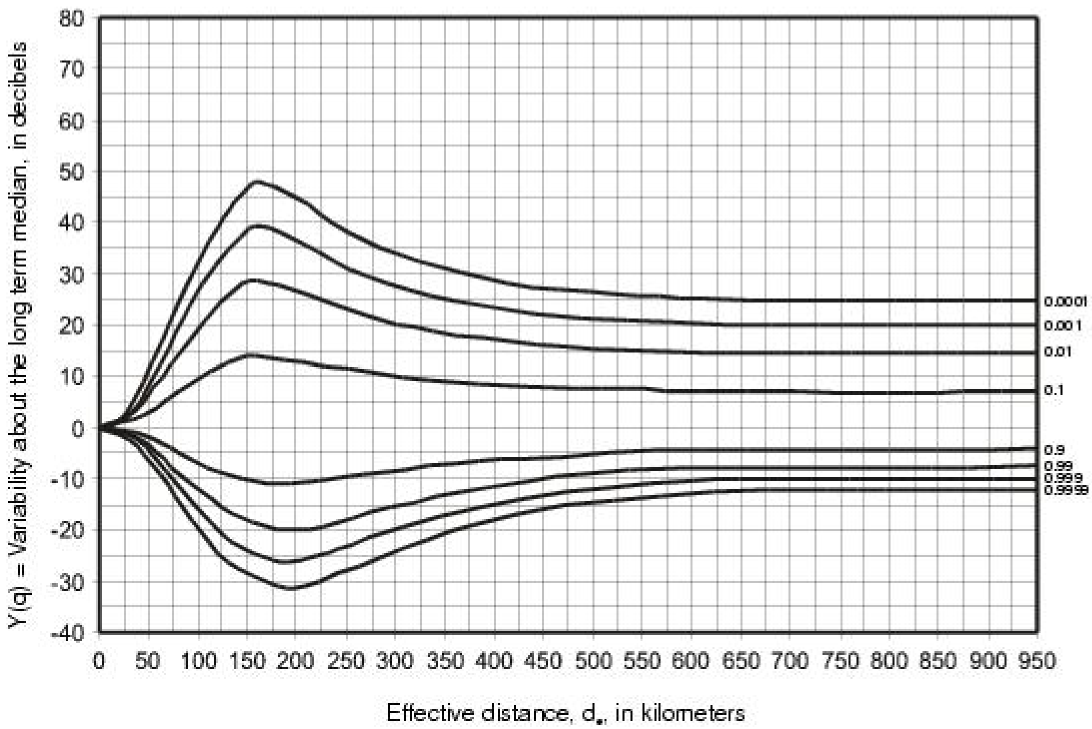


Figure (22): Continental Temperate

Climate 450 - 1000 MHz

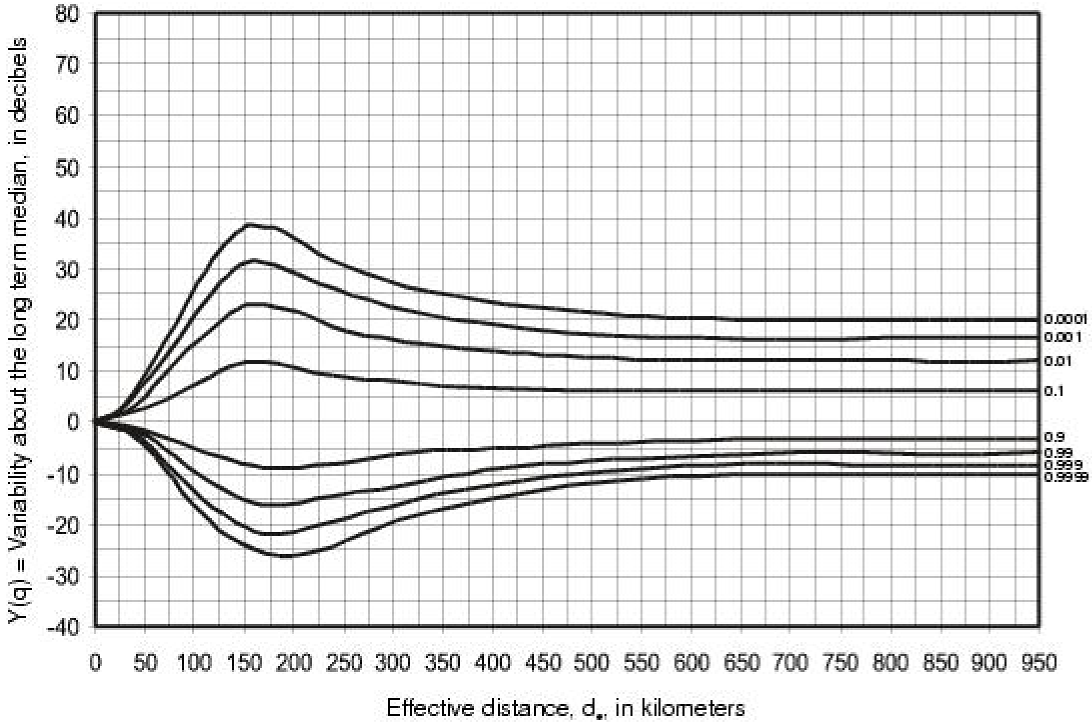


Figure (23): Continental Temperate

Climate > 1000 MHz

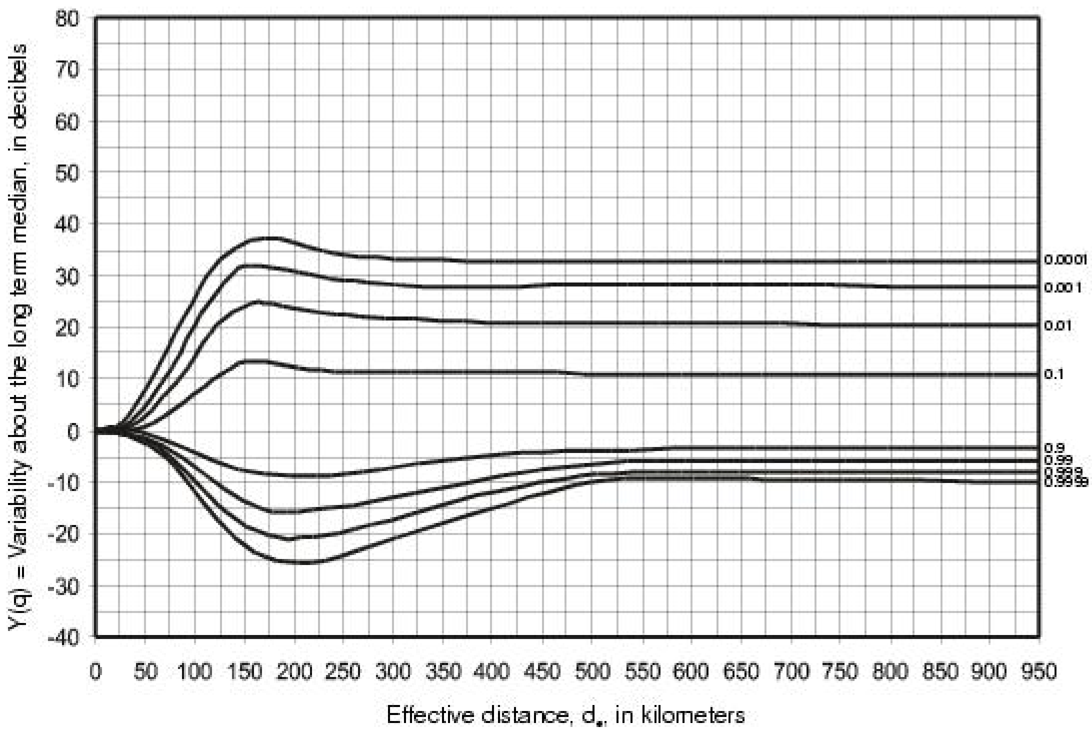


Figure (24): Maritime Temperate Climate

Overland 40 - 100 MHz

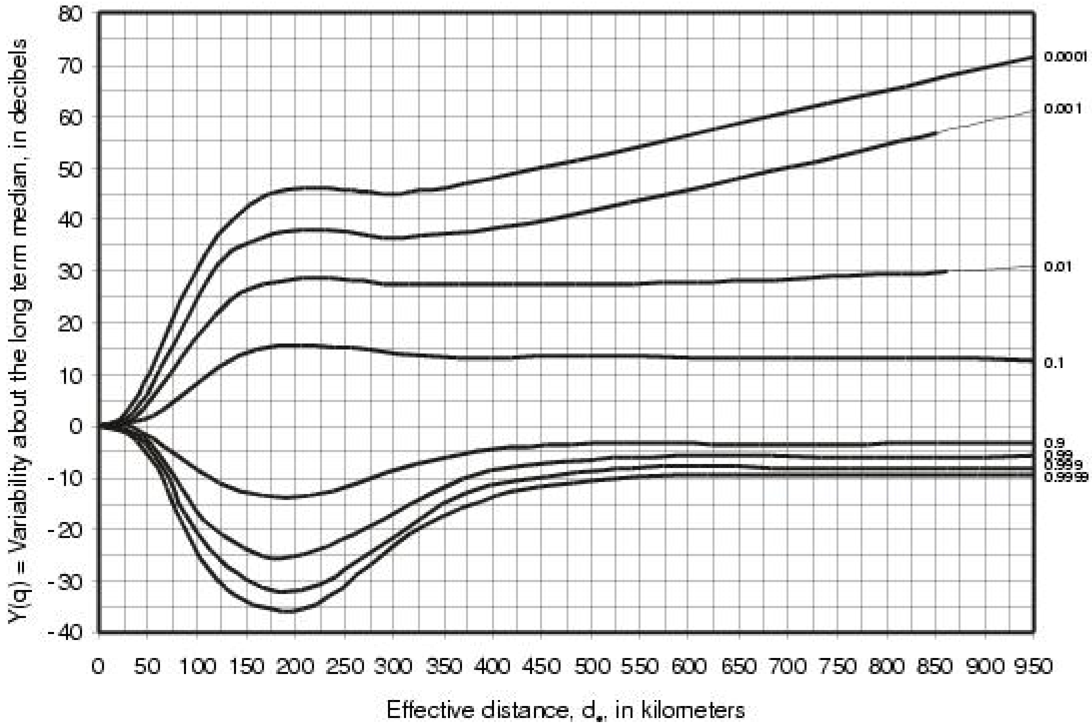


Figure (25): Maritime Temperate Climate

Oversea 40 - 100 MHz

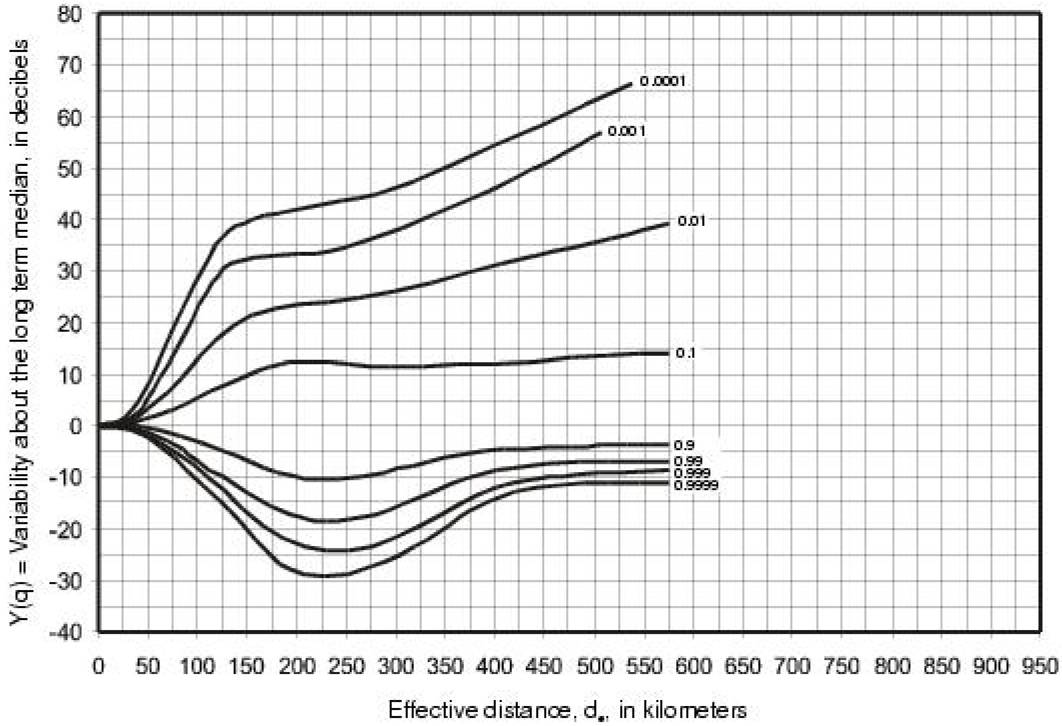


Figure (26): Maritime Temperate Climate

Overland 150 - 250 MHz

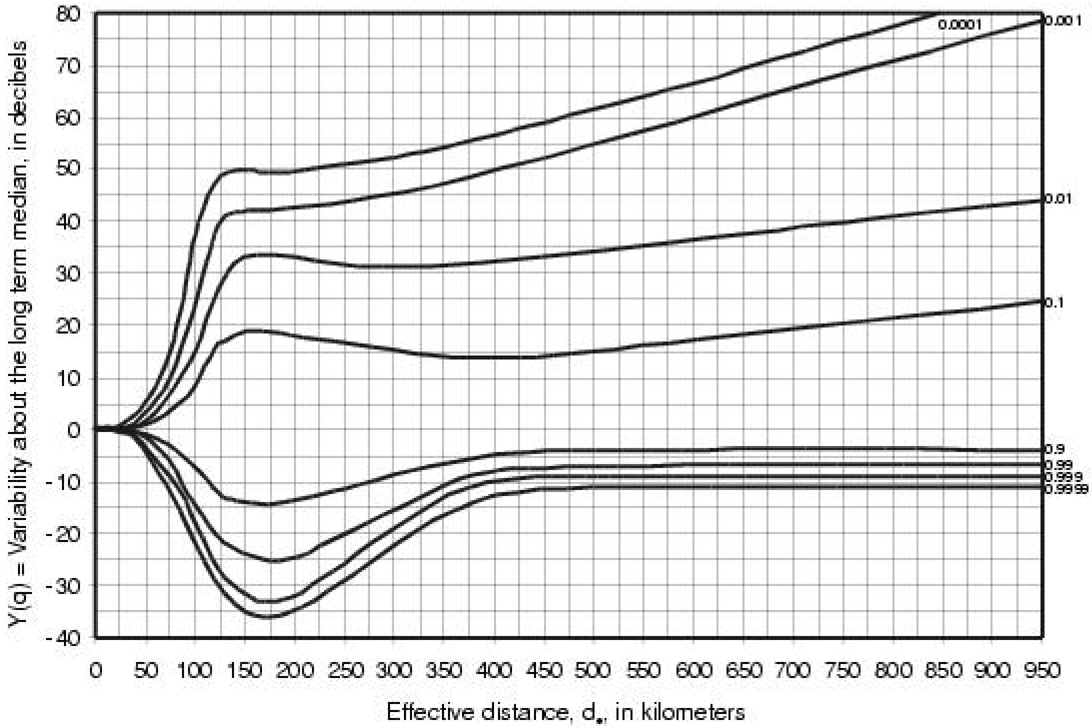


Figure (27): Maritime Temperate Climate

Oversea 150 - 250 MHz

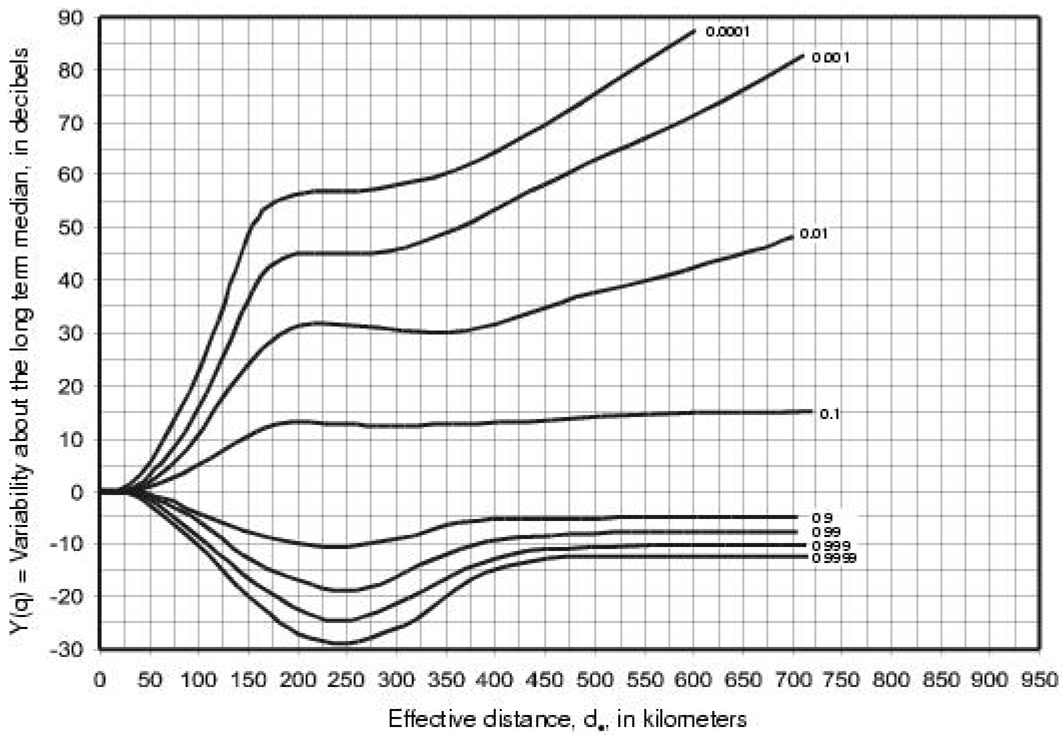


Figure (28): Maritime Temperate Climate

Overland 450 - 1000 MHz

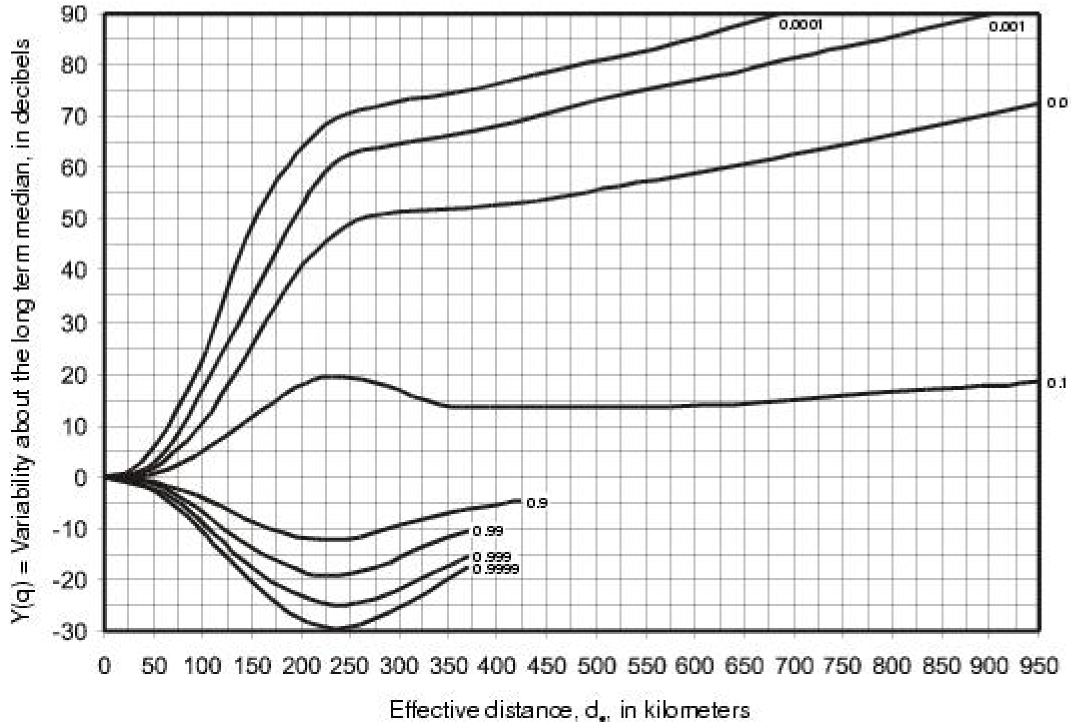


Figure (29): Maritime Temperate Climate

Oversea 450 - 1000 MHz

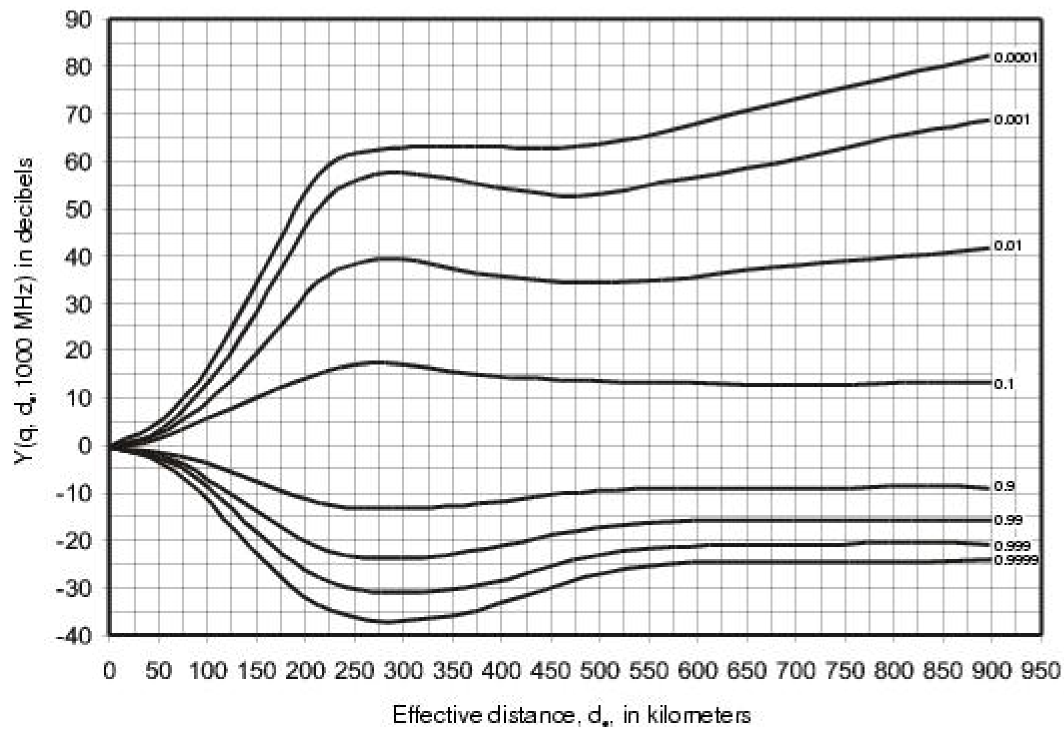


Figure (30): Climate 4 - Maritime

Subtropical Overland

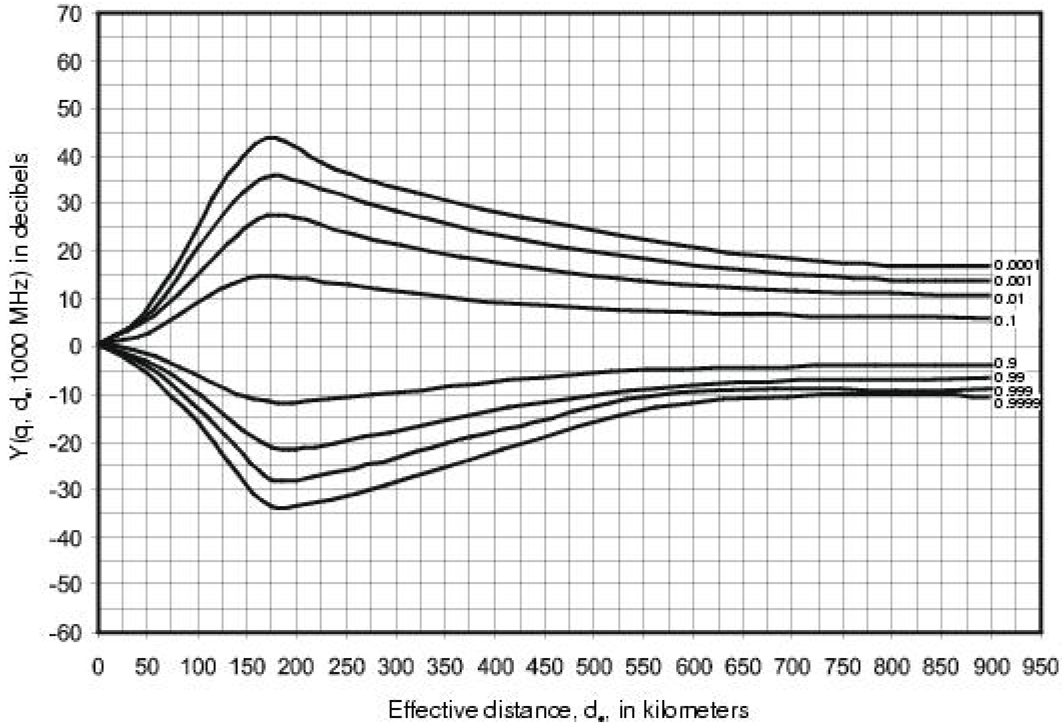


Figure (31): Climate 6 - Desert Sahara

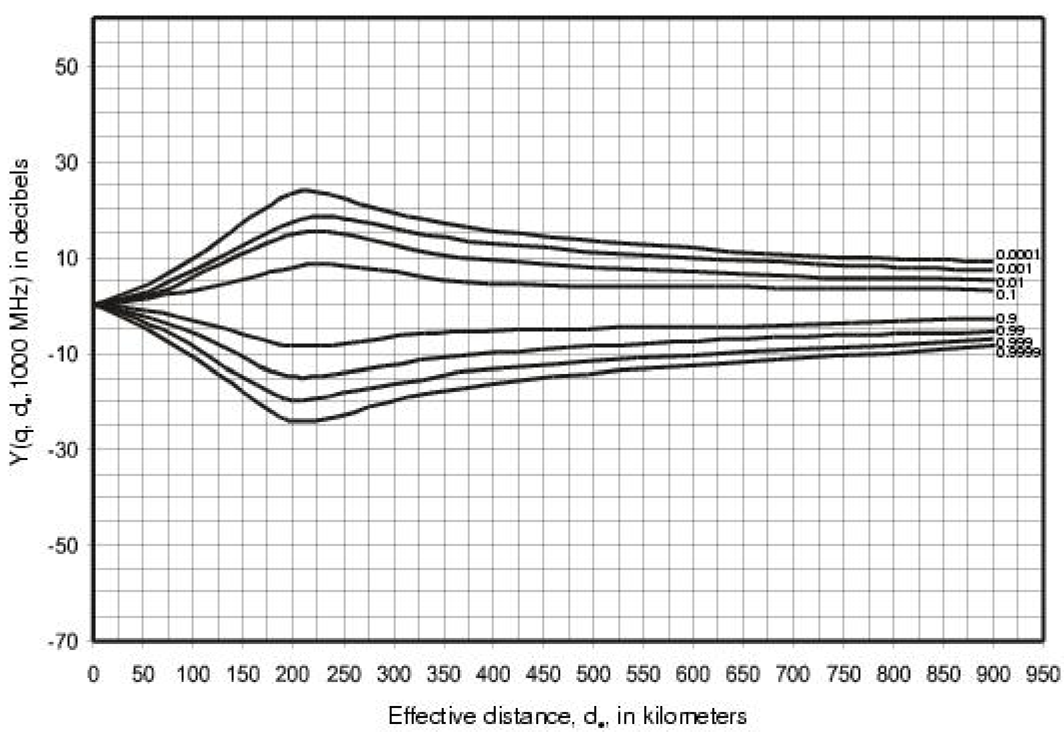


Figure (32): Climate 7, Equatorial

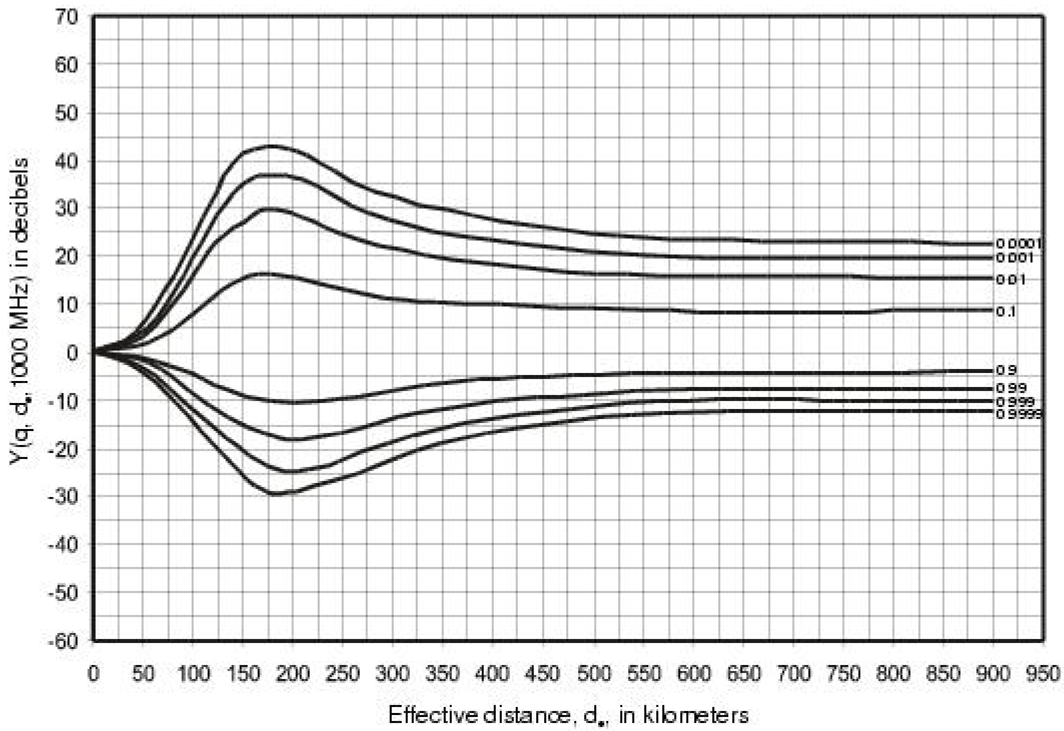


Figure (33): Climate 8, Continental

Subtropical

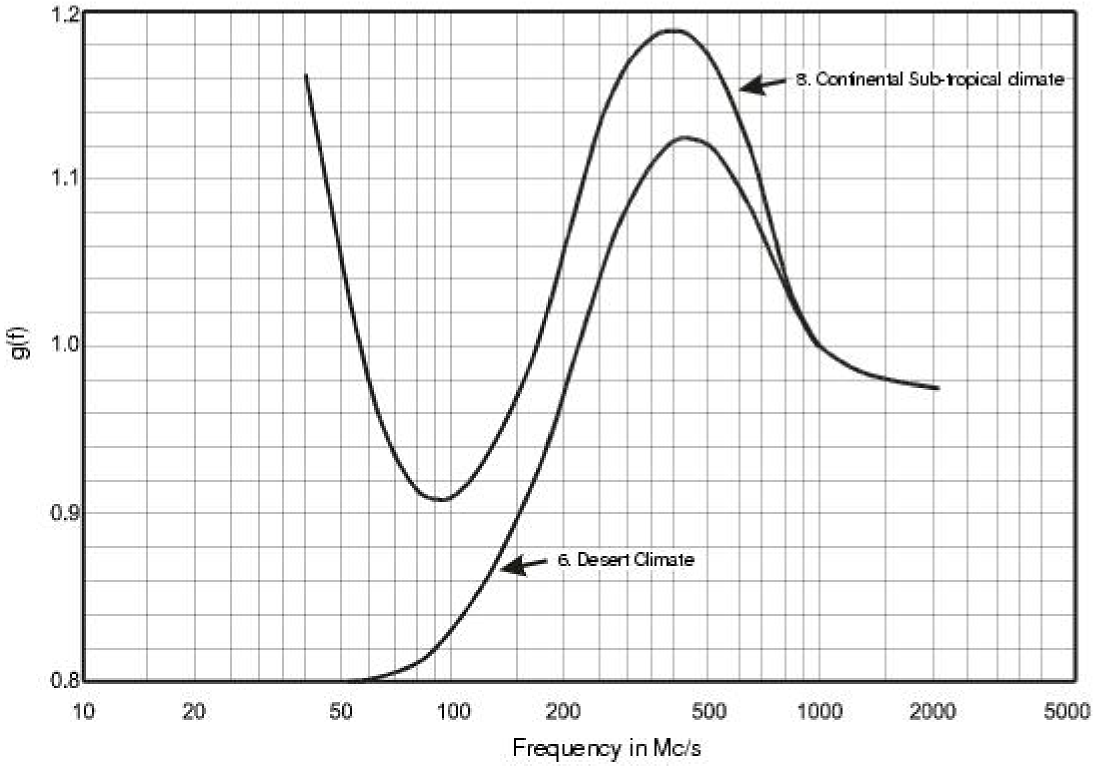


Figure (34): The Factor g(f) - g(f)

= 1 for climates 4, 5 and 7

References

1. Transmission Loss Predictions for Tropospheric Communication Circuits
   Technical Note 101
   Referenced AD 687 820
   National Technical Information Service
   US Department of Commerce
   Springfield, Virginia
   22151
2. Longley A.G. and Reasoner R.K.
   Comparison of Propagation Measurements with Predicted Values in the 20 to 10,000 MHz Range
   ERL 148-ITS 97
   Institute for Telecommunication Sciences, Boulder, Colorado
   January 1970
3. Prediction of Tropospheric Radio Transmission Loss Over Irregular Terrain
   A Computer Method 1968
   A. G. Longley and P. L. Rice
   ESSA Technical Report ERL 79-ITS 67
   Reference AD 676874
   National Technical Information Service
   US Department of Commerce
   Springfield VA 22151
4. Norton K.A., Rice P.L. and Vogler L.E.
   The Use of Angular Distance in Estimating Transmission Loss and Fading Range for Propagation through a Turbulent Atmosphere over Irregular Terrain.
   Proc IRE Vol. 43, October 1955, pp 1488-1526
5. CCIR Report 238-5, section 3
6. CCIR Report 569-3, 1984, section 4
7. Microwave Radio Obstruction Fading
   A. Vigants

Bell System Technical Journal
Volume 60 July-August 1981

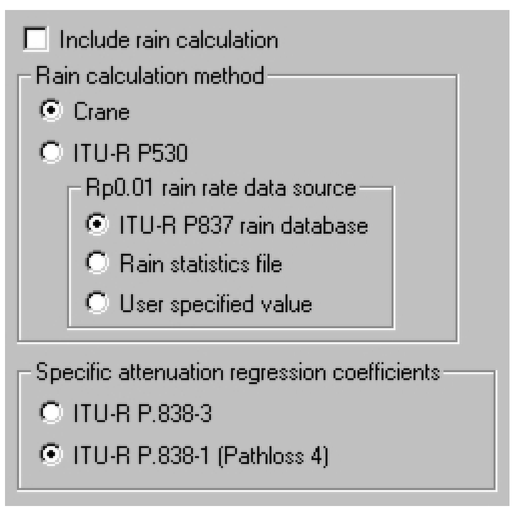
8. Multiple Knife Edge Diffraction of Microwaves
Jacques Deygout
IEEE Transactions on Antennas and Propagation
Vol. AP-14, No 4, July 1966 pp 480 - 489
9. An Experimental Study of Wave Propagation at 850 MHz
J. Epstein and D.W. Peterson
Proc IRE Vol 41, 1953, pp 595-611.
10. Radio Wave Propagation
A. Picquenard
Wiley, New York, 1974
Page 296
11. Radio Propagation Fundamentals
Kenneth Bullington
Bell System Technical Journal
Volume XXXVI May 1957 Number 3
12. Mobile Communications Engineering
W.C.Y. Lee
McGraw Hill
13. P.L. Rice
1971 IEEE Mountain-West conference record
pp 1-10.

Overview

Rain calculations are available in conventional microwave and WiFi-WIMAX applications. Rain attenuation does not usually contribute to the overall link unavailability at frequencies below 8 GHz; however, this will depend on the path length and the geographic location of the path. The user is responsible to enable the rain calculation.

A rain calculation consists of the two basic parts:

- calculate the rain rate (millimeters / hour) which will produce an attenuation equal to the link fade margin
- determine the fraction of time that this rain rate is exceeded i.e. the probability of an outage due to rain
- Rain affects both directions of transmission simultaneously and is a function of frequency, path length and polarization.



Calculation method

Rain calculations can be made using the Crane or ITU-530 algorithms. The choice is made under Configure - PL50L options - Transmission calculations - Rain.

The Crane method requires a rain statistics file (a table of rain rate and the percent of time that the rain rate is exceeded). The ITU method only requires the rain rate which is exceeded for 0.01% of the time. This in turn can be obtained from the following sources:

- ITU-R P837 rain database
- rain statistics file
- user specified rain rate

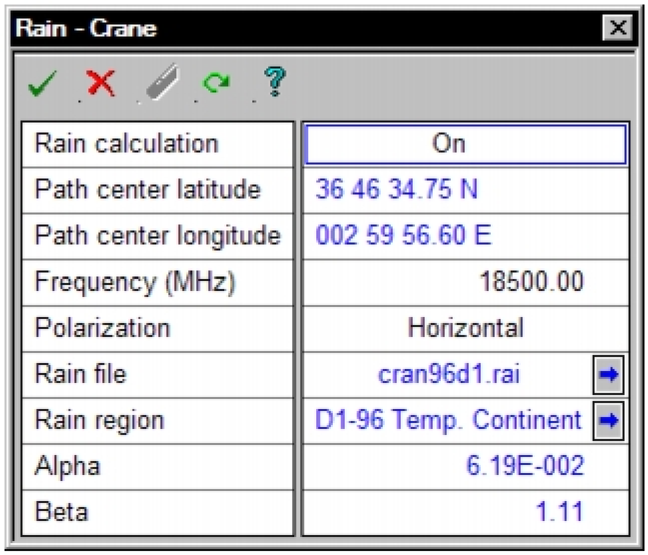
The regression coefficients α and β can be computed from ITU-R-838-1 or 838-3. The former uses a table of values and a logarithmic interpolation procedure. The latter uses analytic equations. Slight differences occur between the two methods. Pathloss version 4 used 838-1.

Operations

Click on the rain cloud in the transmission analysis section to access the rain data entry form. This icon is not available in land mobile applications. The form will be formatted for the calculation method set under PL50L options.

Crane rain data entry form

A rain statistics file is required in the Crane rain method.



Rain calculation

The user is responsible for enabling - disabling the rain calculation.

Path center coordinates

These are required to determine the required rain statistics file. If site coordinates exist, then the average values will be used; otherwise, the coordinates can be manually entered.

Frequency - Polarization

These parameters are common to all design sections

Rain file

Click the calculate button on this line to load a rain file. The rain file name and the rain region will be displayed.

Rain region

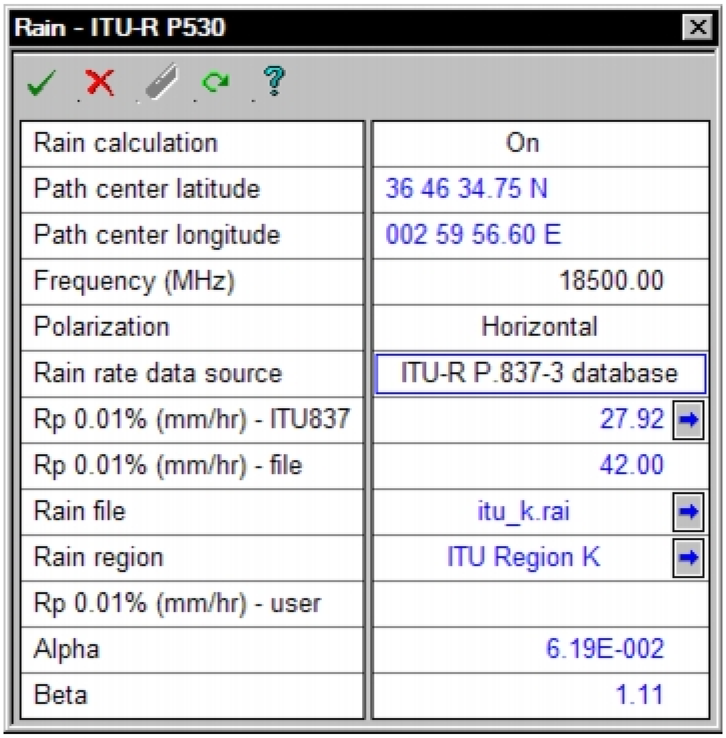
Click the calculate button on this line to determine the required rain statistics file. The file will be automatically loaded and the rain region and rain file name will be displayed. If the path center coordinates are within a latitude between 23.75 and 50.25 degrees north and longitude between 65.75 and 125.25 degrees west, then legacy AT&T rain data files will be used; otherwise the correct Crane 96 rain file will be selected

Alpha - Beta

The calculated values for alpha and beta are shown for reference. These depend on the frequency an polarization

ITR-R P530 rain data entry form

All of the ITU-530 rain options set under Configure -PL50L options... are duplicated in this data entry form



Rain - ITU-R P530

Rain calculation	On
Path center latitude	36 46 34.75 N
Path center longitude	002 59 56.60 E
Frequency (MHz)	18500.00
Polarization	Horizontal
Rain rate data source	ITU-R P.837-3 database
Rp 0.01% (mm/hr) - ITU837	27.92
Rp 0.01% (mm/hr) - file	42.00
Rain file	itu_k.rai
Rain region	ITU Region K
Rp 0.01% (mm/hr) - user	
Alpha	6.19E-002
Beta	1.11

Rain calculation

The user is responsible for enabling - disabling the rain calculation

Path center coordinates

These are required to read the ITU-R P.837-3 data base and to determine the required rain statistics file. The latitude is a required parameter in the ITU 530 algorithm. If site coordinates exist, then the average values will be used; otherwise, the coordinates can be manually entered.

Frequency - Polarization

These parameters are common to all design sections

Rain data source

Select the source for the 0.01% rain rate from the following in the drop down list.

- ITU-R P.837-3 database
- Rain statistics file
- user's Rp 0.01% value

Rp 0.01% ITU837

Click the calculate button on this line to read the value from the database. The path center coordinates are required for this operation

Rp 0.01% file

The Rain file and Rain region lines determine the value entered on this line. Click the calculate button on the Rain file line to load a rain file. The rain region and the 0.01% rain rate will be entered along with the selected rain file name.

Click the calculate button on the Rain region line to determine the required ITU rain file name based on the path center coordinates. The rain file will be loaded and the 0.01`% rain rate and the region will be entered.

Rp 0.01% user

The user can specify the 0.01% rain rate to be used in the calculation.

Alpha - Beta

The interpolated values for alpha and beta are shown for reference.
These depend on the frequency an polarization

Regression coefficients

ITU-R P838-1 method

The regression coefficients (*α* and *β*) are given in Table 1 below for horizontal and vertical polarizations as a function of frequency. This data is take from ITU-R P838-1.

Table 1: Regression coefficients

Frequency (GHz)	α_h	α_v	β_h	β_v
1.0	3.870e-05	3.520e-05	0.912	0.880
2.0	1.540e-04	1.380e-04	0.963	0.923
4.0	6.500e-04	5.910e-04	1.121	1.075
6.0	1.750e-03	1.550e-03	1.308	1.265
7.0	3.010e-03	2.650e-03	1.332	1.312
8.0	4.540e-03	3.950e-03	1.327	1.310
10.0	1.010e-02	8.870e-03	1.276	1.264
12.0	1.880e-02	1.680e-02	1.217	1.200
15.0	3.670e-02	3.350e-02	1.154	1.128
20.0	7.510e-02	6.910e-02	1.099	1.065
25.0	0.124	0.113	1.061	1.030
30.0	0.187	0.167	1.021	1.000
35.0	0.263	0.233	0.979	0.963
40.0	0.350	0.310	0.939	0.929
45.0	0.442	0.393	0.903	0.897
50.0	0.536	0.479	0.873	0.868
60.0	0.707	0.642	0.826	0.824
70.0	0.851	0.784	0.793	0.793
80.0	0.975	0.906	0.769	0.769
90.0	1.060	0.999	0.753	0.754

100.0	1.120	1.060	0.743	0.744

The following equations are used to interpolate values of the regression coefficients, α_x and β_x, for a specific frequency, f_x.

$$\alpha_x = log^{-1}[log\alpha_1 - M \cdot (log\alpha_1 - log\alpha_2)]$$

$$\beta_x = b_1 - M \cdot (\beta_1 - \beta_2)$$

$$M = \left(\frac{logf_1 - logf_x}{logf_1 - logf_2}\right)$$

$$f_1 < f_x < f_2$$

$$\alpha_1 < \alpha_x < \alpha_2$$

$$\beta_1 < \beta_x < \beta_2$$

(1)

ITU-R P838-3 method

Values for the coefficients α and β are determined as functions of frequency, f (GHz), in the range from 1 to 100 GHz, from the following equations, which have been developed from curve-fitting to power-law coefficients derived from scattering calculations given in Equation (2) and Equation (3).

$$\log_{10}\alpha = \sum_{j=1}^{4} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_\alpha \log_{10} f + c_\alpha$$

(2)

$$\beta = \sum_{j=1}^{5} a_j \exp\left[-\left(\frac{\log_{10} f - b_j}{c_j}\right)^2\right] + m_\beta \log_{10} f + c_\beta$$

(3)

Values for the constants for the coefficient α_H for horizontal polarization are given in Table 2 and for the coefficient α_V for vertical polarization in Table 3. Table 4 gives the values for the constants for the coefficient β_H for horizontal polarization, and Table 5 gives the values for the constants for the coefficient β_V for vertical polarization

Table 2: Coefficients for α_H

j	a_j	b_j	c_j	m_α	c_α
1	-5.33980	-0.10008	1.13098	-0.18961	0.71147
2	-0.35351	1.26970	0.45400		
3	-0.23789	0.86036	0.15354		
4	-0.94158	0.64552	0.16817		

Table 3: Coefficients for α_V

j	a_j	b_j	c_j	m_α	c_α
1	-3.80595	0.56934	0.81061	-0.16398	0.63297
2	-3.44965	-0.22911	0.51059		
3	-0.39902	0.73042	0.11899		
4	0.50167	1.07319	0.27195		

Table 4: Coefficients for β_H

j	a_j	b_j	c_j	m_β	c_β
1	-0.14318	1.82442	-0.55187	0.67849	-1.95537
2	0.29591	0.77564	0.19822		
3	0.32177	0.63773	0.13164		
4	-5.37610	-0.96230	1.47828		
5	16.1721	-3.29980	3.43990		

Table 5: Coefficients for β_V

j	a_j	b_j	c_j	m_β	c_β
1	-0.07771	2.33840	-0.76284	-0.053739	0.83433
2	0.56727	0.95545	0.54039		
3	-0.20238	1.14520	0.26809		
4	-48.2991	0.791669	0.116226		
5	48.5833	0.791459	0.116479		

Rain attenuation - Crane

The attenuation due to rain, *A*, is based on Reference (1) and is given by the equation: **(4)**

$$A\left(R_p, D\right) = \alpha R_p^{\beta}\left(\frac{e^{\mu\beta d}-1}{\mu\beta} - \frac{b^{\beta}e^{c\beta d}}{c\beta} + \frac{b^{\beta}e^{c\beta D}}{c\beta}\right)\ \mathrm{dB}$$

for $d \le D \le 22.5$ km

$$\mathrm{A}\left(R_p, D\right) = \alpha R_p^{\beta}\left(\frac{e^{\mu\beta D}-1}{\mu\beta}\right)\ \mathrm{dB}$$

for $0 \le D \le d$

$$\mu = \frac{\ln\left(b e^{cd}\right)}{d}$$

$$b = 2.3 R_p^{-0.17}$$

$$c = 0.026 - 0.03 \ln\left(R_p\right)$$

$$d = 3.8 - 0.6 \ln\left(R_p\right)$$

where:

R_p rain rate in millimeters per hour
D path length in kilometers
a,b regression coefficients

Rain performance in the Crane method is estimated as follows:

- Determine the rainfall rate required to produce an attenuation equal to the fade margin. This depends only on the frequency and path length.
- Determine the percent of the year that this rain rate is exceeded. This represents the annual two way rain outage time for the path and is calculated using high intensity rainfall statistics for the specific geographic region.
- In accordance with Reference (1), if the path length is greater than 22.5 kilometers, rain attenuation is calculated using a value

of 22.5 kilometers and a modified point rain rage given by Equation (5).

$$R_p' = R_p\left(\frac{22.5}{D}\right)$$

(5) where:

R_p' is the modified point rain rate.

R_p is the point rain rate in mm / hr.

D is the path length in kilometers.

Rain attenuation - ITU recommendation 530

Rain outage times are calculated using the following steps as described in Reference (5).

Determine the rain rate, $R_{0.01}$, exceeded for 0.01% of the time. This value will be interpolated from the rain statistics file, read from a database or manually entered.

- Calculate the specific attenuation, γ, as shown below:

$$\gamma = \alpha R_{0.01}^{\beta}$$

(6) where α and β are the regression coefficients

- Calculate the effective path length, d_e:

$$d_e = \frac{d}{1 + \frac{d}{d_0}}$$

$$d_0 = 34 e^{-0.015 R_{0.01}}$$

(7) where d is the path length in kilometers. An upper limit of 100 mm/hr is set for $R_{0.01}$ in the above equation.

- The path attenuation, $A_{0.01}$, exceeded for 0.01% of the time is given by:

$$A_{0.01} = \gamma \bullet d_e$$

(8)

- Attenuations, A, exceeded for other percentages of time, P, are derived from the equations:

for latitudes equal to or greater than 30° north or south

$$\frac{A}{A_{0.01}} = 0.12 \bullet P^{-(0.546 + 0.043 \bullet \log_{10}(P))}$$

(9) for latitudes less than 30° north or south

$$\frac{A}{A_{0.01}} = 0.07 \cdot P^{-(0.855+0.139 \cdot \log_{10}(P))}$$ **(10)**

- The attenuation *A* in the above equations, is set to the fade margin and the equation is solved for *P* as follows:

for latitudes equal to or greater than 30° north or south

$$\log_{10}(P) = 11.628 \cdot \left(-0.546 + \sqrt{0.29812 + 0.172 \cdot \log_{10}\left(\frac{0.12 \cdot A_{0.01}}{A}\right)} \right)$$ **(11)** for latitudes less than 30° north or south

$$\log_{10}(P) = 3.59712 \cdot \left(-0.855 + \sqrt{0.731025 + 0.556 \cdot \log_{10}\left(\frac{0.07 \cdot A_{0.01}}{A}\right)} \right)$$ **(12)** ITU-530 clearly states that the equations are valid only in the range from 1% to 0.001%. On many practical links, this range will be exceeded especially on short links with high fade margins.

If the argument of the square root is negative, the results will be extrapolated from the valid part of the curve. A warning will be issued if the results are outside the range 1% to 0.001%.

Worst month rain outage probability

Both the Crane and ITU-530 methods calculate the annual probability of a rain outage. The worst month rain outage probability is given by:

$$T_{wm} = 1.22 \cdot T_{an}^{0.87}$$

$$P_{wm} = \left(\frac{P_{an}}{0.3}\right)^{0.87}$$

(13) where:

T_{wm} worst month outage time in seconds

T_{an} annual outage time in seconds

P_{wm} worst month rain outage probability

P_{an} annual rain outage probability

High intensity rain statistics

High intensity rainfall statistics are contained in external ASCII text files. These consist of a table of rainfall rates and the corresponding annual percentage of time that the rain rate is exceeded. The following rain statistics files are provided:

Crane rain regions

The rain statistics for the Crane and modified Crane (1996) rain regions are taken from References (1) and (4). The Crane regions are shown geographically for the United States and the world in Figure (1) and Figure (3). The corresponding file names and descriptions are as follows:

Region	***File name***	***Description***
A	CRANE_A.RAI	Polar Tundra (Dry)
B	CRANE_B.RAI	Polar Taiga (Moderate)
C	CRANE_C.RAI	Temperate Maritime
D	CRANE_D.RAI	Temperate Continental
E	CRANE_E.RAI	Sub Tropical Wet
F	CRANE_F.RAI	Sub Tropical Arid
G	CRANE_G.RAI	Tropical Moderate
H	CRANE_H.RAI	Tropical

The temperate continental region D, for the United States has been subdivided into three sub regions: D1, D2 and D3 as shown in Figure (1). The corresponding file names are crane_d1.rai, crane_d2.rai and crane_d3.rai respectively. The modified Crane (1996) rain statistics are shown in Table 7 and the original Crane rain statistics are given in Table 6.

Figure (4) shows a world map for the modified Crane (1996) rain regions.

ITU rain regions

The ITU rain regions A to Q are base on Reference (2) and shown in Table 8. A world map showing the ITU rain regions is given in Figure (2). The file naming convention simply uses the rain region to identify the file e.g. ccir_b.rai is the rain file for CCIR rain region B.

Canadian radiosonde locations

Rainfall rate statistics for 47 Canadian radiosonde locations are available in the directory "geo_data\rain\canada" and are taken from Reference (3). The file naming convention is based on the geographic location.

Legacy AT&T rain data

Legacy AT&T rain data files are available in the directory "geo_data\rain\rain_usa". The file names use the curve number and the geographic location

Rain file format

The format of the rain files is shown below using the file CRANE_D2.RAI as an example. Rain files can be created with any text editor.

Line 1	File identifier	`PL-2.0`	
Line 2	Number of points	`11`	
Line 3	Rain region (47 ch)	`D2 Temp. Continental`	
Line 4	Data Points:	`0.001`	`102.0`
Line 5		`0.002`	`86.0`
Line 6	First term is the percent of time that the rain rate is exceeded.	`0.005`	`64.0`
Line 7		`0.020`	`35.0`
Line 8		`0.020`	`35.0`
Line 9	Second term is the rain rate in mm/hr.	`0.050`	`22.0`
Line 10		`0.100`	`15.0`
Line 11		`0.200`	`9.5`
Line 12		`0.500`	`5.2`
Line 13		`1.000`	`3.0`
Line 14		`2.000`	`1.8`

Table 6: Crane rain statistics

% of Year Exceeded	***Crane Rain Climate Region Point Rainfall Rate Rp (mm/hour)***									
	A	***B***	***C***	***D1***	***D2***	***D3***	***E***	***F***	***G***	***H***
0.001	28.0	54.0	80.0	90.0	102.0	127.0	164.0	66.0	129.0	251.0
0.002	24.0	40.0	62.0	72.0	86.0	107.0	144.0	51.0	109.0	220.0
0.005	19.0	26.0	41.0	50.0	64.0	81.0	117.0	34.0	85.0	178.0
0.010	15.0	19.0	28.0	37.0	49.0	63.0	98.0	23.0	67.0	147.0
0.020	12.0	14.0	18.0	27.0	35.0	48.0	77.0	14.0	51.0	115.0
0.050	8.0	9.5	11.0	16.0	22.0	31.0	52.0	8.0	33.0	77.0
0.100	6.5	6.8	7.2	11.0	15.0	22.0	35.0	5.5	22.0	51.0
0.200	4.0	4.8	4.8	7.5	9.5	14.0	21.0	3.2	14.0	31.0
0.500	2.5	2.7	2.8	4.0	5.2	7.0	8.5	1.2	7.0	13.0

1.000	1.7	1.8	1.9	2.2	3.0	4.0	4.0	0.8	3.7	6.4
2.000	1.1	1.2	1.2	1.3	1.8	2.5	2.0	0.4	1.6	2.8

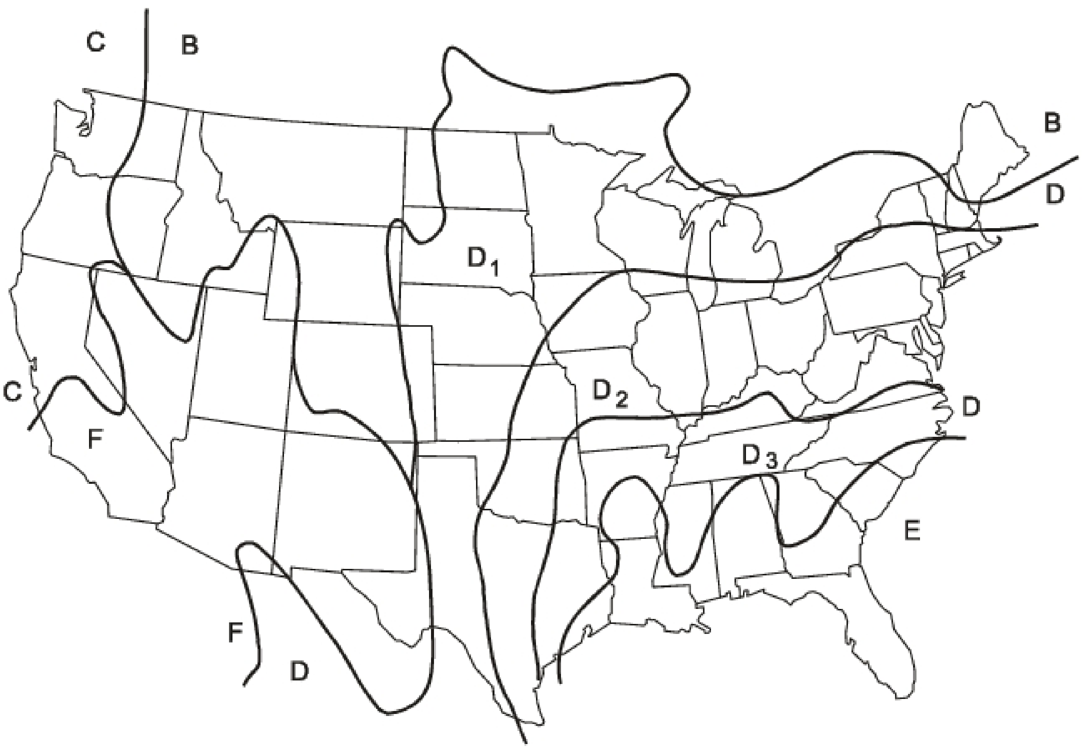


Figure 1: Crane US rain regions

Table 7: Modified Crane (1996) rain statistics

% of Year Exceeded	*Crane 1996 Rain Climate Regions Point Rainfall Rate Rp (mm/hour)*											
	A	***B***	***B1***	***B2***	***C***	***D1***	***D2***	***D3***	***E***	***F***	***G***	***H***
0.001	28.1	52.1	42.6	63.8	71.6	86.6	114.1	133.2	176.0	70.7	197.0	542.6
0.002	20.9	41.7	32.7	50.9	58.9	69.0	88.3	106.6	145.4	50.4	159.6	413.9
0.003	17.5	36.1	27.8	43.8	50.6	60.4	75.6	93.5	130.0	41.4	140.8	350.3
0.005	13.8	29.2	22.3	35.7	41.4	49.2	62.1	78.7	112.0	31.9	118.0	283.4
0.01	9.9	21.1	16.1	25.8	29.5	36.2	46.8	61.6	91.5	22.2	90.2	209.3
0.02	6.9	14.6	11.3	17.6	19.9	25.4	34.7	47.0	72.2	15.0	66.8	152.4
0.03	5.5	11.6	9.0	13.9	15.6	20.3	28.6	39.9	62.4	11.8	55.8	125.9
0.05	4.0	8.6	6.8	10.3	11.5	15.3	22.2	31.6	50.4	8.5	43.8	97.2
0.1	2.5	5.7	4.5	6.8	7.7	10.3	15.1	22.4	36.2	5.3	31.3	66.5
0.2	1.5	3.8	2.9	4.4	5.2	6.8	9.9	15.2	24.1	3.1	22.0	43.5

0.3	1.1	2.9	2.2	3.4	4.1	5.3	7.6	11.8	18.4	2.2	17.7	33.1
0.5	0.5	2.0	1.5	2.4	2.9	3.8	5.3	8.2	12.6	1.4	13.2	22.6
1.0	0.2	1.2	0.8	1.4	1.8	2.2	3.0	4.6	7.0	0.6	8.4	12.4
2.0	0.1	0.5	0.4	0.7	1.1	1.2	1.5	2.0	3.3	0.2	5.0	5.8
3.0	0.02	0.3	0.2	0.4	0.6	0.6	0.9	0.8	1.8	0.1	3.4	3.3
5.0	0.01	0.2	0.1	0.2	0.3	0.2	0.3	0.01	0.2	0.1	1.8	1.1

Table 8: ITU Rain climate zones - Percent of time rainfall intensity exceeded (mm/hour)

%	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*P*	*Q*
1.0	0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2.0	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	50	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	240	170

Rain maps

Figure 2: ITU world rain regions

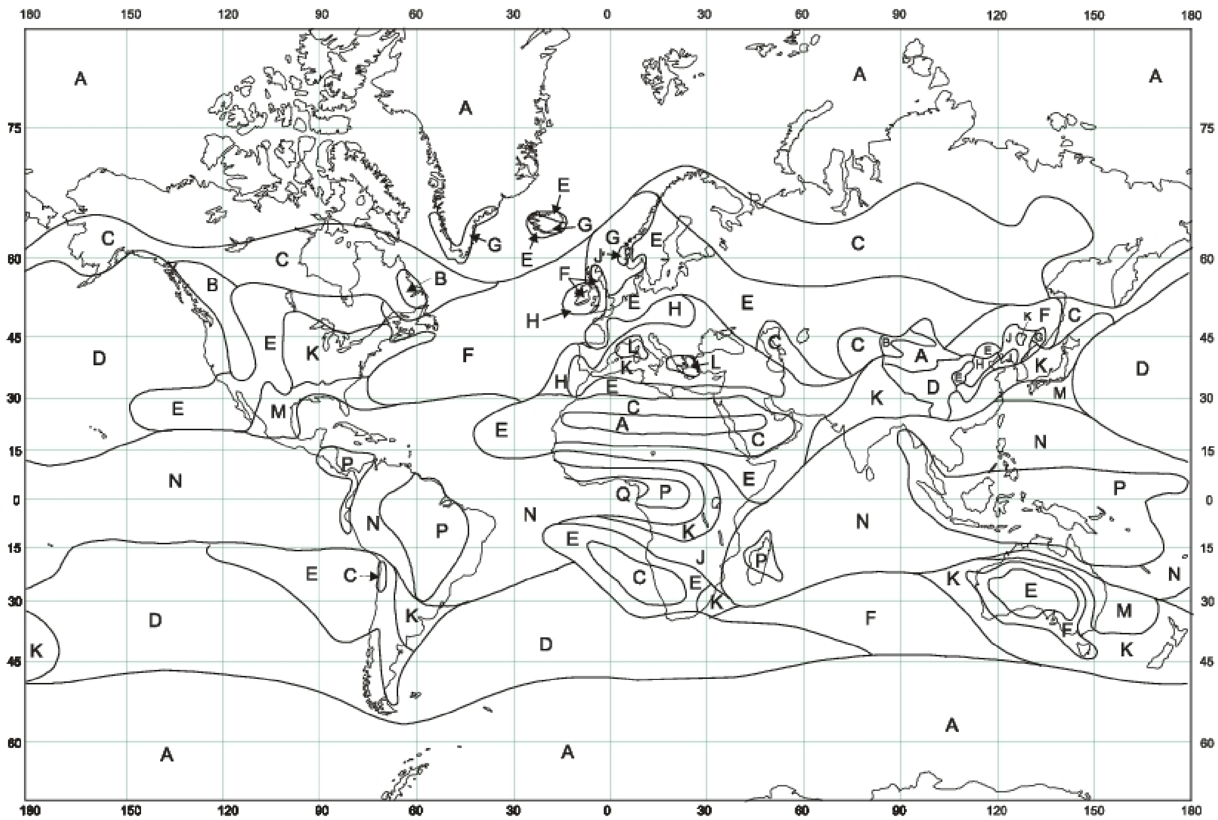


Figure 3: Crane world rain regions

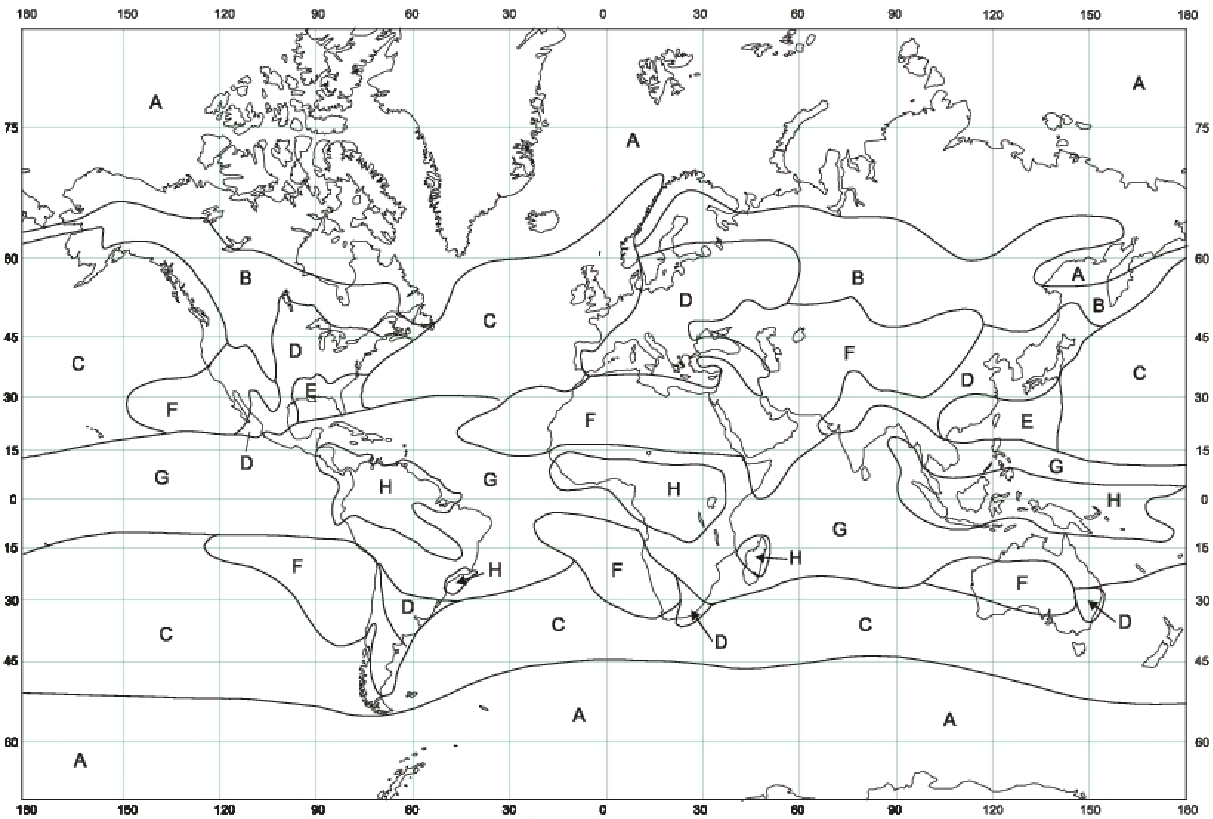
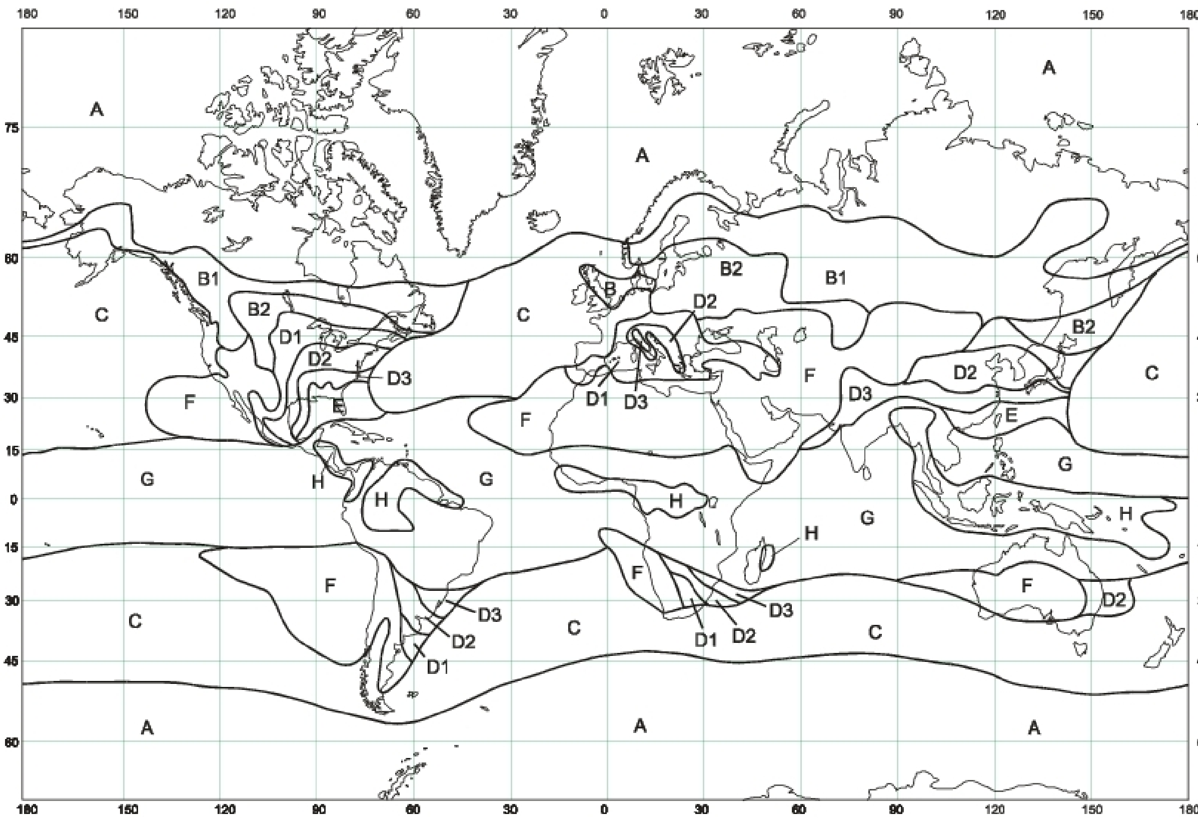


Figure 4: Modified Crane (1996) world rain regions



180
150
120
90
60
30
0
30
60
90
120
150
180
75
60
45
30
15
0
15
30
45
60
A
A
A
B1
B2
D1
D2
D3
E
F
G
H
H
C
C
B
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D3
D2
D1
C
C
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D3
D2
D1
C
F
D2
A
A
A

References

1. Prediction of Attenuation by Rain - Robert K. Crane
   IEEE Transactions on Communications
   VOL. COM-28 NO 9, September 1980
2. Characteristics of Precipitation for Propagation Modeling
   Recommendation ITU-R Pn.837-1
3. High Intensity Rainfall Statistics for Canada - B. Segal
   Communications Research Centre, Department of Communications
   Ottawa Canada CRC Report Number 1329-E
4. Electromagnetic Wave Propagation through Rain - Robert K. Crane
   A Wiley Interscience Publication
   John Wiley & Sons Inc. (1996)
5. Propagation Data and Prediction Methods Required for the Design of Terrestrial Line of Sight Systems - ITU Recommendation P.530-7

You need to know

- The transmission analysis design section can be configured for the following application types: conventional microwave radio, adaptive modulation microwave radio and land mobile radio systems. Each application type has a configurable detailed and summary report. The application type is set under Configure- Set Pl50L options - Transmission calculations - Application - radio type or click on the application on the status bar.
- The multipath fade algorithm is set under Configure- Set Pl50L options - Transmission calculations - Multipath fading method.
- The space diversity method is set under Configure- Set Pl50L options - Transmission calculations - Space diversity methods
- The display shows a system block diagram for the selected application and antenna configuration. Each icon in the block diagram represents a data entry form. Click on the icon to bring up its data entry form. Alternately use the tab key to shift the focus to the next icon and then press Enter.
- The frequency 890 MHz is used as the dividing line between isotropic and dipole gains. For example below 890 MHz, the effective radiated power will be reference to a dipole antenna (ERP). Above 890 MHz, the isotropic EIRP is used.
- Rain and passive repeater area carried out in the transmission analysis section. The documentation for these topics is in separate chapters.
- Rain attenuation calculations are made in the transmission analysis section. The documentation is covered separately under the rain chapter.
- Passive repeater links can be created in the transmission analysis section. This feature is covered in the passive repeater section.
- Data can be imported into the worksheet from lookup tables, radio and antenna data files (codes) or from another Pathloss data file using the Template selection.

- The lower part of the display shows all of the calculations. The worksheet is automatically recalculated as data is entered. The calculation starts by erasing the calculation display. The calculation error and warning status are displayed on the status bar as an ° or ! respectively. No errors or warnings An ¸ means no errors or warnings. Click on thee ° or ! for details on the error warning.

Not all data entries will be applicable to your application. If a data entry is not applicable, leave it blank. Do not enter a zero, as this is considered as an entry and will be printed up in the reports. To erase an entry, place the cursor on the entry and press the F3 key.

Scope

Fading on a radio path can occur from any of the following propagation mechanisms:

- multipath fading which follows a Raleigh probability distribution
- fades produced by rain attenuation at high frequencies
- diffraction fading at low values of the earth radius factor K
- fading due to a specular reflection where the main and reflected signal add vectorially to produce signal nulls
- fading due to anomalous propagation conditions including surface and elevated ducts and space wave fade-outs

With the exception of a specular reflection, these fade mechanisms are mutually exclusive events i.e. they do not occur at the same time. A path design considers the outage probability of each of these mechanisms and the effect on the overall performance objective. The Transmission analysis section deals with the outage probability due to multipath fading and rain attenuation.

Status bar

The status bar at the bottom of the display shows the site names, frequency, antenna configuration, application, multipah fade algorithm, measurement system and the calculation status as an ✔, ✘ or !.

- Click on either of the site names to access the sitedata entry form.
- Click on the frequency to access the path profile data entry form.
- Click on the antenna configuration box to select a new antenna configuration.
- Click on the application to change the application or to select a new calculation method.
- Click on the multipath fade method to access the multipath fade algorithm and options.
- Click on the measurement system box to change between miles-feet and kilometers-meters.
- Click on the reliability method box to select a new reliability method.

Calculation status

The calculation is complete if the error status is a ✔ on the status bar. If a ✘ is displayed, click the left mouse button on the ✘ to display the error which terminated the calculation. Similarly there are no warning messages if a ✔ is displayed on the status bar. If a ! is displayed, click the left mouse button on the ! to display the warning messages.

Microwave and adaptive modulation net path loss components

Figure (1) shows the block diagram of the net path loss components used for microwave and adaptive modulation applications. This is a general diagram and not all of these components may apply to your specific application and configuration. Enter values for the applicable components and the basic path parameters to produce a value net path loss in the worksheet. As a minimum the path length, frequency and the antenna gains are required.

If a space diversity antenna configuration is specified, then the data for these antennas and transmission lines must be entered.

Other components are optional and will depend on the specific equipment configuration.

Terminology

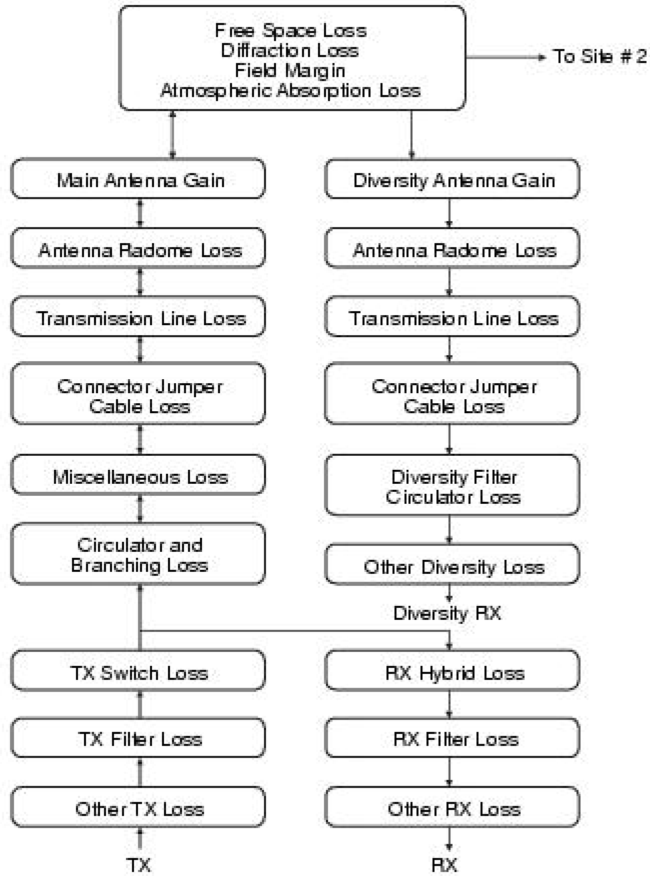


Figure (1): Microwave net path loss components

The main net path loss at Site 1 is the total loss from the transmitter output at Site 2 to the receiver input at Site 1.

Diversity net path loss at Site 1 is defined as the total loss from the transmitter output at Site 2 to the diversity receiver input at Site 1.

The main net path loss at Site 2 is the total loss from the transmitter output at Site 1 to the receiver input at Site 2.

Diversity net path loss at Site 2 is defined as the total loss from the transmitter output at Site 1 to the diversity receiver input at Site 2.

Field margin is a maintenance margin to account for such long term effects as antenna orientation accuracy. Typical values are from 1 to 2 dB.

Land mobile net path loss components

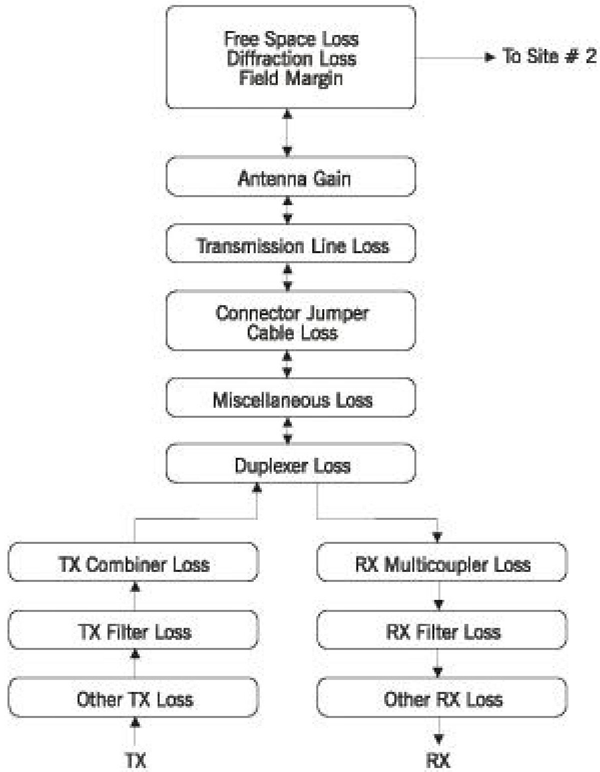


Figure (1): Land mobile net path loss components

Figure (1) shows the net path loss components used in land mobile applications. As in the case of the microwave worksheet, this is a general diagram and not all of these components may apply to your configuration. Enter values for the applicable components and the basic path parameters to produce a value net path loss in the worksheet. As a minimum the following parameters are required:

- Path length
- Frequency
- Site 1 antenna gain
- Site 2 antenna gain

Other components are optional and will depend on the specific equipment configuration.

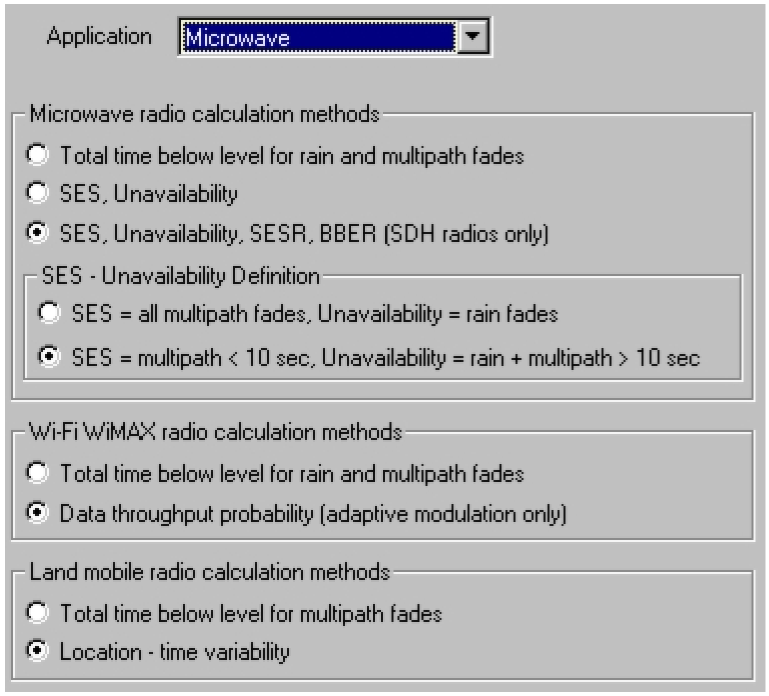
Terminology

The net path loss at Site 1 is the total loss from the transmitter output at Site 2 to the receiver input at Site 1.

The net path loss at Site 2 is the total loss from the transmitter output at Site 1 to the receiver input at Site 2.

Receiver multicouplers are usually active devices and have a gain. Positive values are interpreted as a loss. To enter a gain, you must enter a negative sign in front of the value (a negative loss).

Application type



Transmission calculations can be carried out for the following basic radio types:

- conventional microwave radio
- Adaptive modulation type radios
- Land mobile radios.

Click on the Application on the status bar or select Configure - Set Pl50L options - Transmission calculations - Application (radio type) Additional options under the Transmission calculations section of the PL50L options are.

- Multipath fading method
- Space diversity method
- Rain
- Report format for both summary and detailed design report

Several calculation methods are associated with each radio type. These are set at the same time the application is set. These are described in the following paragraphs

Conventional Microwave Radio

Total time below level for rain and multipath fades

The worst month multipath outage is calculated and converted to an annual value. This is added to the annual rain outage. This method considers all fade durations

SES Unavailability

This method is used for PDH radios in accordance with ITU-T G821. The total outage is divided into two categories - severely errored seconds (SES) and unavailability. The following two definitions can be used for these categories

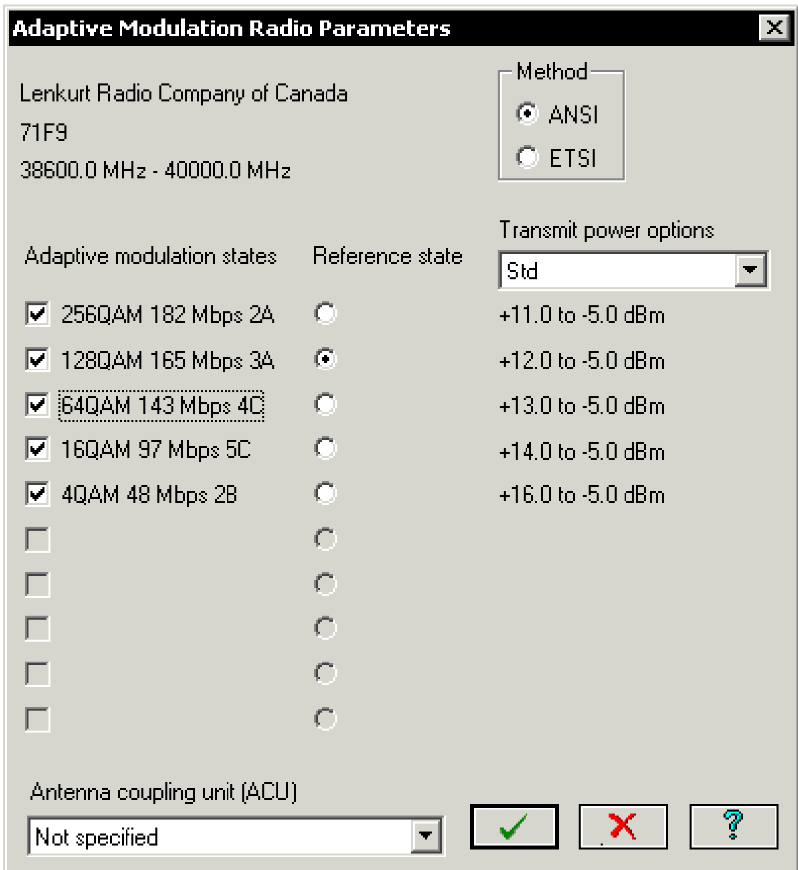
- All multipath fades are considered to be SES. Rain fades are considered to be unavailability
- Multipath fade durations less than 10 seconds are considered to be SES. Multipath fade durations longer than 10 seconds and all rain fades are considered to be unavailability

SES Unavailability SESR BBER

This method is used for SDH radios in accordance with ITU-T G826. The same breakdown for SES and unavailability described above is used. Two additional performance parameters - Severely errored seconds ratio (SESR) and Background block error radio (BBER) are reported in this method

Adaptive modulation radio

When an adaptive radio data files is entered into the radio data entry form, the user is presented with the display on the right.



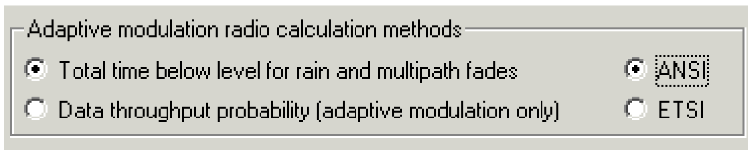
Adaptive modulation states

The user can limit the range of modulation states. The default is all modulation states. The calculations will be limited to the checked states

Reference state

The reference state must be within the selected range of modulation states. The reference state is used as follows:

- the reference state controls the transmit power for all modulation sates in the ETSI mode (See description below)
- the reference state parameters are used for calculations in the Total time below level for rain and multipath fades option
- the reference state parameters are used in interference calculations



Transmit power options

A transmit power option consists of a maximum and minimum value for each modulation state. In addition an ATPC value can be specified which would only be applicable for the top modulation state

ETSI Option

The ETSI option controls the transmit power levels. When an adaptive modulation radio data file is loaded into the radio data entry form, the reference state will determine the transmit power levels. The reference state is shown in blue text

The transmit power of the reference state is the maximum power for all modulation states. It is not possible to manually change the power levels outside the limits set by the reference state.

The transmission analysis is formatted to show the one way availability.

	TX power (dBm)		RX threshold (dBm)	
256QAM 182 Mbps	11.00	11.00	-56.00	-56.00
128QAM 165 Mbps	12.00	12.00	-59.50	-59.50
64QAM 143 Mbps	12.00	12.00	-62.00	-62.00
16QAM 97 Mbps	12.00	12.00	-69.00	-69.00
4QAM 48 Mbps	12.00	12.00	-81.00	-81.00

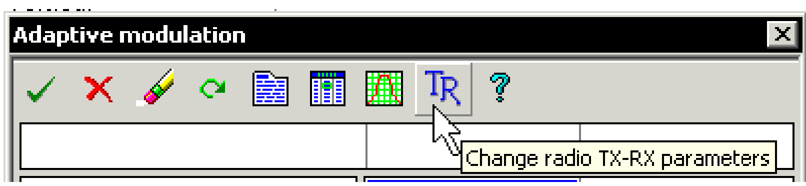
ANSI option

In the ANSI option, the transmit powers are not affected by the reference state.

The transmission analysis is formatted to show the two way availability.

Changing Adaptive Modulation Settings

To change any of the settings, click the TR icon on the radio data entry form.



Two calculation methods are provided for adaptive modulation radios

Total time below level for rain and multipath fades

This calculation method uses the reference modulation state. The display is similar to the conventional microwave application using the total time below level format.

Data Throughput Probability

Calculations are made for each modulation state. In the ANSI display the two way availability is shown. In the ETSI format, the one way availability is shown. There are no options for this report format

	TX power (dBm)		RX threshold		Thermal FM (dB)		Flat FM - mp (dB)	
512QAM 279	27.00	27.00	-56.00	-	23.31	23.31	17.29	17.29
256QAM 248	28.00	28.00	-59.50	-	27.81	27.81	20.37	20.37
128QAM 225	28.00	28.00	-61.75	-	30.06	30.06	20.96	20.96
64QAM 194	28.00	28.00	-64.50	-	32.81	32.81	21.94	21.94
16QAM 131	28.00	28.00	-72.00	-	40.31	40.31	23.74	23.74
4QAM 65	28.00	28.00	-83.00	-	51.31	51.31	28.82	28.82

	Worst month multipath				Total annual		Time in mode (%)	
512QAM 279	99.97563	99.97563	9	725	99.99121	99.99121	99.99121	99.99121
256QAM 248	99.98797	99.98797	9	878	99.99580	99.99580	0.00459	0.00459
128QAM 225	99.98950	99.98950	9	911	99.99651	99.99651	0.00071	0.00071
64QAM 194	99.99163	99.99163	9	943	99.99735	99.99735	0.00084	0.00084
16QAM 131	99.99447	99.99447	9	981	99.99844	99.99844	0.00110	0.00110
4QAM 65	99.99828	99.99828	9	997	99.99954	99.99954	0.00110	0.00110

Land mobile radio

Performance calculations in land mobile radio applications do not include the following

- rain outages
- selective fading
- frequency or space diversity configurations

Total time below level for rain and multipath fades

The worst month multipath outage is calculated and converted to an annual value.

Location - time variability

A location variability is calculated using a log normal variation for metropolitan, urban, suburban, woodland and open terrain environments. A Rayleigh fade probability is used for the time variability.

Worst month to annual conversion

All multipath fade probability algorithms calculate the fade probability for the worst month. Two methods are available to convert the the worst month fade probability to an annual value.

Average annual temperature method

This is associated with the Vigants - Barnett method. Multipath fading is a warm weather phenomenon. The length of the fading season is proportional to the average annual temperature The conversion is based on the premise that there will be 3 fading months for an average annual temperature of 10°C (50°F). The conversion then is given by:

*annual outage time = worst month outage time * average annual temperature (?C) / 10*

ITU Method

This method uses the path center latitude, path length and the path inclination to determine the worst month to annual conversion. Note that if site coordinates are not available then the path center latitude must be entered into the path profile data entry form to complete the calculation.

Selective fading method

Selective fading calculations are applicable to Microwave applications only. The calculation is inhibited for Land mobile and adaptive modulation applications. Selective fading calculations can be disabled or use either of the following methods.

Dispersive fade margin

Selective outage is calculated using the dispersive fade margin as modified by the dispersive fade occurrence factor. The dispersive fade margin is an equipment parameter in the radio data entry form. The dispersive fade occurrence factor is accessed in the path parameters data entry form. If either of these parameters are missing, a warning will be issued. The space diversity method dialog include several non ITU options for space diversity and quad diversity improvement factors. These options can only be used with the dispersive fade margin option.

ITU P-530 equipment signature

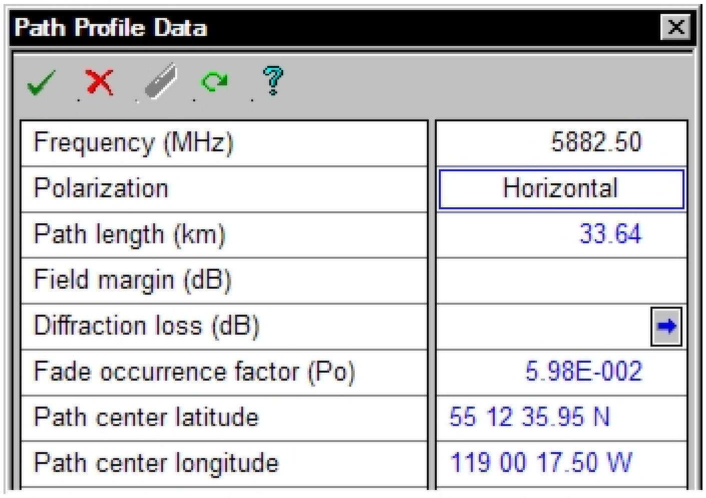
Selective outage is calculated using the equipment signature. This is an equipment parameter in the radio data entry form and consists of the following terms: signature width, signature delay, signature depth for minimum and non minimum phase. In space / quad diversity applications, an ITU method must be selected in the space diversity method dialog.

Shallow fade depths

Traditionally, multipath fade probability algorithms were based on the assumption of deep fades greater that 25 dB which occur at a small percent of the time. At lower fade margins in the order of 10 dB, the results are overly optimistic and could by in error by an order of magnitude. An option is provided to use the ITU method applicable to all fade margins when ever the fade margin is less that 25 dB.

Path profile data entry form - Common parameters

The first eight lines in the path profile data entry form are common to all multipath fade algorithms.



Frequency

This is the design frequency used throughout the program and is usually the band center of the frequency plan

Polarization

Currently only horizontal and vertical polarization are actually used in the program

Path length

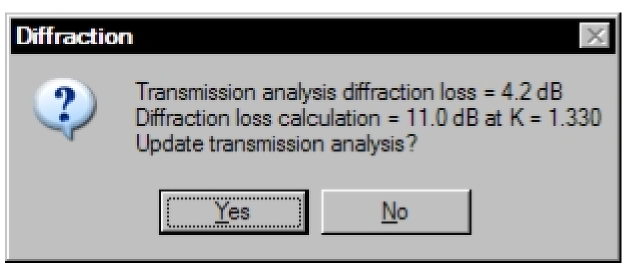
If a path profile exists, the path length is calculated as the actual distance of the ray path at K = 4/3. The calculation takes into account the elevation differences of the two sites. If a path profile does not exist, the path length is calculated from the coordinates. In either of these cases, the path length cannot be edited; otherwise, any value for the path length can be entered. If you are calculating performance as a function of path length, create a new file. Select Files - New on the menu bar.

Field margin

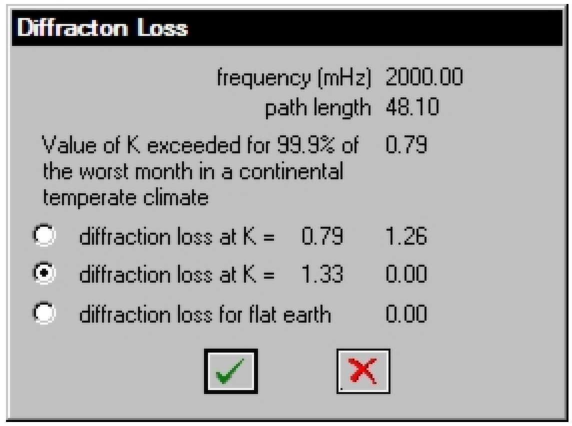
Field margin is a safety factor to account for the long term degradation of connectors and antenna orientation in a practical installation. A typical value would be in the order of 1 to 2 dB.

Diffraction loss

Diffraction loss calculations are normally carried out in the Diffraction design section and are not automatically transferred to the transmission analysis section If a diffraction calculation exists and the value is different from the value in the transmission analysis, the user is prompted to update the transmission analysis with the new calculated value. The Diffraction section is used for a variety of different analysis and there is no way of determining whether a diffraction loss calculation should be included in the transmission analysis. The question "When should diffraction loss be included in the analysis?" arises here. Suppose a link has 6 dB of diffraction loss at K = 4/3 and no diffraction loss (free space loss) at K = 5. Multipath fading typically occurs at high values of K and therefore, free space loss conditions exist during the fading and the diffraction loss should not be considered for the reliability calculation.



The diffraction loss calculate button in the path profile data entry form provides a convenient method of examining / entering a diffraction loss value. Values are calculated and displayed for the minimum value of K based on the path length, the median value of K and a K of infinity



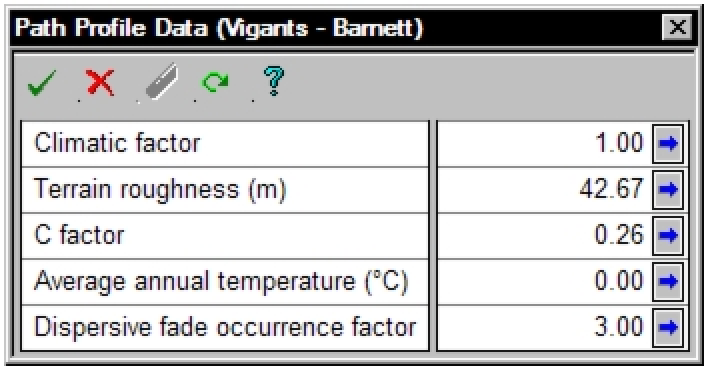
Fade occurrence factor (Po)

The worst month multipath fade probability is given by the expression P = Po * pow(10, -A/10) where A is the fade margin.

Path center latitude and longitude.

If site coordinates have been entered, these are the average values of the two sites and cannot be edited. Path center coordinates are required to access geographic data such as average annual temperature.

Path profile data entry form - Vigants Barnett



The first portion of this data entry form is common to all multipath fade probability algorithms.

The Vigants Barnett method uses a C factor to calculate propagation reliability. If the path center coordinates are available, the C factor can be obtained with its calculate button. World C factor maps are are provided in the technical portion of this section. The following guidelines are given for direct entry of the C factor:

C = 0.25	good propagation conditions in mountainous and dry climates
C = 1	average propagation conditions for average terrain and climatic conditions
C = 4 to 6	difficult propagation conditions over water and in gulf coastal areas

Alternately, the C factor can be calculated from the terrain roughness and a climatic factor. This is the preferred method. If the path center coordinates are available, the climatic factor can be obtained with its calculate button. The following guidelines are used for the climatic factor

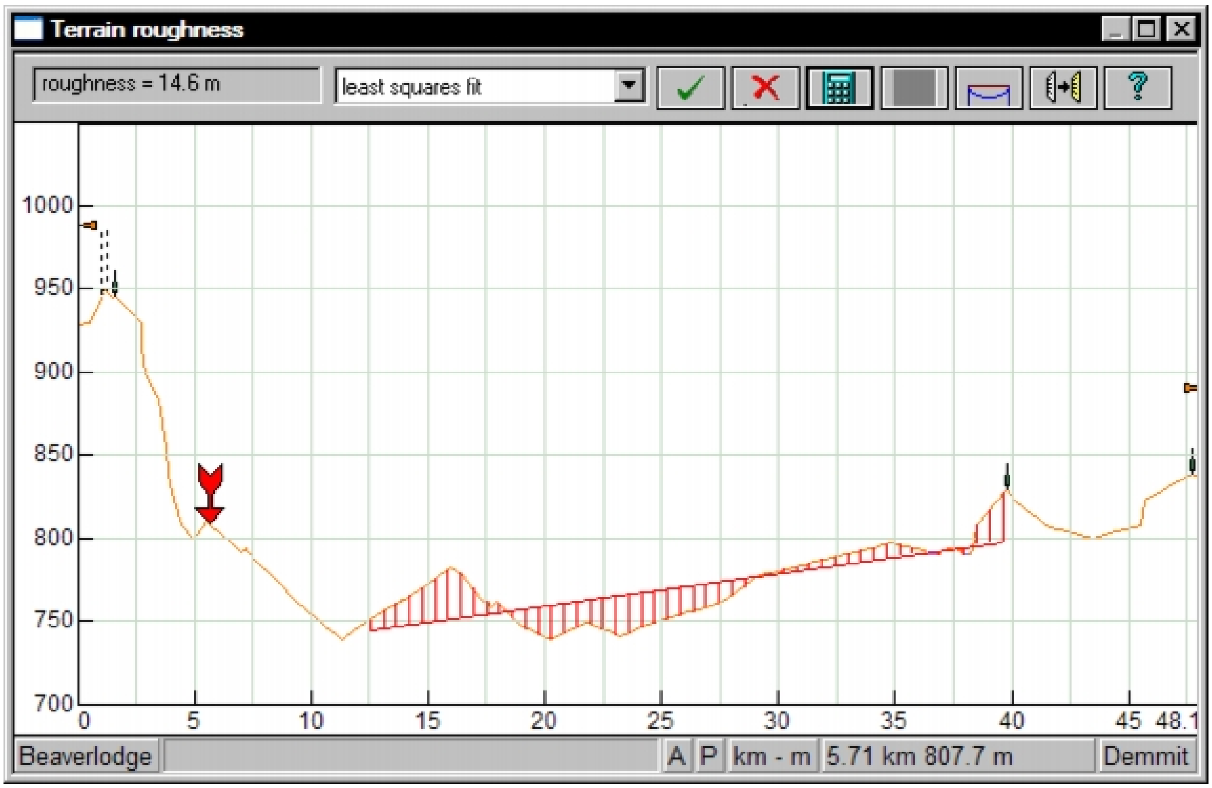
cf = 0.5	good propagation conditions in mountainous and dry climates

cf = 1	average propagation conditions for average terrain and climatic conditions
cf = 2	difficult propagation conditions over water paths and in gulf coastal areas

Terrain roughness can be entered directly in the range 6 to 42 meters (20 to 140 feet) or graphically calculated by clicking its calculate button.

Terrain roughness calculation

In the Vigants - Barnett path profile data entry form, click the calculate button on the terrain roughness line. The terrain roughness calculation uses standard profile display screen formatted for flat earth. Refer to the General program operation section for details of this display.



The user defines the start and end points on the profile over which roughness will be calculated. The roughness calculation interpolates 50 uniformly spaced points between the start and end points. Terrain roughness is defined as the standard deviation of the terrain elevations (square root of the average square of the deviation from the mean). Two calculation methods are available. In the first method, the elevations are referenced to sea level. In the second method, the elevations are referenced to a least squares fit (y = ax + b) of the terrain over the profile segment defined by the start and end points. This selection is made on the drop down list on the tool bar.

The roughness limits are 6 meters (20 feet) minimum and 42 meters (140 feet) maximum for the Vigants - Barnett reliability method. These limits are imposed when the roughness is transferred to the Path data entry form. Note that a terrain roughness calculation is also made in the Multipath-reflection section. The limits of the Vigants - Barnett method do not apply to the in the Multipath-reflection section

Significant differences will occur on paths with a uniform slope and an elevation difference between the end points greater than 40 meters. If the least squares method is used, the terrain roughness will be the minimum value. If the sea level reference is used, the terrain roughness will be the maximum value. In strict accordance with the original reference, "Space Diversity Engineering by A. Vigants", the elevations should be relative to sea level.

The Vigants-Barnett method does not take into account the path inclination. In practice, a high to low path, with an elevation difference of several hundred meters performs better than a flat path with the same terrain characteristics. If terrain roughness is calculated using a sea level reference, the higher terrain roughness is more applicable. However, if the elevation difference of the path is in the order of 50 meters and relatively flat, the least squares method should be used.

Status bar

The status bar shows the site names, cursor style and movement state, measurement system, and the cursor location.

To display the current terrain point data, click the left mouse button on the cursor location box or press the Ins key.

Automatic procedure

Click the calculate button on the tool bar. The program determines the range of points which are intervisible to both antennas. If this range if greater than 50% of the path length, terrain roughness is calculated over this range. Otherwise, terrain roughness is calculated over the central 80% of the path profile.

Manual procedure

- Place the arrow at one end of the profile segment over which terrain roughness is to be calculated and click the right mouse button.
- Move the arrow to the opposite end of the section and click the right mouse button again.

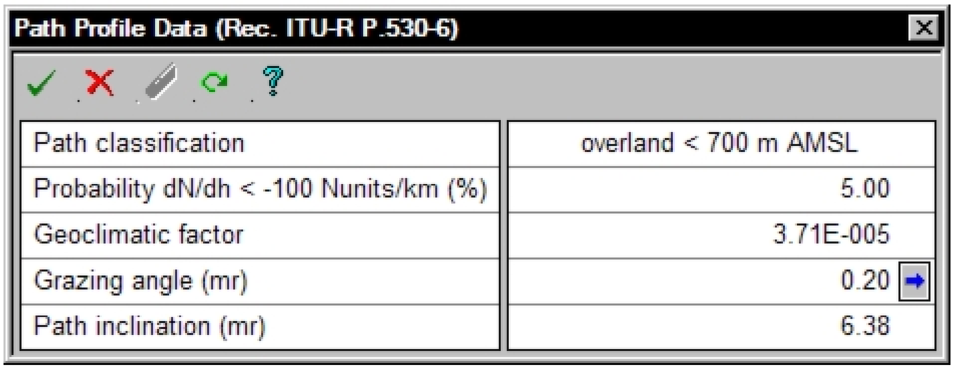
The Reset button is active when the first point has been selected. This will only cancel the first point selection.

To repeat a terrain roughness calculation, just reselect the end points of the new reflective plane. This is carried out over the existing calculation.

Click the OK button to accept the calculated value of terrain roughness. The Cancel button discards the calculation.

Path profile data entry form - ITU-R P.530-6

The following parameters are required to calculate the multipath fade probability.



Geoclimatic Factor

The geoclimatic factor can be entered directly into the path profile data entry form in scientific notation "e.g. 1.45E-5". In most cases, this will be calculated in the path profile data entry form using the following parameters:

- The path center coordinates are required in this method. If site coordinates are available, these will be used to determine the coordinates at mid path; otherwise, enter the approximate coordinates of the path. This is not critical.
- Probability that the refractivity gradient (dN/dh) is less than -100 N units /kilometer. Refer to the refractivity gradient atlases in the reference section for the months of February, May, August and November. The month with the highest value (worst month) should be used. An exception to this is the map for February which should not be used in the Arctic.
- Select the type of terrain which best matches the path from the drop down list on the "Path classification" line.

Path Inclination

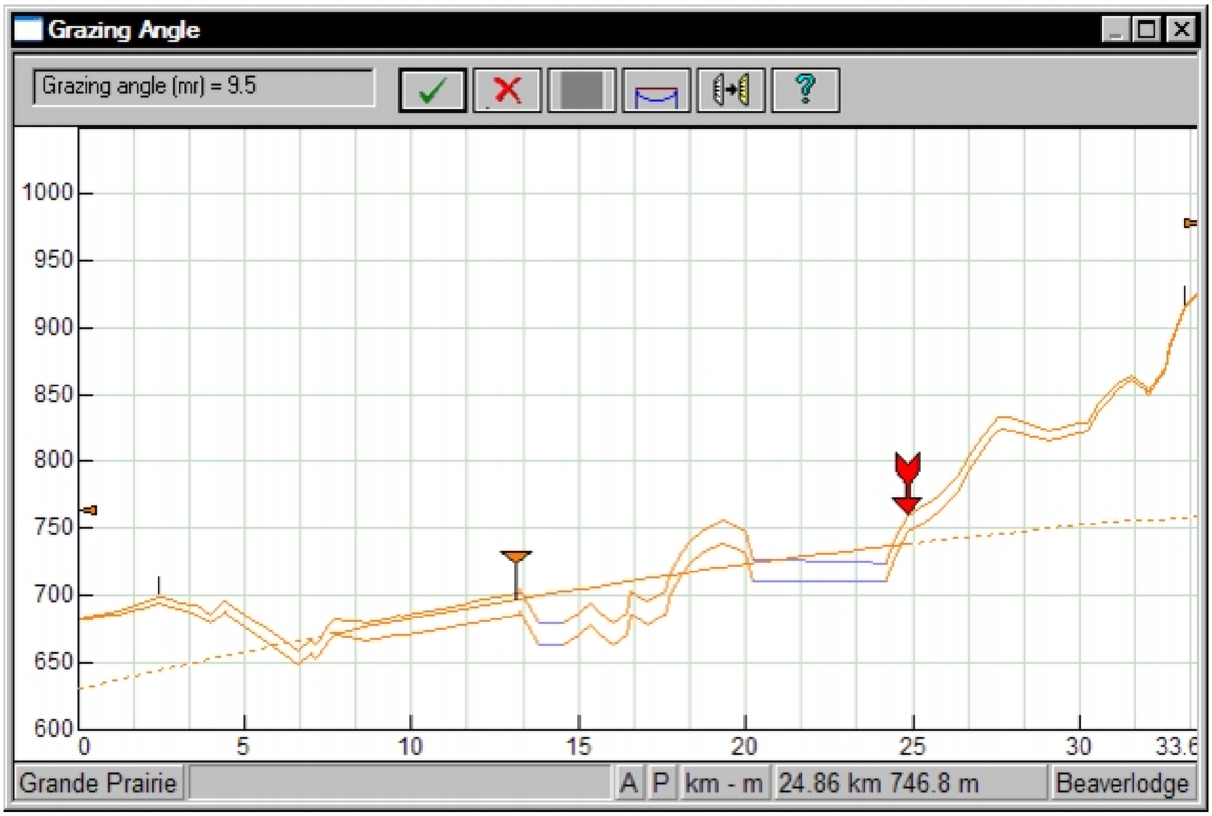
The path inclination is calculated from the site elevations, the antenna heights and the path length. The path inclination can be entered directly in milliradians; however, the value will be over written if the antenna heights, site elevation or path length are changed.

Grazing Angle

The grazing angle is the angle of incidence or reflection at the reflection point. The value can be entered directly into the Path Profile data entry form in milliradians or calculated if a terrain profile is available. Click the calculate button on the Grazing angle line.

Grazing angle calculation

In the ITU-R P.530-6 path profile data entry form, click the calculate button on the grazing angle line. The grazing angle calculation uses a standard profile display screen. Refer to the General program operation section for details of this display.



The profile is displayed with an earth radius factor of K = 4/3. The lower profile represents the flat earth profile. If a reflective plane has been defined in another section of the program, then this will be displayed along with the value of the grazing angle. The grazing angle is the angle of incidence or reflection at the reflection point. A reflective plane must be defined to determine the reflection point. The user selects the start and end points on the path profile and the plane is determined by a least squares fit of the form y = ax + b over the defined range. Effective antenna heights are determined by extending the reflective plane to the end points of the profile. The effective antenna heights are the heights of the antenna above the reflective plane end points.

Status Bar

The status bar shows the site names, cursor style and movement states, measurement system, and the cursor location. To display information at the terrain point under the arrow, click the left mouse button on the cursor location box or press the Ins key.

Procedure

- Place the arrow at one end of the reflective plane and press the F1 key or click the right mouse button.
- Move the arrow to the opposite end and press the F1 key or click the right mouse button again.

The following error messages may appear:

<u>Plane is not Valid</u> The reflective plane elevation at one end of the profile is greater than the antenna height. Redefine the reflective plane.

<u>Reflection Point not Found</u> The algorithm failed to locate the reflection point. This can occur if the reflection point is very close to one of the sites. Increase the antenna heights or change the reflective plane definition.

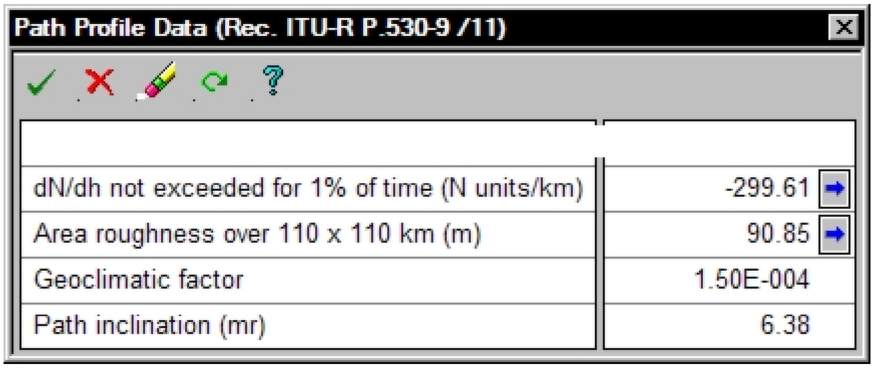
<u>Reflection Point outside Plane Limits</u> The location of the reflection point is outside of the defined range. Either the reflective plane definition is questionable or the path does not have a reflection point in this area. This is a warning message and the grazing angle will still be calculated. In some cases it will be necessary to ignore this warning.

The Reset button is active when the first point has been selected. This will only cancel the first point selection.

- To repeat a grazing angle calculation, just reselect the end points of the new reflective plane. This is carried out over the existing calculation.
- Click the OK button to accept the calculated value of the grazing angle. The Cancel button discards the calculation.
- On over water paths or paths which are predominately flat, the choice of end points is obvious. On other paths, some judgment is required to define the reflective plane. The following guidelines can be used.
- Draw a 100% first Fresnel zone reference and note the extent of the terrain closest to this Fresnel zone reference.
- Place the arrow at the center of this extent and press the Ins key to display the terrain point data. Note the clearance to the first Fresnel zone ratio (C/F1).
- Using this value as a guide, draw additional Fresnel zone references until approximately 50% of the Fresnel zone reference is below the terrain.
- Define the end points of the reflective plane at the first and last intersections of the Fresnel zone reference with the terrain.

Path profile data entry form - ITU-R P.530-9/12

The first portion of this data entry form is common to all multipath fade probability algorithms.



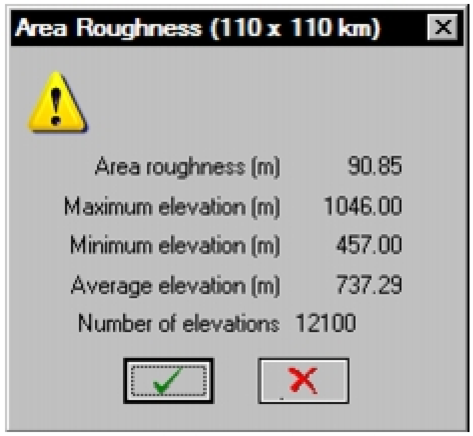
The following two parameters are required to calculate the multipath fade probability in the ITU-R P530-9/12 method.

Geoclimatic Factor

The geoclimatic factor can be entered directly into the path profile data entry form in scientific notation "e.g. 2.62E-6". In most cases, this will be calculated in the path profile data entry form using the following parameters:

- The path center coordinates are required in this method. If site coordinates are available, these will be used to determine the coordinates at mid path; otherwise, enter the approximate coordinates of the path.
- The point refractivity gradient that is not exceeded for 1% of the time. Click the calculate button on this line read the value from tables in ITU-R P.543. The calculation uses bilinear interpolation methods based on the nearest four points to the path center coordinates.
- Ar ea roughness Click the calculate button on this line. The calculation uses the currently configured terrain database. A 1 kilometer grid is constructed over a110 by 110 kilometer area

centered on the path profile. Elevations are determined for each cell. The area roughness is defined as the standard deviation of these 12100 elevations.



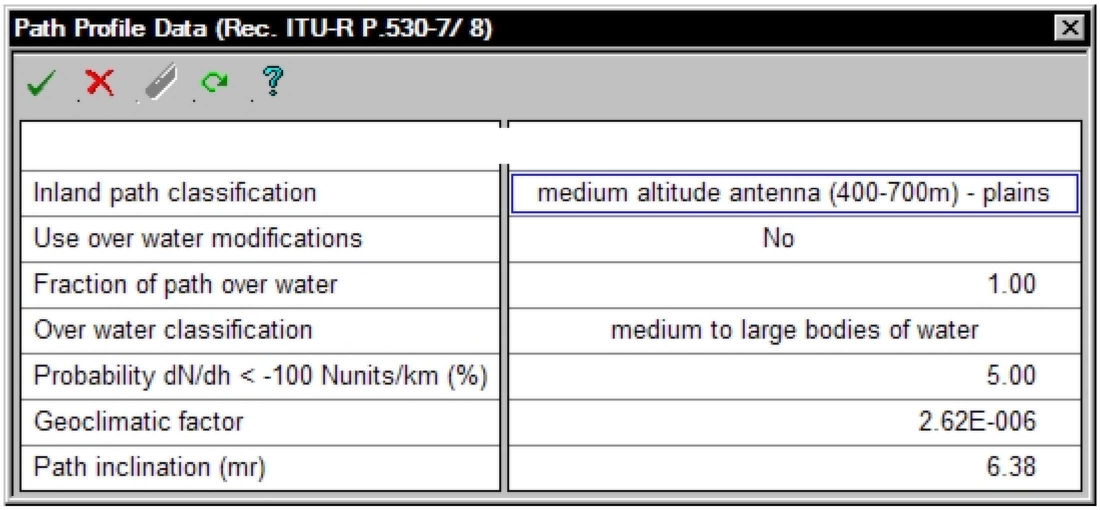
Path Inclination

The path inclination is calculated from the site elevations, the antenna heights and the path length. The path inclination can be entered directly in milliradians; however, the value will be over written if the antenna heights, site elevation or path length are changed.

Path profile data entry form - ITU-R P.530-7/8

The first portion of this data entry form is common to all multipath fade probability algorithms.

The following two parameters are required to calculate the multipath fade probability in the ITU-R P530-8 method.



Path Profile Data (Rec. ITU-R P.530-7/ 8)

Inland path classification	medium altitude antenna (400-700m) - plains
Use over water modifications	No
Fraction of path over water	1.00
Over water classification	medium to large bodies of water
Probability dN/dh < -100 Nunits/km (%)	5.00
Geoclimatic factor	2.62E-006
Path inclination (mr)	6.38

Geoclimatic Factor

The geoclimatic factor can be entered directly into the path profile data entry form in scientific notation "e.g. 2.62E-6". In most cases, this will be calculated in the path profile data entry form using the following parameters:

- The path center coordinates are required in this method. If site coordinates are available, these will be used to determine the coordinates at mid path; otherwise, enter the approximate coordinates of the path. This is not critical.
- Probability that the refractivity gradient (dN/dh) is less than -100 N units /kilometer. Refer to the refractivity gradient atlases in the reference section for the months of February, May, August and November. The month with the highest value (worst month)

should be used. An exception to this is the map for February which should not be used in the Arctic.

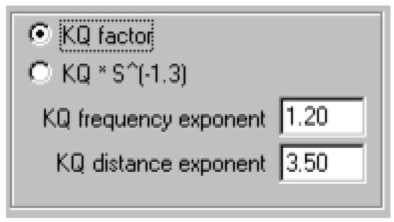
- Select the type of terrain which best matches the path from the drop down list on the "Inland path classification" line.
- If this is an over water path or in a coastal area, set the "Use over water modifications" to yes box and select the Over water classification from the drop down list.
- Enter the fraction of the path which is actually over water.

Path Inclination

The path inclination is calculated from the site elevations, the antenna heights and the path length. The path inclination can be entered directly in milliradians; however, the value will be over written if the antenna heights, site elevation or path length are changed.

Path profile data entry form - KQ factor

This method requires one parameter - a KQ factor to calculate multipath fade probability. The distance and frequency exponents are set in the PL50L options. Select Configure - Set PL50L options - Transmission calculations - Multipath fading method or click on the multipath algorithm on the status bar.



Typical values for the KQ factor and the frequency and distance exponents are given in the table below.

Table 1: KQ Factors

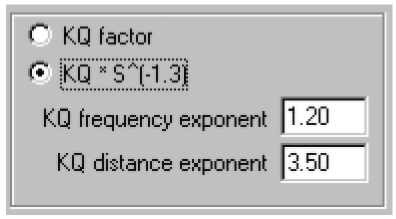
		Japan	N.W. Europe	USSR
Frequency exponent		1.2	1.0	1.5
Distance exponent		3.5	3.5	2.0
KQ	maritime temperature, Mediterranean, coastal or high humidity and temperature climatic regions			$2 \cdot 10^{-5}$
	continental temperature climates or mid	10^{-9}	$1.4 \cdot 10^{-8}$	$4.1 \cdot 10^{-6}$

	latitude inland climatic regions with average rolling terrain			
	temperature climates, coastal regions with fairly flat terrain	$9.9 \cdot 10^{-8} / H$		$2.3 \cdot 10^{-5}$ to $4.9 \cdot 10^{-5}$

$$H = \sqrt{h_1 + h_2} \quad (1)$$

h_1 and h_2 are the antenna heights in meters above ground level

Path profile data entry form - KQ factor with terrain roughness



This method requires a KQ factor and terrain roughness to calculate multipath fade probability. The distance and frequency exponents are set in the PL50L options. Select Configure - Set PL50L options - Transmission calculations - Multipath fading method or click on the multipath algorithm on the status bar.

Click the calculate button on the Terrain roughness line to access the graphical calculation procedure for this parameter.

Typical values for the KQ factor and the frequency and distance exponents are given in the table below.

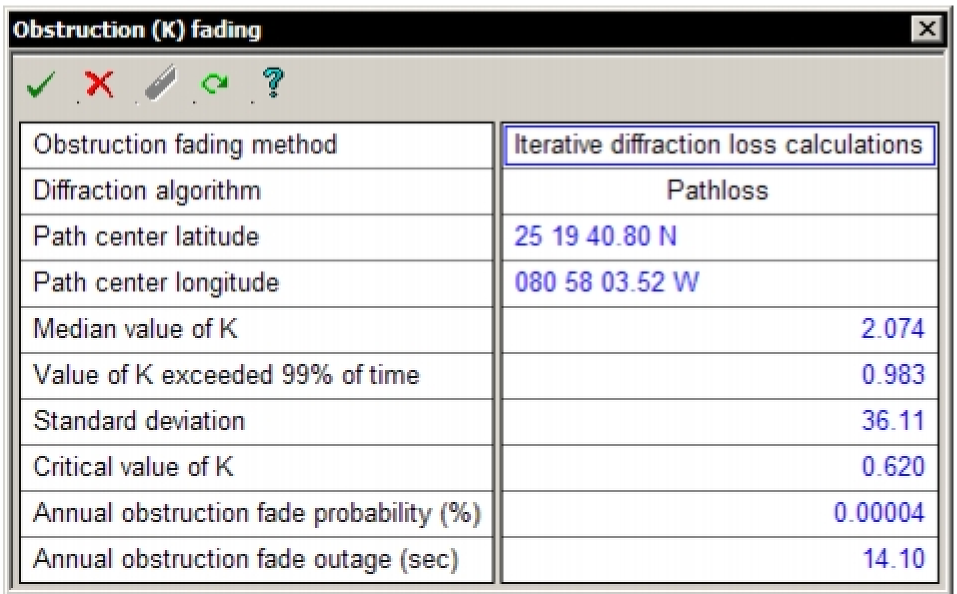
Table 1: K-Q Factors Including Terrain Roughness

Frequency exponent		1.0
Distance exponent		3.0
KQ	maritime temperate, Mediterranean, coastal or high humidity and temperature climatic regions	$4.1\,10^{-5}S^{-1.3}$
	maritime subtropical climate regions	$3.1\,10^{-5}S^{-1.3}$
	continental temperate climates or mid latitude inland climatic regions with average rolling terrain	$2.1\,10^{-5}S^{-1.3}$
	high dry mountainous climatic regions	$10^{-5}S^{-1.3}$

S is the terrain roughness in meters $(6<S<42)$

Obstruction (K) Fading

Both multipath and rain fading have been extensively analysed and form the basis of all performance calculations. An underlying assumption in this analysis is that fading produced by the earth bulge at low values of K will not be a significant contribution to the overall outage.



Obstruction fading method	Iterative diffraction loss calculations
Diffraction algorithm	Pathloss
Path center latitude	25 19 40.80 N
Path center longitude	080 58 03.52 W
Median value of K	2.074
Value of K exceeded 99% of time	0.983
Standard deviation	36.11
Critical value of K	0.620
Annual obstruction fade probability (%)	0.00004
Annual obstruction fade outage (sec)	14.10

Historically, obstruction fading has been handled by specifying two sets of antenna clearance criteria. For example, the classic heavy route clearance criteria:

- 100% F1 at K = 4/3
- 30% F1 at K = 2/3

This provides 100% F1 clearance for the median value of K and sufficient additional clearance to limit the obstruction loss to a small value at some arbitrary low value of K. Unfortunately the second clearance criteria can result in excessively high towers and cases of second Fresnel zone clearance under median K conditions.

The atmospheric conditions for multipath fading, high intensity rain and obstruction fading are completely different and it is assumed that these are mutually exclusive events, Therefore the total outage time would be the sum of the individual outages.

In the case of unavailability and severely errored seconds, it is assumed that obstruction fades will always last longer than 10 seconds and therefore, obstruction fading is classed as unavailability.

The obstruction fading calculation determines two parameters:

- A critical value of K defined as that value which results in an obstruction loss equal to the thermal fade margin.
- The probability of occurrence of the critical value of K.

Critical Value of K

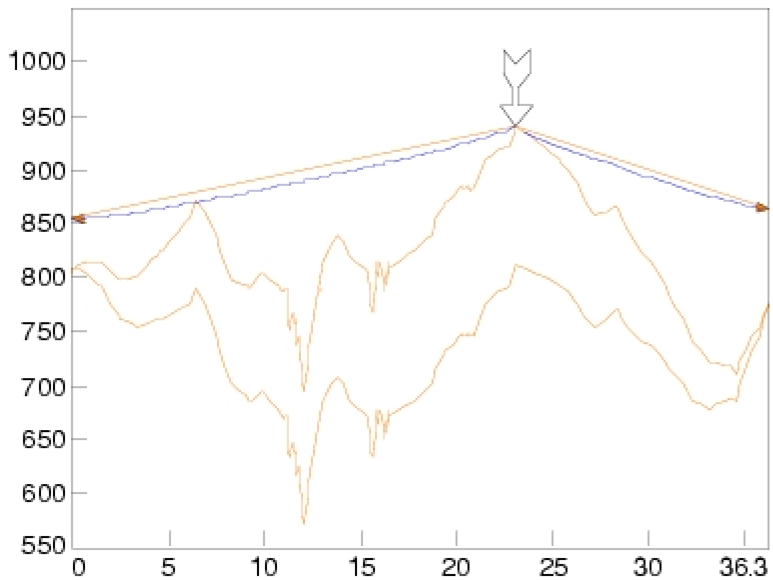
This value can be determined by either of the two methods below

Iterative diffraction loss calculations.

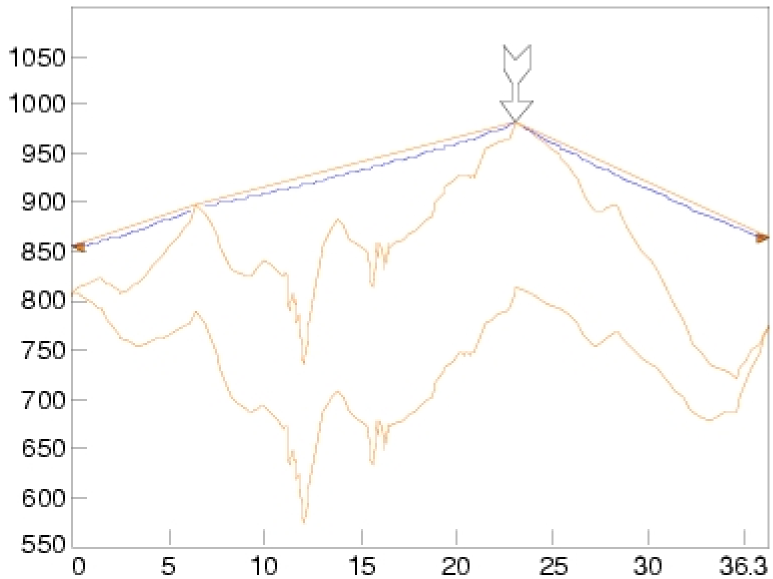
Stating with the median value of K, an iterative procedure is used to determine the critical value of K.

As K is varied, the diffraction algorithm may switch and cause a discontinuity in the diffraction loss versus K relationship. An example is given below

The first diagram shows the obstruction analysed as a single knife edge.



In the second diagram, the value of K has been reduced and the path is now analysed as a double knife edge. This transition results in a discontinuity in the diffraction loss versus K relationship.This is referred to as algorithm switching. If the critical value of K falls in this region, the iteration will not converge



The calculation will terminate under the following conditions:

- The diffraction loss is within 1 dB of the thermal fade margin.
- A maximum of 50 calculations have been completed.
- The difference between successive values of K is less than 0.001.

ATT empirical diffraction loss algorithm

The critical value of K is determined in accordance with the reference

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This empirical algorithm is available in the diffraction design section of the program under the name "Average" and is defined by the equation

$$M = -10 + 20\frac{Clearance}{F_1} \quad \textbf{(1)}$$

where $M < -20$

At each point on the path, the clearance to F1 ratio is calculated for $K = 0.5$. At the distance corresponding to the minimum value of C/F1, the value of F1 is substituted in Equation (1) and M is set to the thermal fade margin. The calculated value of clearance is used to determine the value of K for this condition.

Determining the probability of a specific low value of K

The refractivity data files in Recommendation ITU-R P.453.8 are used to derive the probability of a low value of K. The data provides the refractivity gradient in the lower 65 meters of the atmosphere. The resolution of the data is 1.5 degrees in latitude and longitude. The complete ITU refractivity data consists of 5 files:

- dndz_01 - values of dN/dh which are exceeded for 99 percent of the time (very high values of K).
- dndz_10 - values of dN/dh which are exceeded for 90 percent of the time (high values of K).
- dndz_50 - the median value of dN/dh (approximately K = 4/3).
- dndz_90 - values of dN/dh which are not exceeded for 10 percent of the time (low values of K).
- dndz_99 - values of dN/dh which are not exceeded for 1 percent of the time (very low values of K).

The total data set represents the composite cumulative probability distribution of dN/dh. In order to use this data to determine the probability of a given value of K, this composite data will be treated as three separate distributions which share a common mean value as described below

- A central segment extending over approximately 80% of the total distribution and characterized by an atmosphere of vertically mixed air.
- A segment characterized by a stratified atmosphere which produced dN/dh values more negative than the mean. This distribution will determine the severity of multipath fading; however this has no effect on obstruction fading.
- A segment characterized by a stratified atmosphere which produced dN/dh values more positive than the mean. This distribution will determine the depth of an obstruction fade; however this has no effect on multipath fading.

Only the dndz_50 and dndz_99 refractivity data files will be used in the analysis. The critical value of K is converted to a refractivity gradient as follows:

$$dNdh_{obs} = 157\left(\frac{1}{K_c} - 1\right) \quad \textbf{(2)}$$

The standard deviation is calculated as shown in Equation (3) below

$$\sigma = \frac{dNdh_{99} - dNdh_{50}}{2.32635}$$
$$x = \frac{dNdh_{obs} - dNdh_{50}}{\sigma} \quad \textbf{(3)}$$

where:

$dNdh_{99}$	is the value of dN/dh which is exceeded for 99% of the time.
$dNdh_{50}$	is median value of dN/dh.
σ	is the standard deviation.
χ	is the required number of standard deviations into the distribution to determine the probability.

The Abromowitz and Stegun approximation is used to computes the integral of the normal distribution probability distribution function from -infinity to x as shown in Equation (4) below with a maximum absolute error of 7.5 10^{-8}

$$n(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}$$
$$t = \frac{1}{1 + 0.2316419x}$$
$$N(x) = 1 - n(x)\left(b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5\right) + \epsilon \quad \textbf{(4)}$$

where:

$b_1 = 0.319381530$
$b_2 = -0.356563782$
$b_3 = 1.781477937$
$b_4 = -1.821255978$
$b_5 = 1.330274429$

Antenna Data Entry Form

Click on either the Site 1 or 2 antenna icon to access the antenna data entry form. The format for land mobile applications includes the antenna gain in both dbi and dbd units but does not include the radome loss or antenna diameter. The caption on the data entry form show the antenna configuration. Data can be entered from an antenna lookup table or the from the antenna data index.

Antennas TR - TR

	Grande Prairie	Beaverlodge
Antenna model	UHX10-58W (R)	HPX8-58W
Antenna diameter (m)	3.05	2.44
Antenna height (m)	82.50	50.00
Antenna gain (dBi)	42.10	40.80
Radome loss (dB)		
Antenna code	2008	1992
Antenna 3 dB beamwidth H (°)	1.10	1.40
Antenna 3 dB beamwidth E (°)		
True azimuth (°)	271.71	91.27
Vertical angle (°)	0.25	-0.48
Antenna azimuth (°)		
Antenna downtilt (±°)		
Orientation loss (dB)		

.

Antenna model - information only.

Antenna Diameter - This is required for near field calculations in rectangular passive repeater applications.

Antenna height - Antenna heights can be entered directly in this data entry form but are normally calculated in the Antenna Heights design section. If you change the value here, be sure to reassess the clearance or diffraction loss.

Antenna gain (dBi) - Antenna gains are a required entry.

Radome loss - Optional entry. On high frequency systems, where rain attenuation is a factor, the value should reflect the wet radome loss.

Code - The antenna code is required for interference and orientation loss calculations. Note that the code cannot be directly entered and must be loaded from a lookup table or antenna data index.

Antenna 3 dB beamwidth - Information only. This will become the default value for antenna discrimination calculations in the Multipath - Reflections design section.

True azimuth - This is calculated from the geographic coordinates and cannot be edited.

Vertical angle - This is calculated using an earth radius factor of K = 4/3. A path profile must be available. For antenna configurations with more than one antenna, the vertical angle is calculated for the first antenna only and is assumed to be the same for the others.

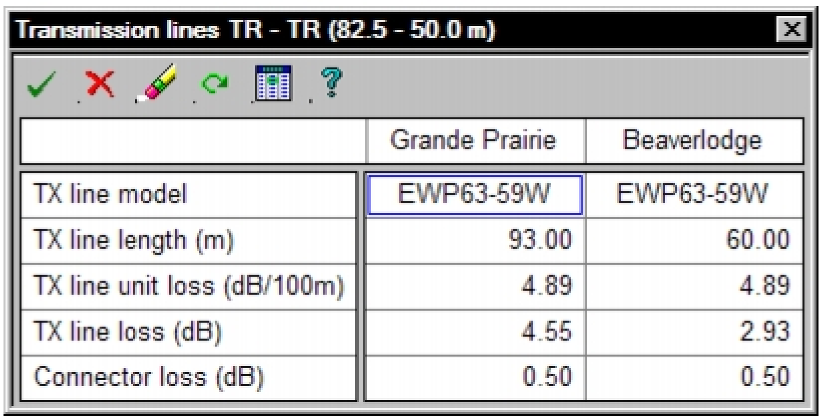
Antenna Azimuth - This will be primarily used for the hub site on point to multi point applications where a fixed antenna azimuth interconnects with remote antennas. The antenna discrimination is determined from the difference of the true azimuth and the antenna azimuth. If this entry is blank (F3 key), the horizontal antenna orientation is assumed to correspond to the true azimuth.

Antenna Downtilt - This is the corresponding fixed vertical angle at a hub site in a point to multipoint application. Downtilt is positive below the horizontal. The antenna discrimination is determined from the difference of the actual vertical angle and the antenna downtilt. In a microwave application, the vertical angle is calculated at K = 4/3 and line of sight is assumed. In a land mobile application, the vertical angle will be the horizon angle on an obstructed path. If this entry is blank (F3 key), the vertical antenna orientation is assumed to correspond to the vertical angle. Note that in a land mobile application the antenna boresight is always horizontal.

Orientation Loss - This the antenna response to the off azimuth and off elevation and off vertical angles above. Refer to the technical reference at the end of this section for details. An antenna code must be available for this calculation.

Transmission Lines Data Entry Form

The caption on the data entry form shows the current antenna configuration and the antenna heights. The TX line loss is automatically calculated from the TX line length and the TX line unit loss entries. The entries are unaffected by any subsequent changes made to the antenna heights. Be sure to check the values in this form when finalizing a design.

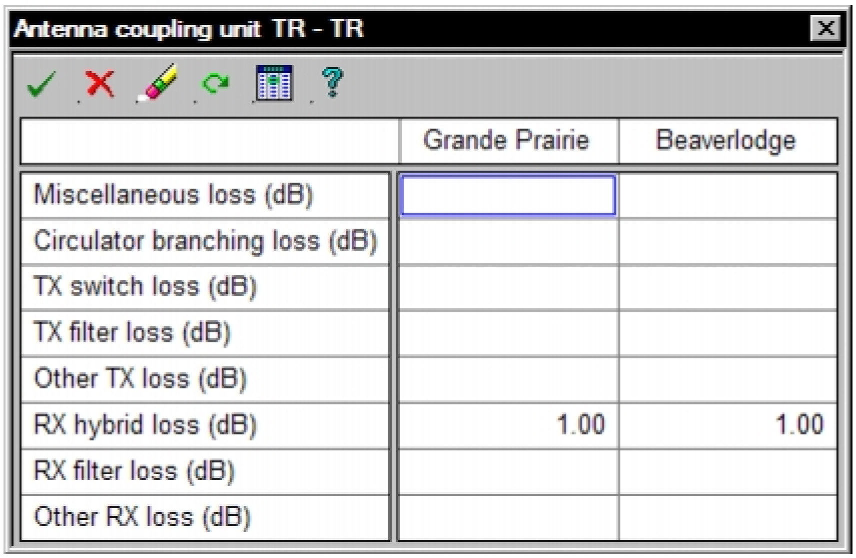


Transmission lines TR - TR (82.5 - 50.0 m)

	Grande Prairie	Beaverlodge
TX line model	EWP63-59W	EWP63-59W
TX line length (m)	93.00	60.00
TX line unit loss (dB/100m)	4.89	4.89
TX line loss (dB)	4.55	2.93
Connector loss (dB)	0.50	0.50

Antenna Coupling Unit Data Entry Form

The entries in the Antenna Coupling Unit data entry form depend on the antenna configuration. In the case of a TXRXDR_TXRXDR antenna configuration, there will be three different levels to enter branching network data for. Refer to the overall block diagram in Figure (1).

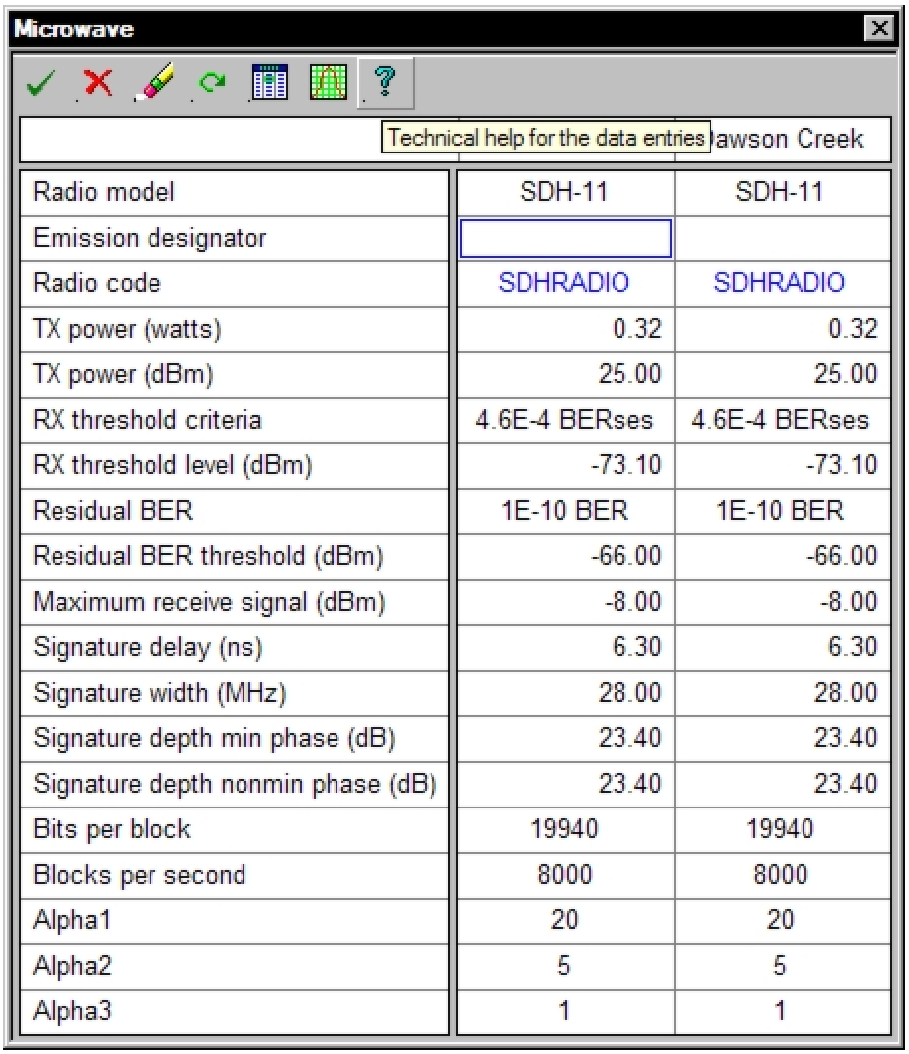


Antenna coupling unit TR - TR

	Grande Prairie	Beaverlodge
Miscellaneous loss (dB)		
Circulator branching loss (dB)		
TX switch loss (dB)		
TX filter loss (dB)		
Other TX loss (dB)		
RX hybrid loss (dB)	1.00	1.00
RX filter loss (dB)		
Other RX loss (dB)		

Radio data entry form

This specific entries and formatting of the radio data form depends on the application (microwave or land mobile) and the calculation methods (total time below level, SES-unavailability, SES-unavailability-BBER-ESR) and the selective fading method. Adaptive modulation is a special case and details are provided following the description of the microwave - land mobile data entry fields below:


Microwave

Technical help for the data entries

		awson Creek
Radio model	SDH-11	SDH-11
Emission designator		
Radio code	SDHRADIO	SDHRADIO
TX power (watts)	0.32	0.32
TX power (dBm)	25.00	25.00
RX threshold criteria	4.6E-4 BERses	4.6E-4 BERses
RX threshold level (dBm)	-73.10	-73.10
Residual BER	1E-10 BER	1E-10 BER
Residual BER threshold (dBm)	-66.00	-66.00
Maximum receive signal (dBm)	-8.00	-8.00
Signature delay (ns)	6.30	6.30
Signature width (MHz)	28.00	28.00
Signature depth min phase (dB)	23.40	23.40
Signature depth nonmin phase (dB)	23.40	23.40
Bits per block	19940	19940
Blocks per second	8000	8000
Alpha1	20	20
Alpha2	5	5
Alpha3	1	1

Radio model - Information only.

Emission designator - Information only.

Radio code - This the index to the radio data file and is required for interference calculations. Note that the code cannot be entered directly and must be loaded from a lookup table or the radio index.

TX power - A required entry. The value may be entered in watts or dBm. The opposite entry is automatically calculated.

RX Threshold criteria - This is a descriptive term for receiver threshold level on the line below. In land mobile applications this is shown as RX sensitivity criteria.

RX threshold level - This is used to calculate the thermal fade margin and is a required entry. In land mobile applications, this shown as RX sensitivity and can be entered in either dBm or microvolts.

Residual BER - This is a descriptive term for the residual BER threshold entered on the line below. This format is used in the SES-unavailability-BBER-ERS calculation method

Residual BER threshold - This is the threshold level at the residual BER specified in the line above

Maximum receive signal - Information only at present.

Signature parameters - This format is used is microwave applications when the selective fading method is set to the equipment signature. The signature delay, width and the depth for minimum and non minimum phase entries are required.

Dispersive fade margin - This format is used in microwave applications when the selective fading method is set to the dispersive fade margin. The selective outage calculation uses a dispersive fade occurrence factor to adjust the dispersive fade margin for different geographic areas. This fade factor is entered in the path data entry form and both terms must be present to complete the calculation; otherwise a warning is issued

Bits per block - This term is required for the SES-unavailability-BBER-ERS calculation method on SDH radio systems

Blocks per second - This term is required for the SES-unavailability-BBER-ERS calculation method on SDH radio systems

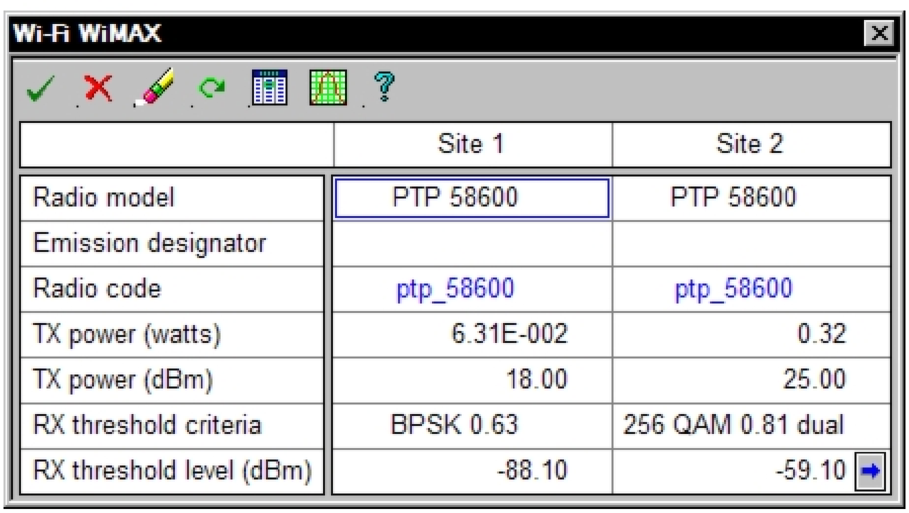
Alpha 1 - This is the number of errors per burst for the BER in the range from 1E-003 to BERSES. This term is required for the SES-unavailability-BBER-ERS calculation method on SDH radio systems

Alpha 2 - This is the number of errors per burst for the BER in the range from BERSES to the residual bit error rate. This term is required for the SES-unavailability-BBER-ERS calculation method on SDH radio systems

Alpha 3 - This is the number of errors per burst for the BER lower than the residual bit error rate, This term is required for the SES-unavailability-BBER-ERS calculation method on SDH radio systems

Adaptive modulation radio data entry form

In microwave and land mobile applications, performance is calculated with a fixed transmit power and receiver threshold. In the adaptive modulation case there can be up to eight sets of transmit power and receiver threshold corresponding to each modulation.


Wi-Fi WiMAX

	Site 1	Site 2
Radio model	PTP 58600	PTP 58600
Emission designator		
Radio code	ptp_58600	ptp_58600
TX power (watts)	6.31E-002	0.32
TX power (dBm)	18.00	25.00
RX threshold criteria	BPSK 0.63	256 QAM 0.81 dual
RX threshold level (dBm)	-88.10	-59.10

Click the radio icon to access the radio data entry form. Then click the calculate button on the RX threshold level line to access the table of the OFDM radio parameters.

Note that the radio data entry form contains transmit power and receive threshold data. These represent two tx-rx combinations in the OFDM table and provide some insight on the receive signal and fade margin for these two cases.

To change these values, place the cursor on the site 1 or site 2 side as required and then click the calculate button on the RX threshold level line. Select the sample and click the check mark to enter this into the radio data entry form. Normally the values for the highest and lowest throughput are entered.

Wi-Fi WiMAX - Site 1

	Modulation	TX power (dBm)	RX threshold level (dBm)	Throughput
1	256 QAM 0.81 dual	18.00	-59.10	300.2 Mbps
2	64 QAM 0,75 dual	18.00	-68.10	206.7 Mbps
3	16QAM 0.63 dual	22.00	-75.20	115.6 Mbps
4	QPSK 0.87	23.00	-81.60	40.2 Mbps
5	BPSK 0.63	24.11	-88.10	14.4 Mbps
6				
7				
8				

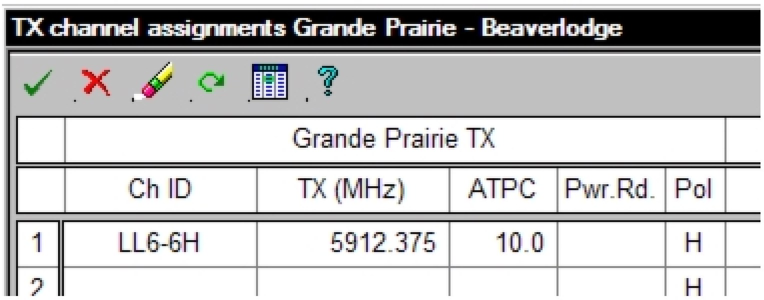
Suppose that the cursor was in the site 1 column when the calculate button was clicked. When a tx-rx combination is selected, the receive threshold will be inserted into the site 1 column and the transmit power into the site 2 column.

Receive signal (dBm)	-42.52	-49.52
Thermal fade margin (dB)	45.58	9.58
Worst month multipath throughput		
300.2 Mbps	99.43235	99.43235
206.7 Mbps	99.92854	99.92854
115.6 Mbps	99.99445	99.99445
40.2 Mbps	99.99899	99.99899
14.4 Mbps	99.99986	99.99982

The calculation results show the receive signal and fade margin for the selected tx-rx combinations.

The throughput analysis is calculated using the same tx-rx combination at each site

TX channel assignments



Click the TX channels button to bring up the transmit channels data entry form. Transmit channel assignments must be specified to run an interference analysis. The channel assignments are also used to calculate the effective frequency spacing in frequency diversity applications.

The data entry form contains the following fields for each site:

Channel ID The channel identifier is used in an interference calculation to determine if a high - low violation exists at a site. To accomplish this, the last letter of the channel identifier must be an H (high) or L (low).

TX Frequency The transmit center frequency expressed in MHz.

ATPC Range The automatic transmit power control range in dB. This is only used in an interference calculation as described below.

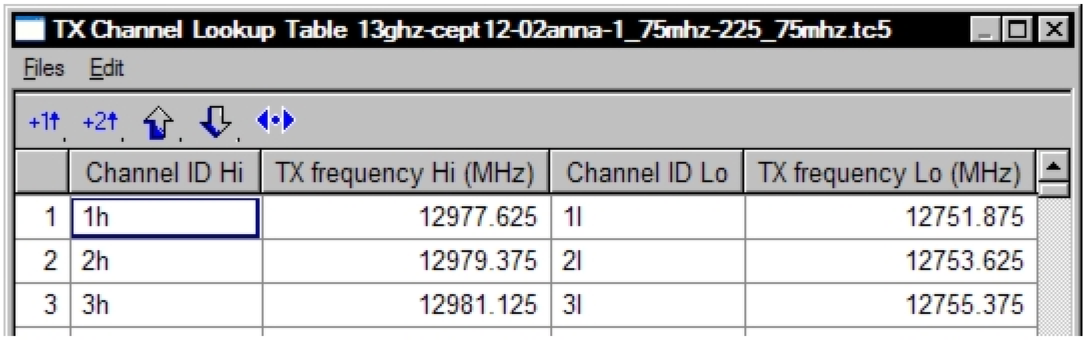
Power Reduction The transmit power used in an interference calculation can be reduced from the design power on an individual channel.

Polarization Press Enter or double click on the polarization cell to change between horizontal polarization. If the site 1 polarization is changed, the site 2 polarization and the design polarization are both automatically changed to the site 1 polarization. Changing the site 2 polarization does not have the equivalent effect. In most cases the site 1 and site 2 polarization will be the same; however, in some frequency plans and links using back to back antennas as a passive repeater, opposite polarizations will be used at each site.

The ATPC range and power reduction fields determine the transmit power to be used in an interference calculation. The transmit power used to calculate the interfering signal level is given by:

design power - ATPC range - power reduction

Transmit channel lookup table



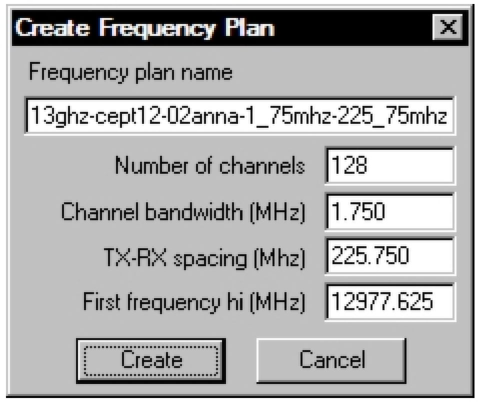
	Channel ID Hi	TX frequency Hi (MHz)	Channel ID Lo	TX frequency Lo (MHz)
1	1h	12977.625	1l	12751.875
2	2h	12979.375	2l	12753.625
3	3h	12981.125	3l	12755.375

Lookup tables are used for the transmit channel assignments. These use a standard grid data entry form. Refer to the General Program Operation section in this manual for details on the use of this form. The last used TX Channel lookup file is automatically loaded when the lookup table is accessed. The file name of the current frequency plan is shown on the caption.

The +1 up button on the tool bar loads the high transmit channel into site 1 and the low channel into site 2. Similarly the +2 up button loads the high transmit channel into site 2 and the low into site 1.

The TX Channel table window will be positioned in front of the TX channel table which will be disabled. The up and down arrows on the tool bar set the row number in the TX channel table. Position the TX Channel lookup window so that both windows are visible.

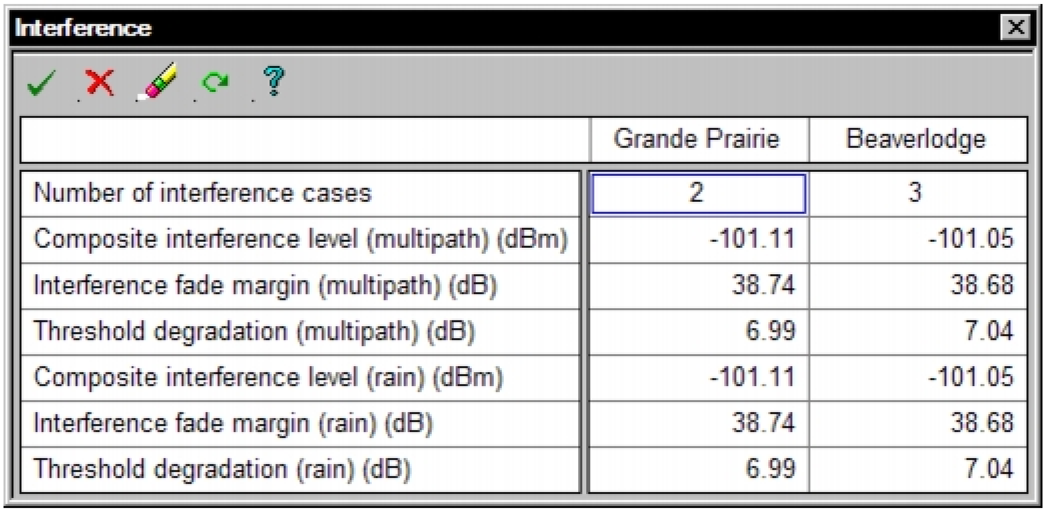
Create frequency plan



Click the <?> symbol on the tool bar to create an new frequency plan or extend an existing one. Complete the entries and click the create button.

The channel bandwidth is the frequency difference between the center frequencies of successive channels.

Interference



Interference

	Grande Prairie	Beaverlodge
Number of interference cases	2	3
Composite interference level (multipath) (dBm)	-101.11	-101.05
Interference fade margin (multipath) (dB)	38.74	38.68
Threshold degradation (multipath) (dB)	6.99	7.04
Composite interference level (rain) (dBm)	-101.11	-101.05
Interference fade margin (rain) (dB)	38.74	38.68
Threshold degradation (rain) (dB)	6.99	7.04

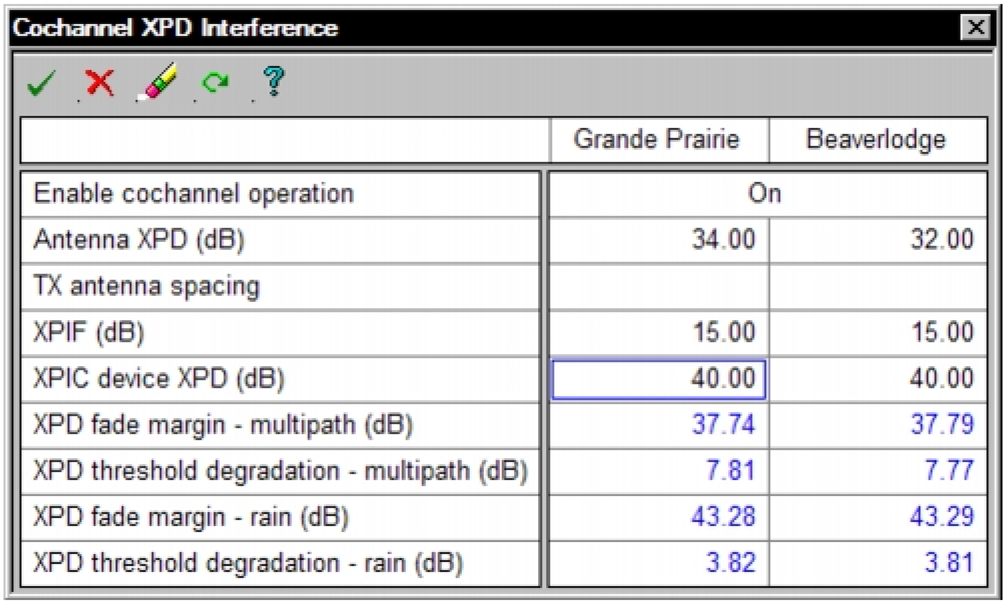
Select Operations - Interference from the Transmission analysis menu bar. Normally this form would be automatically filled in as part of an interference calculation; however, a user could make an allowance for interference with a manual entry. The interference can be expressed in any of the three following formats. The other formats will be automatically calculated.

- composite interference level - this is the total power level in the passband of the receiver. If the interfering signal does not have the same frequency, modulation and bandwidth as the receiver, the interfering signal level must be adjusted to account for the receiver filtering.
- interference fade margin
- threshold degradation

To account for fade correlation, separate components are provided for multipath and rain.

The number of exposures is for information only and is not used in any calculations.

Cochannel operation



Cochannel XPD Interference

	Grande Prairie	Beaverlodge
Enable cochannel operation	On	
Antenna XPD (dB)	34.00	32.00
TX antenna spacing		
XPIF (dB)	15.00	15.00
XPIC device XPD (dB)	40.00	40.00
XPD fade margin - multipath (dB)	37.74	37.79
XPD threshold degradation - multipath (dB)	7.81	7.77
XPD fade margin - rain (dB)	43.28	43.29
XPD threshold degradation - rain (dB)	3.82	3.81

The capacity of a link can be effectively doubled by simultaneously transmitting a channel on both horizontal and vertical polarization. This mode is referred to as cochannel operation. The viability of the link will be determined by the increased outage time resulting from the mutual interfering effect of this operation when the cross polarized discrimination degrades during multipath and high intensity rain conditions. Cochannel operation is invoked by checking this option under Configure - PL50L options - Transmission calculations - Multipath fading method. Select Operations - Cochannel operation to access the data entry form for this option.

Details of the calculation are provided in the technical reference in this section.

Data entry consists of the following:

Antenna XPD - This will be automatically entered if the antenna data entry form contains an antenna code.

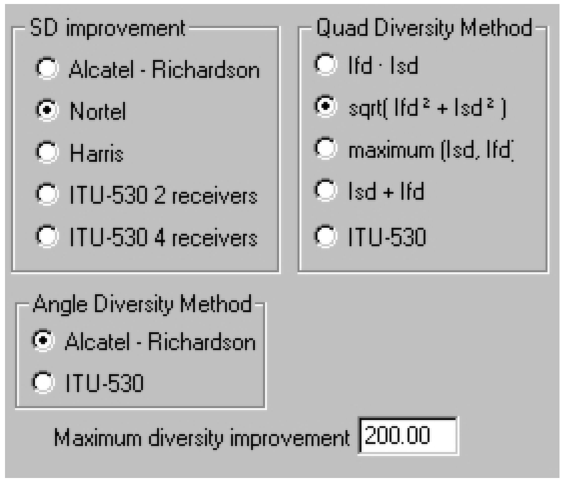
TX antenna spacing - If separate antennas are used for vertical and horizontal polarization, enter the vertical separation between antennas. Otherwise, this entry must be blank (F3 key).

XPIF - If a antenna system is equipped with a cross polarized improvement device (XPIC device), enter the XPD improvement produced by the device. Otherwise, this entry must be blank (F3 key).

XPIC device XPD - If an XPIC device is equipped then enter the cross polarized discrimination of the XPIC device itself. Otherwise, this entry must be blank (F3 key).

The interference fade margin and threshold degradation are calculated for both rain and multipath activity on the path.

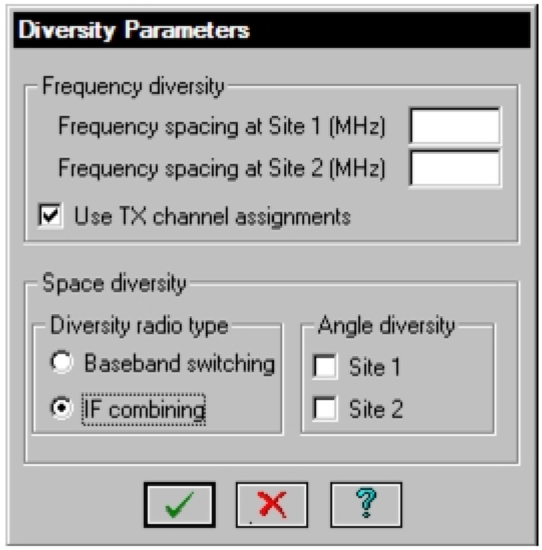
Diversity options



The basic space diversity methods are set under Configure - Set PL50L program options - Transmission calculations - Space diversity methods.

Note that the options under SD improvement and Angle diversity method are provided for compatibility with radio equipment manufacturers in house software programs.

The maximum diversity improvement factor applies to all type of diversity (space, frequency and quad)



Select Operations - Diversity Calculation to access the Diversity Parameters dialog box. The settings in this dialog are extensions to the general options under PL50L options - Transmission calculations - Space diversity methods which are applied to specific links

Frequency diversity

Frequency diversity will be enabled under the following conditions:

- the "Use TX channel assignments" option is checked and the transmit channel table contains more than one frequency entry. The effective frequency spacing will be calculated based on the number of channels.
- the "Use TX channel assignments" option is not checked and the and values have been entered for the frequency diversity spacing at site 1 and site 2

Diversity radio type

Select either base band switching or IF combining. The diversity radio type can be specified in the radio data file. Space diversity radios using IF combining can improve the thermal fade margin up to 3 dB. This improvement can also be specified in the radio data file.

The default improvement is 2.6 dB. The actual improvement depends on the difference between the main and diversity receive signals signal and the combiner efficiency. It can be argued that this improvement is artificial and is not realized in practice. During deep fades, there will be significant difference between the main and diversity signals; and therefore, the performance will be identical to a baseband switching system.

Angle diversity

Angle diversity can be specified at either or both sites. A space diversity antenna configuration must be selected. Angle diversity cannot be used with a hybrid diversity antenna configuration. At the angle diversity site set both antenna heights to the same value. The display will show a 30 foot (9.1 meter) angle diversity separation between the antennas. The overall improvement for angle diversity is calculated using a 30 foot separation. The improvement will be the same for the dispersive component as in conventional space diversity; however, the improvement to the flat component will be one tenth of conventional space diversity.

C factors

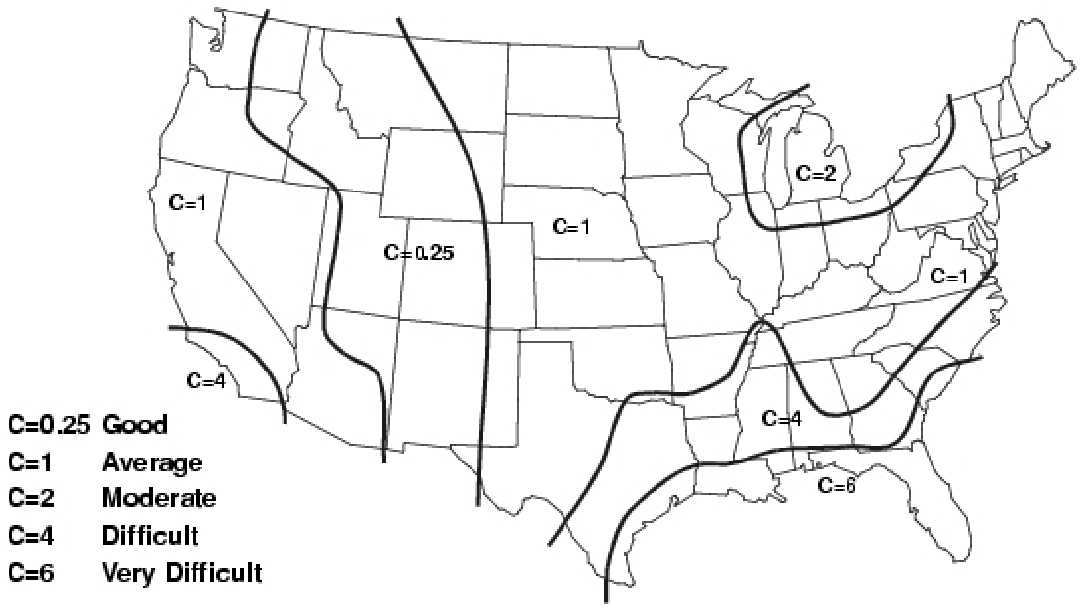


Figure 1: C Factors - United States

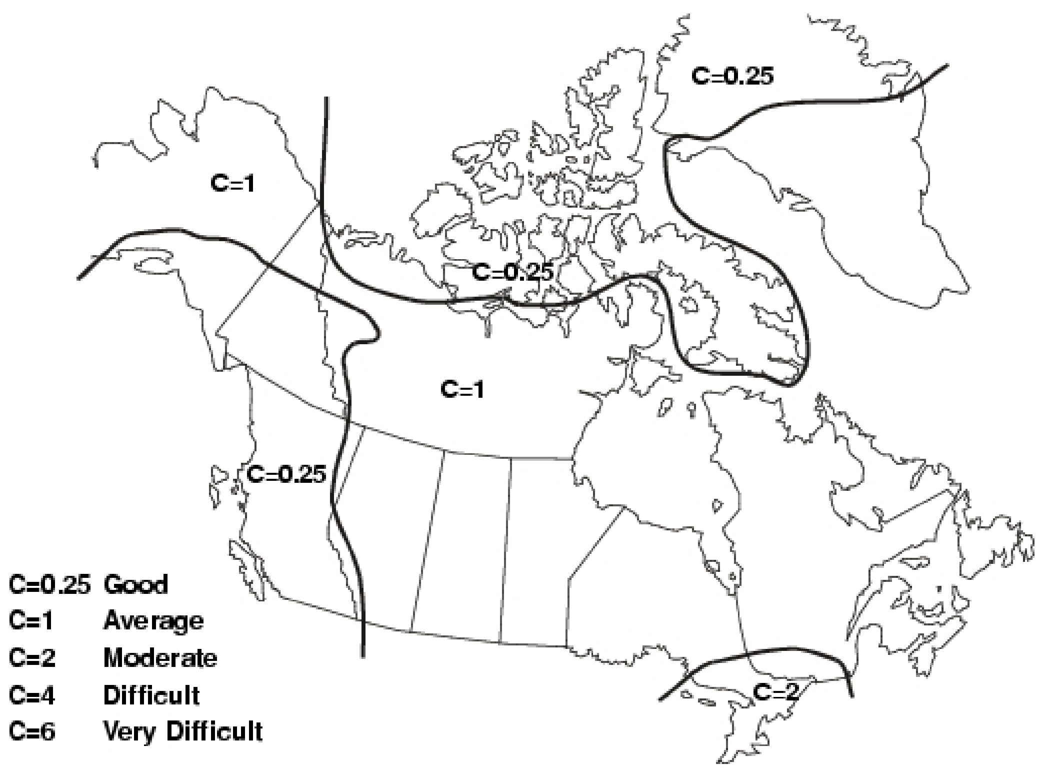


Figure 2: C Factors - Canada

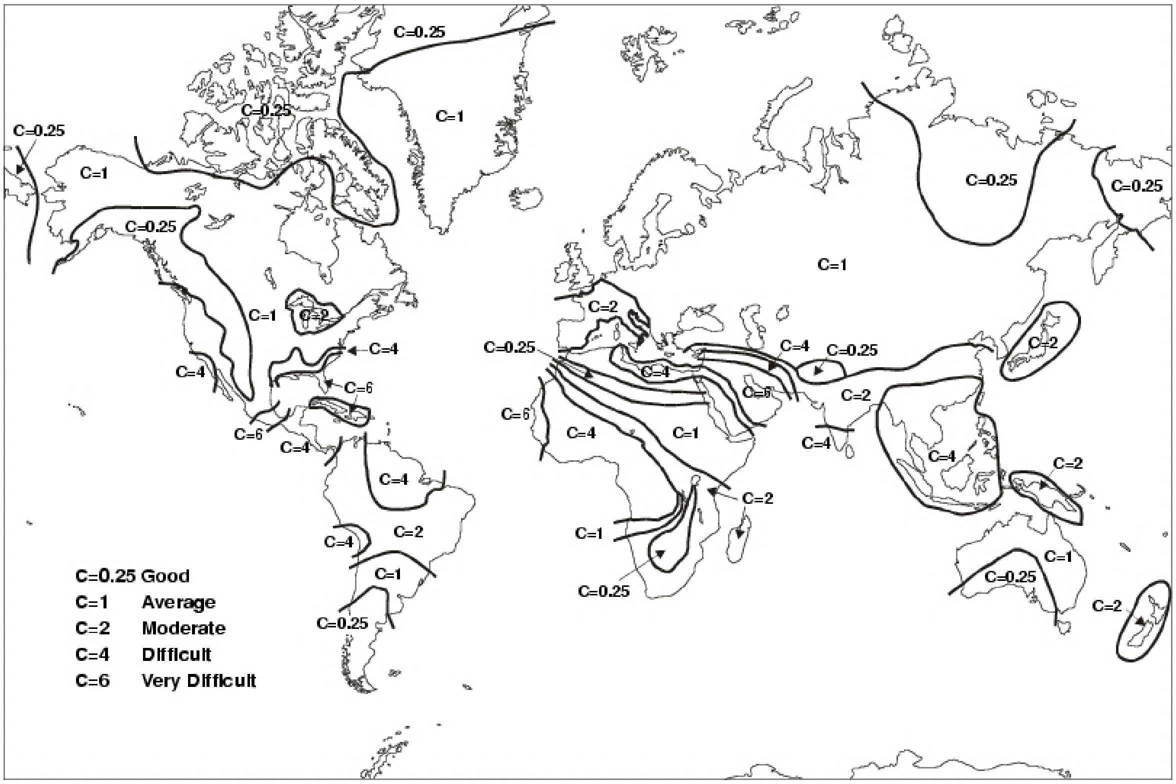


Figure 3: C Factors - World

dN/dH Gradient < 100 N units / kilometer

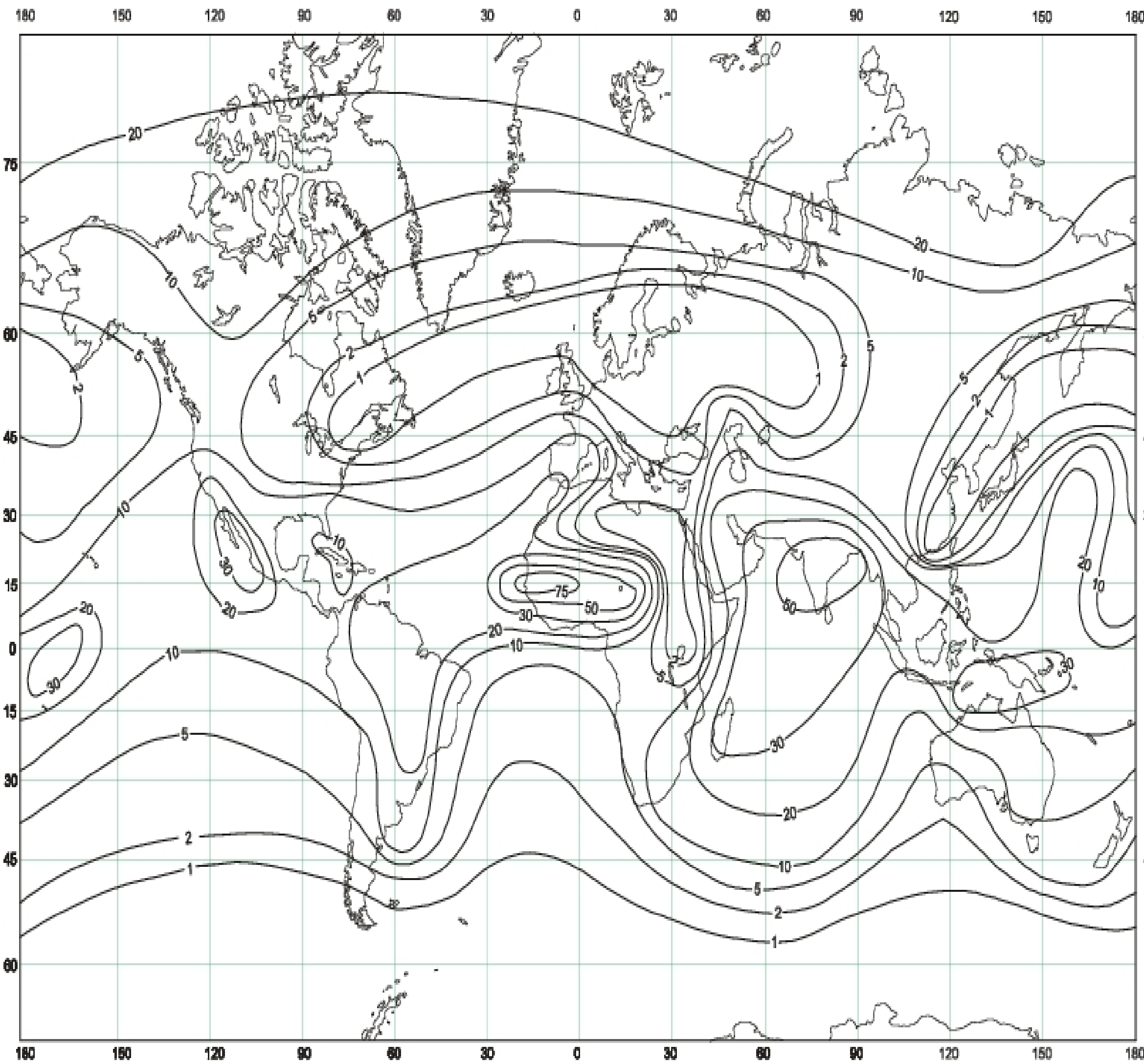


Figure 1: Percent of Time Gradient ≤ -100 N units / km - February

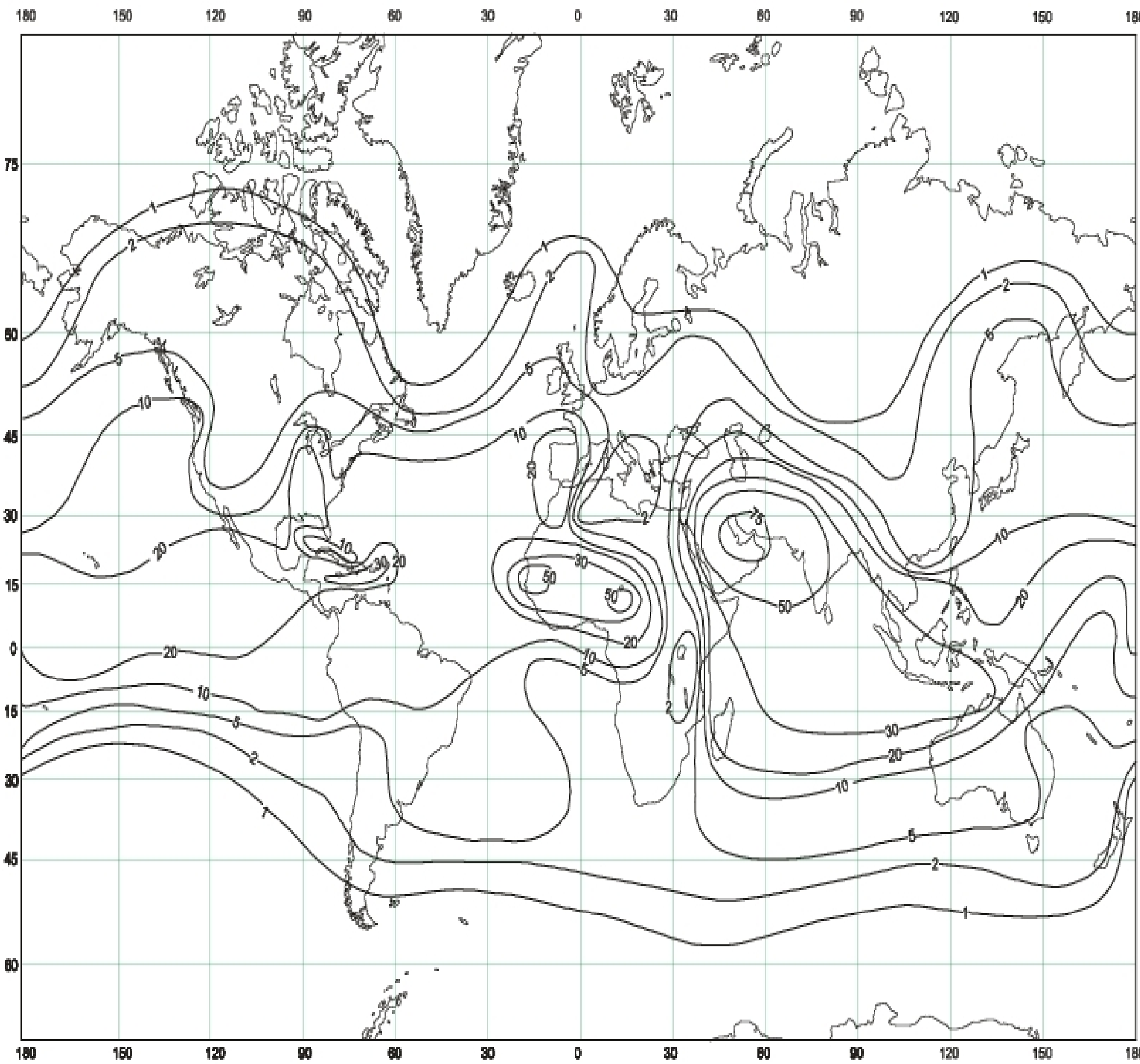


Figure 2: Percent of Time Gradient ≤ -100 N units / km - May

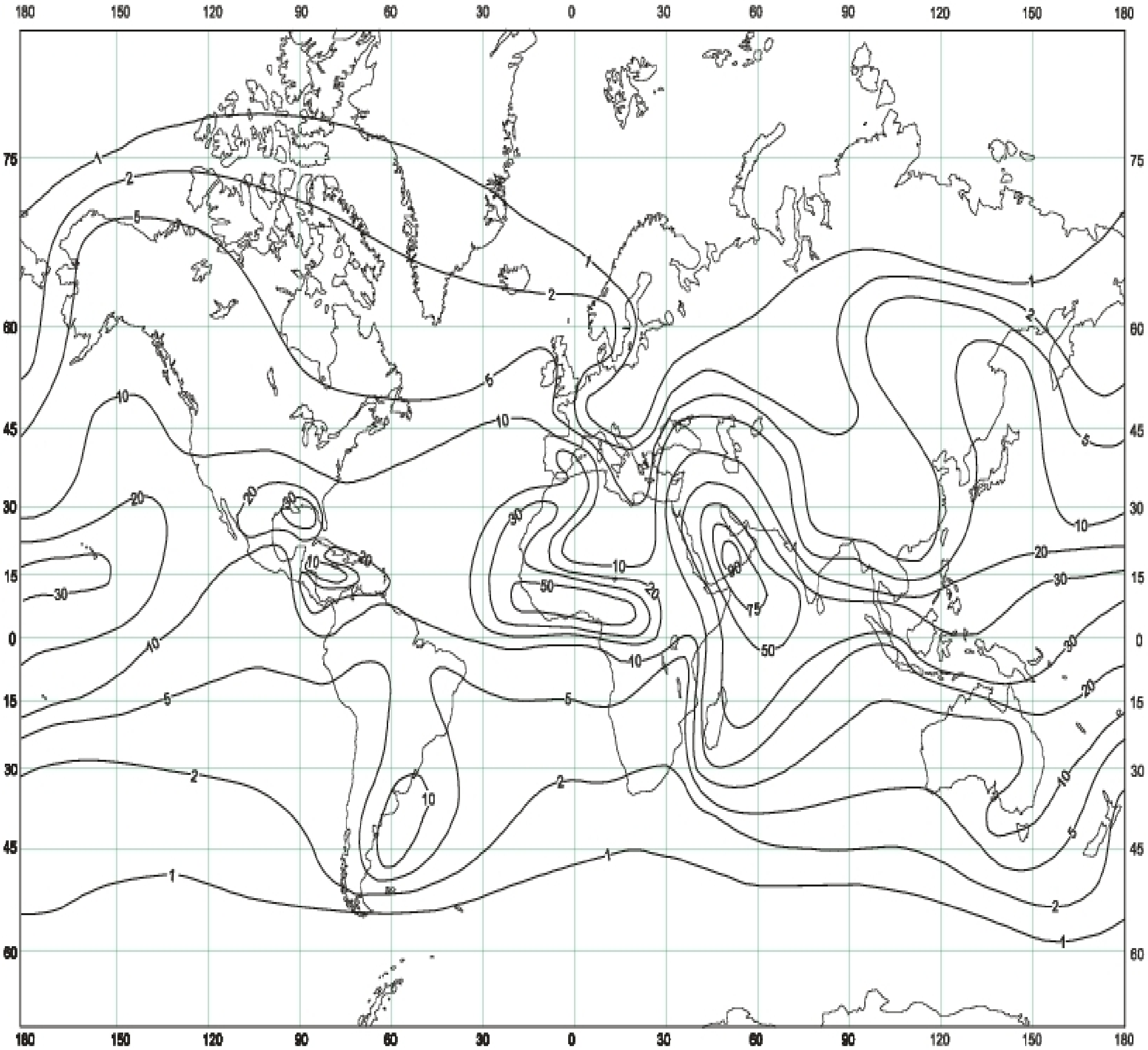


Figure 3: Percent of Time Gradient ≤ −100 N units / km - August

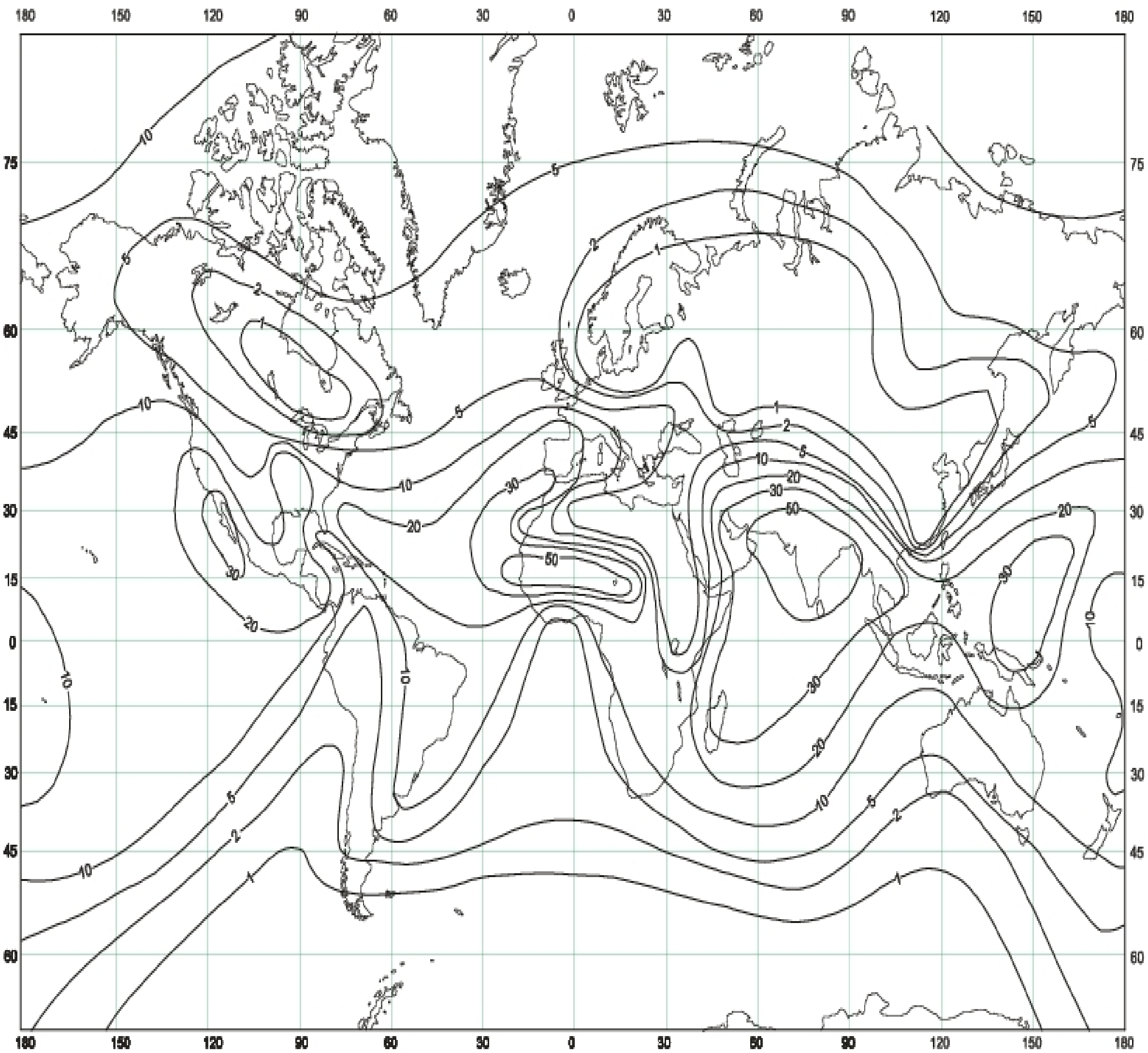


Figure 4: Percent of Time Gradient ≤ −100 N units / km - November

Geoclimatic factor - Canada (ITU-R P.530.6 only)

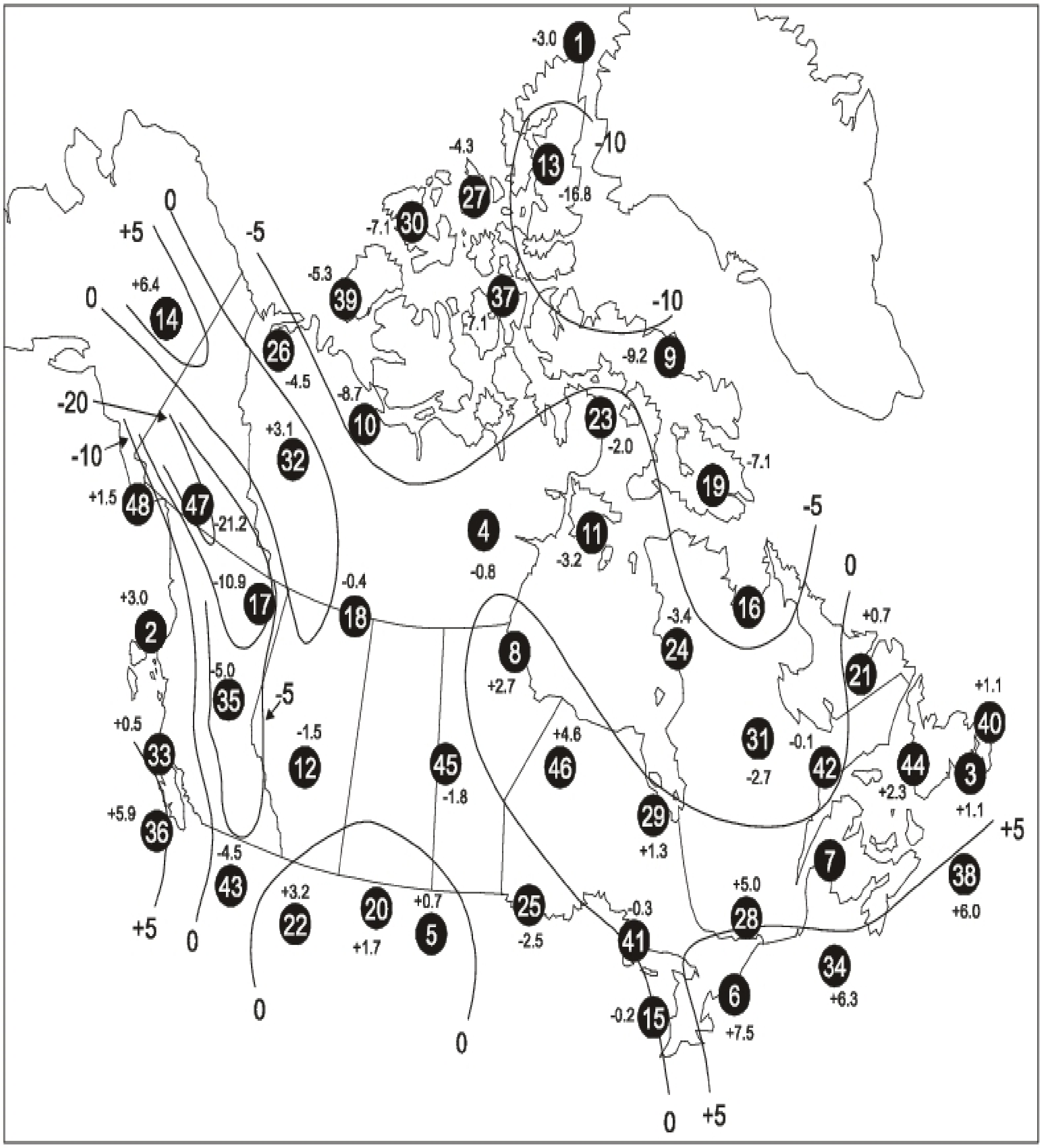


Figure 1: Geoclimatic Factors - Canada

Average annual temperature

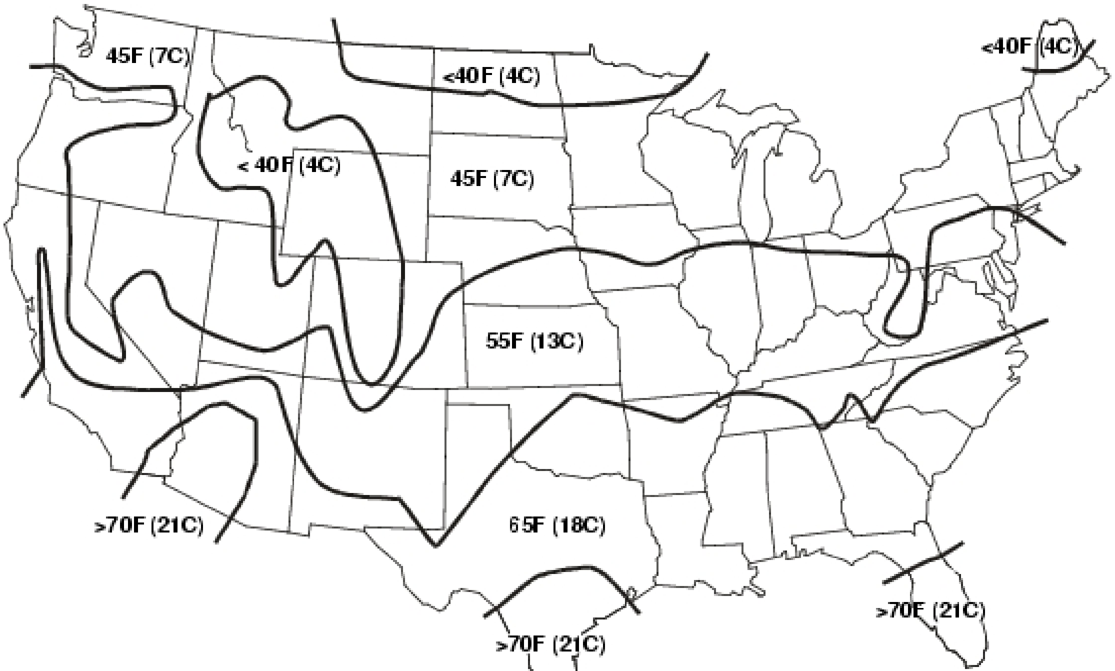


Figure 1: Average Annual Temperature - United States

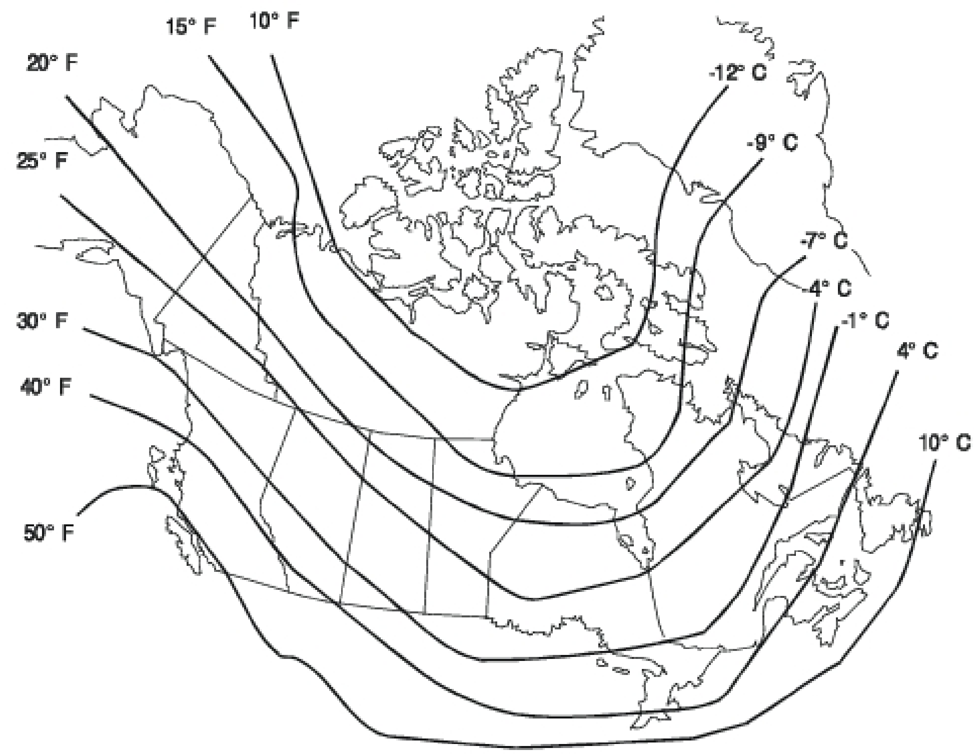


Figure 2: Average Annual Temperature - Canada

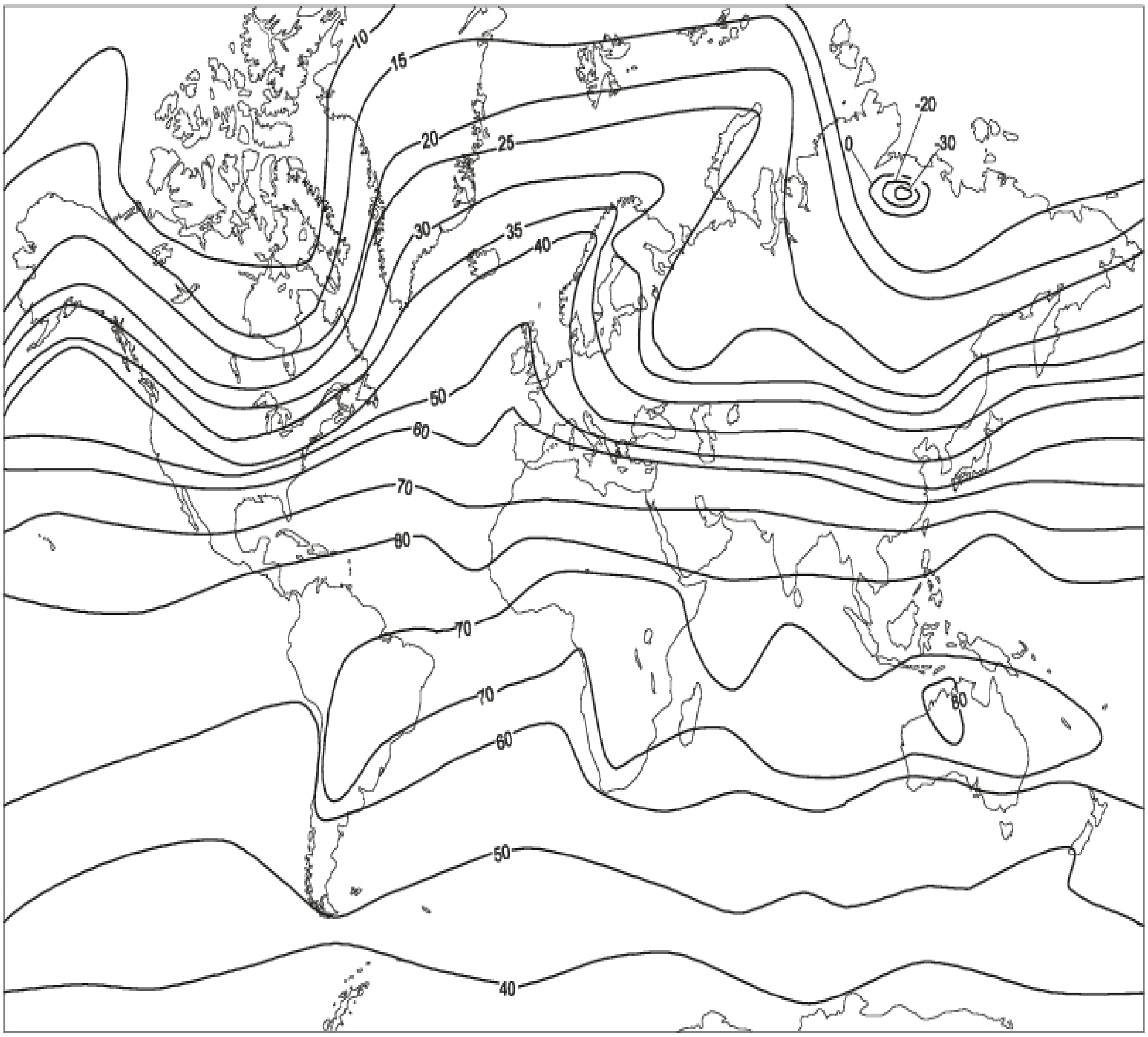


Figure 3: Average Annual Temperature - World

Multipath propagation reliability

Fading on a microwave link can result from any of the following mechanisms:

- atmospheric multipath fading
- rain attenuation
- diffraction fading at low values of K
- fades produced by a specular reflection
- propagation anomalies produced by atmospheric ducts or layers

Each of these mechanisms can contribute to the overall propagation reliability and must be separately analysed. The parameter of particular interest is the total time that the receive signal is below its threshold level.

It is generally assumed that these fading mechanisms are mutually exclusive events and the total time below the threshold level is the sum of the outage times for each mechanism. For example, multipath fading does not occur during periods of heavy rainfall; and therefore, the multipath and rain outage times can be added together.

Atmospheric multipath fading is the result of a number of rays with varying length paths arriving at the receive antenna. The different ray paths can result from both changes in the refractivity gradient and diffuse ground reflections. The rays add vectorially in the receive antenna to produce both signal enhancement and fades.

Multipath fading follows a Raleigh probability distribution. The fade probability represents the fraction of time (in the worst month), that the depth of multipath fades will exceed the fade margin. Note that this fade probability does <u>not</u> include any of the other fade mechanisms mentioned above and does not include the additional time required to reframe the digital signal following a fade which results in loss of framing.

The fade probability, P, is a function of the frequency, path length and the fade margin of the radio link and takes the following general form:

$$P \propto f^b \cdot d^c \cdot 10^{-\frac{A}{10}} \qquad (1)$$

d	path length
f	frequency
A	fade margin in dB

Note that P is expressed as a fraction of time and not as a percentage. Equation (1) is valid for fade margins greater than 15 dB and applies to unprotected (non diversity) radio systems in one direction of transmission. The exponents b and c and the constant of proportionality in Equation (1) are based on empirical data.

The following methods of calculating the fade probability are available in the Pathloss program.

- Vigants - Barnett
- Recommendation ITU-R P.530-6
- Recommendation ITU-R P.530-7/8
- Recommendation ITU-R P.530-9/10/11/12
- KQ Factor
- KQ Factor including terrain roughness

Additional performance parameters can be calculated from the fade probability P, as follows:

- Worst month unavailability (%) = $100 \cdot P$

- Worst month availability (%) = 100·(1 - *P*)
- Worst month outage time (sec) = *P*·seconds_month

Assuming 3 heavy fading months per year (0.25 of a year), the annual performance can be expressed as:

- Annual unavailability (%) = 100·*P*·0.25
- Annual availability (%) = 100·(1 - 0.25·*P*)
- Annual outage time (sec) = 0.25·*P*·seconds_year

Multipath fading is a warm weather phenomenon. Two methods of converting the worst month values to an annual outage are available:

Worst month to annual conversion using Vigants Barnett

The length of the fading season is proportional to the average annual temperature and is given in Reference (4). The fade duration, T_o, expressed as a fraction of a year, is given by:

$$T_0 = 0.25 \cdot \left(\frac{t}{50}\right) \quad (2)$$

t is the average annual temperature in ?F
35 ≤ *t* ≤ 75?F
2 ≤ *t* ≤ 24?C
0.175 ≤ T_0 ≤ 0.375

Worst month to annual conversion using ITU

Calculate the logarithmic geoclimatic conversion factor *ΔG* from Equation (3)

$$\Delta G = 10.5 - 5.6\times\log_{10}\left(1.1\pm\left|\cos\left(2\xi\right)\right|^{0.7}\right) - 2.7\times\log_{10}\left(d\right) + 1.7\times\log_{10}\left(1+\left|\varepsilon_p\right|\right) \qquad (3)$$

where ΔG is <= 10.8 and the + sign is used for latitudes <= 45? and the - sign is used for latitudes > 45? and where:

d path length in kilometers

ε_p magnitude of path inclination in milliradians

ζ latitude - north or south

The fade duration, T_o, expressed as a fraction of a year, is given by:

$$T_0 = 10^{-\frac{\Delta G}{10}} \qquad (4)$$

The annual one way performance is expressed in terms of T_o as follows:

- Annual unavailability (%) = $100 \cdot T_o P$
- Annual availability (%) = $100 \cdot (1 - T_o P)$
- Annual outage time (sec) = $T_o \cdot P$sec_year

Figure (5), Figure (6) and Figure (7) provide geographic maps showing the average annual temperature for the United States, Canada and the world respectively.

Fade margins

The fade probability of a microwave radio link is a function of its fade margin. A multipath fade can be considered as the sum of two components:

- a flat fade component which is frequency independent
- a selective or dispersive fade component which is a function of frequency.

Selective fading is characteristic of wide band digital radios and depends on the equipments ability to equalize the amplitude versus frequency response in its passband. Analog radios (FM-FDM) and very narrow band digital radios do not experience selective fading. Two methods of predicting the selective fade probability were developed.

- ATT Bell Labs developed the concept of a dispersive fade margin in the early 1980's, This was based on the premise that flat fading and selective fading are not correlated and therefore, the overall fade probability will be the sum of the flat component and the selective or dispersive component. The dispersive fade margin is a measured equipment parameter based on industry standard procedures.
- The 1997 release of ITU-R P.530-7 included a procedure to calculate the selective fade probability based on the equipment signature in terms of the width, delay and the minimum and non-minimum notch depths.

Thermal Fade Margin

The thermal fade margin is the difference between the free space receive signal and the receiver threshold level. This represents the additional attenuation to the free space received signal required to produce an outage due to thermal noise alone, independent of any interference.

Interference Fade Margins

Interference effectively degrades the receiver threshold. The interference fade margin is defined as the additional attenuation to the free space received signal required to produce an outage due to the interference, independent of thermal noise.

Flat Fade Margin

The flat fade margin A_F, consists of the thermal and interference fade margins combined as follows:

$$A_F = -10 \cdot \log\left(10^{-\frac{A_t}{10}} + 10^{-\frac{A_i}{10}}\right) \qquad (1)$$

A_t thermal fade margin in dB
A_i channel interference fade margin in dB

Dispersive fade margin

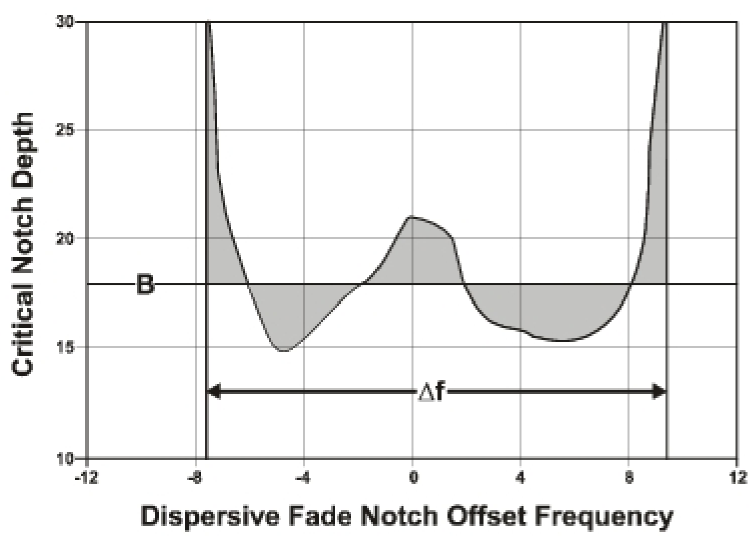


Figure 1: Dispersive fade margin measurement

The ATT Bell Labs selective outage calculation is based on the dispersive fade margin. This is defined as the average depth of multipath fade which causes an outage, independent of thermal noise and interference. This is a measured equipment parameter in accordance with Reference (1). The dispersive fade margin depends on the equipment design and the specific type of equalizer provided. The basic measurement procedure for a 45 Mbs 64QAM radio is described below:

A 6.3 nanosecond frequency response notch is introduced into the RF /IF passband. The center of the notch is moved across the passband. At each frequency, the depth of the notch is adjusted to produce a 10^{-3} BER. The results are shown in Figure (1) and are referred to as an equipment signature, M or W curves.

The average depth of multipath fade, B, is determined by integrating the curve. The dispersive fade margin, A_d, is given by:

$$\begin{aligned} S &= 2 \cdot \Delta f \cdot e^{-\frac{B}{3.8}} \\ A_d &= 17.6 - 10 \cdot \log\left(\frac{S}{158.4}\right) \end{aligned} \tag{2}$$

Typical values of the dispersive fade margin for 64 QAM modulation are 50 dB for a radio equipped with an adaptive transversal equalizer, and as low as 35 dB for the same radio without equalization.

Dispersive Fade Factor

The dispersive fade margin measurement procedure is based on the fade statistics of a 26 mile path from Palmetto to Atlanta, Georgia. In general, dispersive multipath fading depends on the following:

- terrain roughness and ground type

- climatic conditions
- path length
- path clearance

To account for these factors, it is necessary to adjust the value of the dispersive fade margin. This is accomplished with the term, "fade occurrence factor" in the Pathloss program. By definition, the fade occurrence factor is equal to 1 for the Palmetto - Atlanta path. At present, there are no published guidelines for this factor. Experience on extremely difficult paths in eastern Ontario and Florida indicate that factor may be as high as 9. The following values are suggested:

0.5 to 1 good propagation conditions
3 average propagation conditions
5 to 7 difficult propagation conditions
9 extremely difficult propagation conditions

Effective Fade Margin

The effective fade margin, *A*, combines the flat and dispersive fade margin components as follows:

$$A = -10 \cdot \log\left(10^{-\frac{A_f}{10}} + R_d \cdot 10^{-\frac{A_d}{10}}\right) \tag{3}$$

A_f flat fade margin in dB
Rd fade occurrence factor
A_d dispersive fade margin in dB

ITU 530 selective outage fade probability

ITU standards use the equipment signature to calculate the fade probability of a selective outage. This is a measured equipment parameter consisting of the following components: signature delay, signature width and the signature depth for minimum and non minimum phase. The outage probability is defined as the probability that the BER exceeds a given threshold as defined by the BER of the signature data.

Step 1: Calculate the mean path delay from Equation (1):

$$\tau_m = 0.7 \cdot \left(\frac{d}{50}\right)^{1.3} \text{nanoseconds} \qquad (1)$$

where

d is the path length in kilometers

Step 2: Calculate the multipath activity factor from Equation (2):

$$\eta = 1 - e^{-\left(0.2 \cdot P_0^{0.75}\right)} \qquad (2)$$

where

P_0 fade occurrence factor

Step 3: Calculate the selective outage probability Ps from Equation (3):

$$P_s = 2.15 \cdot \eta \cdot W \cdot \frac{\tau_m^2}{\tau_r}\left(10^{\frac{-B_m}{20}} + 10^{\frac{-B_{nm}}{20}}\right) \tag{3}$$

where

W signature width in GHz

B_m minimum phase signature depth in dB

B_{nm} non minimum phase signature depth in dB

τ_r reference delay in nanoseconds used to obtain the signature

ITU unavailability - severely errored seconds definitions

The above paragraphs show the basic relation between the fade margin and the probability of a fade below threshold level P. The formulation of dispersive fade margin allows the dispersive fade margin to be logarithmically added to the flat fade margin (effective fade margin). This allows *P* to be calculated from Equation () for both flat and dispersive fades. In the ITU method, the selective fade probability is separately calculated.

All multipath propagation models (e.g ITU-530) calculate the fade probability for the worst month in one direction of transmission. The fade probability is defined as the probability that the receive signal is below the specified receiver threshold. The fade probability considers the sum of all fades and does not take into account the duration of the individual fades.

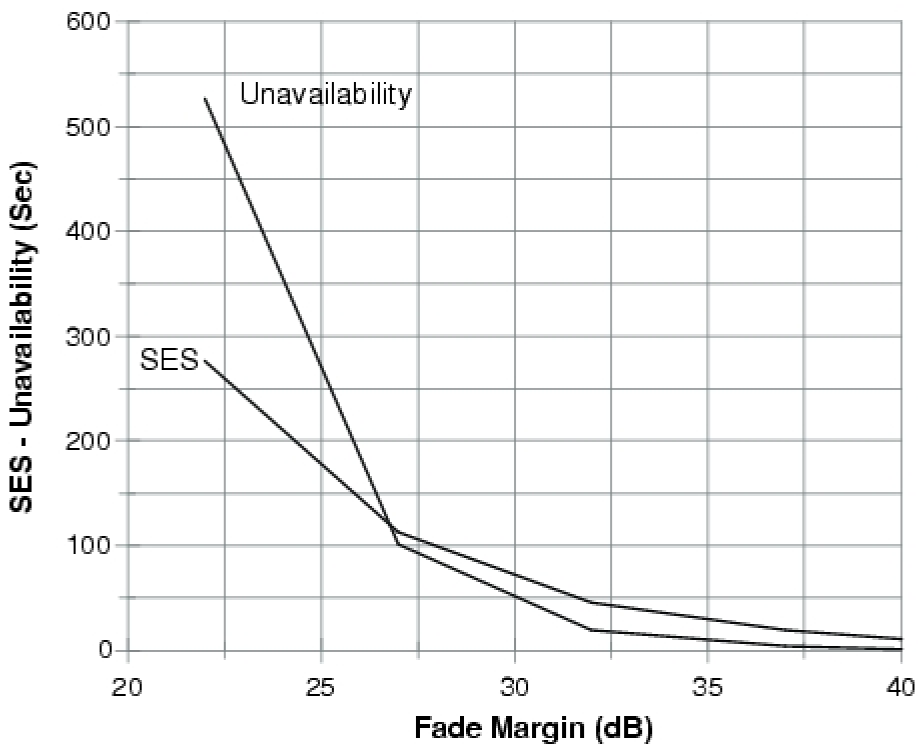


Figure 1: Relationship between SES - Unavailability and Fade Margin

G.821 and G.826 take this analysis one step further and classify fades lasting longer than 10 consecutive seconds as unavailability and all other fades as severely errored seconds (SES). The SES term is often referred to as performance. The duration of a multipath fade depends on the fade margin. The probability of a multipath fade lasting longer than 10 consecutive seconds increases with decreasing fade margin.The relationship is shown in Figure (1)

In the case of rain fades, it is universally agreed that a rain fade will always last longer than 10 consecutive seconds and is classified as unavailability only.

G.821 and G.826 provide performance objectives in terms of SES and unavailability without stating the relationship between the two parameters

$$\text{worst month time below level} = \text{unavailability} + SES \qquad (1)$$

At very high frequencies, multipath fading becomes negligible compared to the rain fades.

At lower frequencies where rain is insignificant, two different approaches have been taken:

- Multipath is considered to affect the performance only and in this scenario the severely errored seconds ratio (SESR) is equal to multipath fade probability. Objectives are more difficult to achieve as the allowance for unavailability cannot be used. The real reason for this approach is the lack of any published procedures to breakdown the total time below level into SES and unavailability.
- Other companies have developed their own fade duration statistics to carry this out however, the formulas have not been published.

Using the dispersive fade margin, the total fade probability P is separated into the flat and dispersive components P_f and P_d as shown below

$$
\begin{aligned}
P_f &\propto f^b \cdot d^c \cdot 10^{-\frac{A_f}{10}} \\
P_d &\propto f^b \cdot d^c \cdot 10^{-\frac{A_d}{10}}
\end{aligned}
\tag{2}
$$

where:

A_f flat fade margin (dB)
A_d dispersive fade margin (dB)

As described above P_d is calculated from the equipment signature under ITU standards.

The probability of a non selective (flat) fade lasting longer than t consecutive seconds is given by:

$$
\begin{aligned}
\rho_f &= 0.5 \cdot \mathrm{erfc}\left(\frac{\ln\left(\frac{t}{T_d}\right) + 0.673}{1.27 \cdot \sqrt{2}} \right) \\
T_d &= 163 \cdot k \cdot \sqrt{\frac{d}{f}} \cdot 10^{-\frac{A_f}{20}}
\end{aligned}
\tag{3}
$$

where:

erfc() complementary error function
T_d average fade duration

k 0.5 for space diversity
0.5 for 1: 1 frequency diversity
0.75 for 1: N frequency diversity (N > 1)
1.0 for non diversity
d path length in kilometers
f frequency in GHz

The probability of a selective (dispersive) fade lasting longer than t consecutive seconds is given by:

$$\rho_d(t) = \left(1 + 0.85 \cdot \sqrt{t} + 0.36 \cdot t\right) \cdot e^{-0.85\sqrt{t}} \qquad (4)$$

The ITU definition of multipath unavailability is the probability of fades below threshold lasting 10 consecutive seconds or longer. Severely errored seconds represents the probability of all other fades below threshold. i.e fades which last less than 10 consecutive seconds. The unavailability and severely errored seconds probability are given by:

$$\begin{aligned} \mathrm{U}_{\mathrm{ITU}} &= \rho_f \cdot P_f + \rho_d \cdot P_d \\ SES_{ITU} &= \left(1 - \rho_f\right) \cdot P_f + \left(1 - \rho_d\right) \cdot P_d \end{aligned} \qquad (5)$$

Vigants - Barnett

The Vigants - Barnett fade probability (Reference (4) and Reference (5)) is given by:

$$P = 2.5 \cdot 10^{-6} \cdot C \cdot f \cdot d^3 \cdot 10^{-\frac{A}{10}} \quad (1)$$
$$d \text{ in miles}$$

$$\mathrm{P} = 6.0 \cdot 10^{-7} \cdot C \cdot f \cdot d^3 \cdot 10^{-\frac{A}{10}} \quad (2)$$
$$d \text{ in kilometers}$$

where

d path length

f frequency in GHz

C C Factor

A effective fade margin in dB

The following guidelines are given for values of the C factor.

C = 0.25 good propagation conditions - mountainous and dry climates
C = 1 average propagation conditions - average terrain and climatic conditions
C = 4 difficult propagation conditions - over water paths and gulf coastal areas

In areas with very difficult propagation, a value of *C* as high as 6 may be applicable. Figure (8), Figure (9) and Figure (10) provide geographic maps showing typical ranges of the *C* Factor for the United States, Canada and the world respectively. Alternately, the *C* Factor can be calculated from the terrain roughness and a climatic factor, c_f, in accordance with the following formula:

$$
\begin{aligned}
C &= c_f \cdot \left(\frac{S}{50}\right)^{-1.3} \\
&S \quad \text{in} \quad \text{feet} \quad (20 \le S \le 140) \\
C &= c_f \cdot \left(\frac{S}{15.2}\right)^{-1.3} \\
&S \quad \text{in} \quad \text{meters} \quad (6 \le S \le 42)
\end{aligned}
\tag{3}
$$

Typical values for the climatic factor are:

c_f = 0.5 good propagation conditions - mountainous and dry climates
c_f = 1 average propagation conditions - average terrain and climatic conditions
c_f = 2 difficult propagation conditions - over water paths and gulf coastal areas

Terrain Roughness

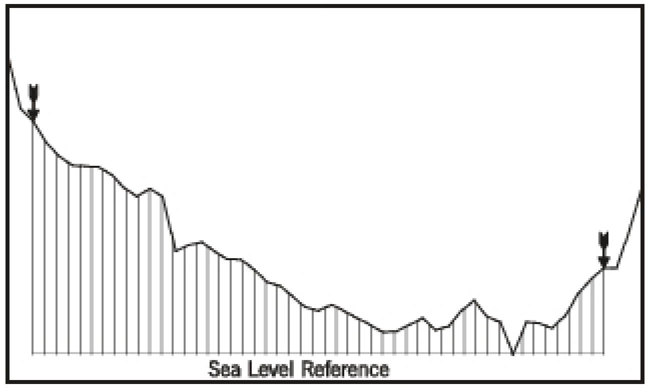


Figure 1: Terrain roughness - sea level reference

Terrain roughness is defined as the standard deviation of the terrain profile (square root of the average square of the deviation from the mean). In Reference (4), terrain elevations are referenced to sea level and are taken at one mile increments excluding the end points of the profile. Other references use a one kilometer increment. In the Pathloss program, terrain roughness is calculated using 50 uniformly spaced points over a user defined range on the profile. The value of terrain roughness is limited to a range between 20 to 140 feet (6 to 42 meters).

Terrain roughness can be calculated with respect to sea level as shown in Figure (1) or with respect to a least squares fit as shown in Figure (2). In both cases, the user must define the end points of the range over which terrain roughness will be calculated. This is similar to the definition of a reflective plane described in the Reflections section of this manual.

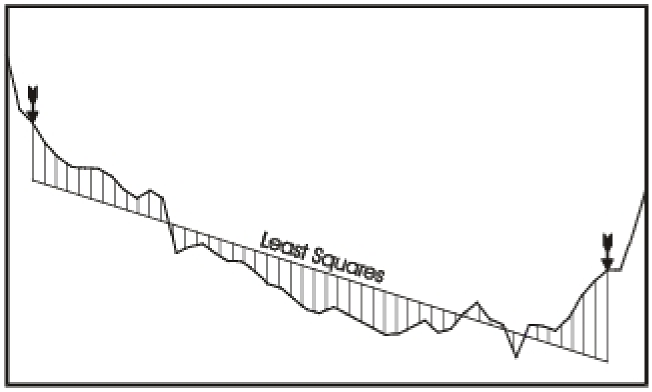


Figure 2: Terrain roughness - least squares refer-

Significant differences will occur on paths with a uniform slope and an elevation difference between the end points greater than 140 feet. If the least squares method is used, the terrain roughness will be the minimum value. If the sea level reference is used, the terrain roughness will be the maximum value. In strict accordance with Reference (4), the elevations should be relative to sea level. This will provide some correlation between the terrain roughness and path inclination. The propagation reliability on a high - low path is better than a flat path. If the elevation difference is in the order of one hundred feet, the least squares reference should be used. The equations used to calculate terrain roughness are given below:

$$S = \sqrt{\frac{1}{50}\sum_{i=1}^{50}\left(x_i - M\right)^2}$$

$$M = \frac{1}{50}\sum_{i=1}^{50} X_i$$

Recommendation ITU-R P.530-6

The following description is essentially taken from paragraph 2.3.2 "Method for detailed link design at small percentages of time (Method 2)" of this report. The fade probability *P*that fade depth A (dB) is exceeded in the worst month from is given by:

$$P = K \cdot d^{3.3} \cdot f^{0.93} \cdot \left(1+\varepsilon_p\right)^{-1.1} \cdot \theta^{-1.2} \cdot 10^{-\frac{A}{10}} \quad \textbf{(1)}$$

K	geoclimatic factor for the worst fading month
d	path length in kilometers
f	frequency in GHz
ε_p	path inclination in milliradians
θ	average grazing angle in milliradians corresponding to a 4/3 earth radius factor
A	effective fade margin in dB

Geoclimatic factor

For the path location in question, estimate the geoclimatic factor *K* for the average worst month from fading data for the area. If such data are not available, *K* can be estimated from the percentage of time P_L that the average refractivity gradient in the lowest 100 m of the atmosphere is less than -100 N units/km. Refer to the contour maps shown in Figure (11), Figure (12), Figure (13) and Figure (14) in this section for values of P_L. The value for the worst month should be used, The geoclimatic factor is then given by:

- overland links for which the lower of the transmitting and receiving antennas is less than 700 m above mean sea level (see Note 2)

$$K = 10^{-(5.4 - C_{lat} - C_{lon})} P_L^{1.5} \quad \textbf{(2)}$$

- overland links for which the lower of the transmitting and receiving antennas is higher than 700 m above mean sea level (see Notes 1 and 2 for links crossing small lakes and rivers)

$$K = 10^{-(6.0 - C_{lat} - C_{lon})} P_L^{1.5} \quad \textbf{(3)}$$

- links over medium-sized bodies of water (see Note 3), coastal areas beside such bodies of water (see Note 4), or regions of many lakes (see Note 5)

$$K = 10^{-(4.8 - C_{lat} - C_{lon})} P_L^{1.5} \quad \textbf{(4)}$$

- links over large bodies of water (see Note 3), or coastal areas beside such bodies of water (see Note 4)

$$K = 10^{-(4.4 - C_{lat} - C_{lon})} P_L^{1.5} \quad \textbf{(5)}$$

where the coefficient C_{Lat} of latitude ξ is given by:

$C_{Lat} = 0$	for 53?S ≥ ξ ≤ 53?N
$C_{Lat} = -5.3 + \xi /10$	for 53?N or S < ξ < 60?N or S
$C_{Lat} = 0.7$	for ξ ≥ 60?N or S

and the longitude coefficient C_{Lon}, by:

$C_{Lon} = 0.3$ for longitudes of Europe and Africa
$C_{Lon} = -0.3$ for longitudes of North and South America
$C_{Lon} = 0$ for all other longitudes

The month that has the highest value of P_L should be chosen for the months of February, May, August and November. An exception to this is that only the maps for May and August should be used for latitudes greater than 60? N or 60? S.

NOTE 1 - In mountainous areas for which the data used to prepare the maps in Figure (11), Figure (12), Figure (13) and Figure (14) (Recommendation ITU-R P.453) were non-existent or very sparse, these maps have insufficient detail and the value of K estimated from Equation (2) tends to be an upper bound. Such areas include the mountainous regions of Western Canada, the European Alps and Japan. The adjustment contained in Equation (3) can be used until a more detailed correction is available.

NOTE 2 - Links passing over a small lake or river should normally be classed as overland links. In cases of uncertainty, replace exponent coefficient 5.4 by 5.1 in Equation (2). (see also Note 4)

NOTE 3 - Medium-sized bodies of water include the Bay of Fundy (east coast of Canada) and the Strait of Georgia (west coast of Canada), the Gulf of Finland, and other bodies of water of similar size. Large bodies of water include the English Channel, the North Sea, the larger reaches of the Baltic and Mediterranean Seas, Hudson Strait, and other bodies of water of similar size or larger. In cases of uncertainty as to whether the size of the body of water in question should be classed as medium or large, the first coefficient in the exponent of Equation (4) or Equation (5) should be replaced by 4.6.

NOTE 4 - The link may be considered to be crossing a coastal area if a section of the path profile is less than 100 m above mean sea level and within 50 km of the coastline of a medium or large body of water, and if there is no height of land above 100 m altitude between the link and the coast. If the entire path profile is less than 100 m above mean sea level, then *K* should be obtained from Equation (4) or Equation (5) as appropriate. If only a fraction, r_c, of the path profile is below 100 m altitude and within 50 km of the coastline, then the coefficient 4.8 in the exponent of Equation (4) can be replaced by 4.8 - 0.6 r_c and the exponent 4.4 in Equation (5) by 5.4 - r_c

NOTE 5 - Regions (not otherwise in coastal areas) in which there are many lakes over a fairly large area are known to behave like coastal areas. The region of lakes in southern Finland provides the best known example. Until such regions can be better defined, *K* can be obtained from Equation (4). In cases of uncertainty, the coefficient 4.8 in the exponent of Equation (4) can be replaced by 5.1.

Geoclimatic factor - Canada

A logarithmic geoclimatic factor, *G*, is used in Canada and is defined by:

$$
\begin{aligned}
G &= 10 \cdot \log(K) + 46 \\
K &= 10^{\frac{G}{10} - 4.6}
\end{aligned}
\qquad \textbf{(6)}
$$

Figure (15) provides a map of *G* for Canada. The following refinements are recommended:

At latitudes above 60 degrees, add 5 dB to the value in Figure (15).

For paths over medium sized bodies of water (Bay of Fundy, Strait of Georgia, Frobisher Bay, Lake Ontario, Lake Erie), add 6 dB to the values in Figure (15). Add 11 dB if the path is above 60 degrees latitude.

For paths over large bodies of water (Hudson Strait, Viscount Melville Sound, Hecate Strait, Cabot Strait, Lake Superior, Lake Huron, Lake Michigan), add 14 dB to the value in Figure (15). Add 19 dB if the path is above 60 degrees latitude.

Path inclination

- The path inclination, ε_p, is given by:

$$1000 \cdot \operatorname{atan}\left(\frac{|h_t - h_r|}{1000 \cdot d}\right) \text{milliradians} \quad \textbf{(7)}$$

h_t transmitter antenna height in meters above sea level
h_r receiver antenna height in meters above sea level
d path length in kilometers

The valid range of the path inclinations is from 0 to 24 milliradians. The program does not impose any restrictions on this value.

Grazing angle

The grazing angle is the angle of incidence or reflection at the reflection point of a reflective plane using an earth radius factor of 4/3. The average grazing angle θ, is determined by first defining the dominant reflective plane for the terrain profile. This plane is represented by a least squares fit, ($y = a?x + b$) over a user defined range of the terrain profile. Effective antenna heights h_1 and h_2, are then calculated from this plane by the equations:

$$\begin{aligned} h_1 &= h_t - b \\ h_2 &= h_r - a \cdot d - b \end{aligned} \quad \textbf{(8}$$

where h_t and h_r are the transmit and receive antenna heights above ground level and d is the path length.

The average grazing angle θ, is given by:

$$
\begin{aligned}
\theta &= \frac{h_1 + h_2}{d} \cdot \left(1 - m \cdot \left(1 + b^2\right)\right) \text{milliradians} \\
\mathrm{m} &= \frac{d^2}{4 \cdot a_e \cdot \left(h_1 + h_2\right)} \\
c &= \frac{\left|h_1 - h_2\right|}{h_1 + h_2} \\
b &= 2\sqrt{\frac{m+1}{3 \cdot m}} \cdot \cos\left[\frac{\pi}{3} + \frac{1}{3} \cdot \arccos\left(\frac{3 \cdot c}{2}\sqrt{\frac{3 \cdot m}{(m+1)^3}}\right)\right]
\end{aligned} \qquad \textbf{(9)}
$$

where

h_1 effective transmitter antenna height
h_2 effective receiver antenna height
a_e effective earth radius (8500 km for K = 4/3)

The coefficients m and c must be calculated with a_e, d, h_1 and h_2 expressed in the same units.

In the calculation of θ, h_1 and h_2 are expressed in meters and d in kilometers to obtain the required value in milliradians. The valid range of average grazing angles is from 1 to 12 milliradians. The program does not impose any limits on this value.

Equation (1) applies only to narrow-band systems. It is considered valid for fade depths greater than about 15 dB or the value exceeded for 0.1% of the worst month, whichever is greater. Equation (1) was derived from fading data paths with lengths in the range 7-95 km, frequencies in the range 2-37 GHz, path inclinations for the range 0-24 mrad, and grazing angles in the range 1-12 mrad. Checks using several other sets of data for paths up to 189 km in length and frequencies as low as 500 MHz suggest, however, that they are valid for larger ranges of path length and frequency. The results of a semi-empirical analysis indicate that the lower frequency limit of validity is inversely proportional to path length. A rough estimate of this lower frequency limit f_{min} can be obtained from:

$$f_{\min} = \frac{15}{d} \text{ GHz} \qquad \textbf{(10)}$$

Recommendation ITU-R P.530-7/8

The following description is essentially taken from paragraph 2.3.1 "Method for small percentages of time" of the subject report. The fade probability P that fade depth A (dB) is exceeded in the average worst month from is given by:

$$P = K \cdot d^{3.6} \cdot f^{0.89} \cdot \left(1+\varepsilon_p\right)^{-1.4} \cdot 10^{-\frac{A}{10}} \qquad \textbf{(1)}$$

K geoclimatic factor for the worst fading month

d path length in kilometers

f frequency in GHz

ε_p path inclination in milliradians

A effective fade margin in dB

Geoclimatic factor

For the path location in question, estimate the geoclimatic factor K for the average worst month from fading data for the geographic area of interest if these are available.

Inland links

If measured data for *K* are not available, *K* can be estimated for links in inland areas (see Note 1 for definition of inland links) from the following empirical relation in the climatic variable P_L (i.e., the percentage of time that the refractivity gradient in the lowest 100 m of the atmosphere is more negative than -100 N units/km in the estimated average worst month; see below):

$$K = 5.0 \cdot 10^{-7} \cdot 10^{-0.1(C_0 - C_{lat} - C_{lon})} P_L^{1.5} \qquad \textbf{(2)}$$

Table 1: Values of C_o for Antenna Altitudes and Terrain Types

Terrain Characteristics	***C_0(dB)***
Low altitude antenna (0 - 400 m) - Plains Overland or partially overland links, with lower antenna altitude less than 400 m above mean sea level, located in largely plains areas	0.0
Low altitude antenna (0 - 400 m) - Hills Overland or partially overland links, with lower antenna altitude less than 400 m above mean sea level, located in largely hilly areas	3.5
Medium altitude antenna (400 - 700 m) - Plains Overland or partially overland links, with lower antenna altitude in the range 400 - 700 m above mean sea level, located in largely plains areas	2.5
Medium altitude antenna (400 - 700 m) - Hills Overland or partially overland links, with lower antenna altitude in the range 400 - 700 m above mean sea level, located in largely hilly areas	6.0
High altitude antenna (> 700 m) - Plains Overland or partially overland links, with lower antenna altitude more than 700 m above mean sea level, located in largely plains areas	5.5
High altitude antenna (> 700 m) - Hills Overland or partially overland links, with lower antenna altitude more than 700 m above mean sea level, located in largely hilly areas	8.0
High altitude antenna (> 700 m) - Mountains Overland or partially overland links, with lower antenna altitude more than 700 m above mean sea level, located in largely mountainous areas	10.5

The value of the coefficient C_0 in Equation (2) is given in Table 1 for three ranges of altitude of the lower of the transmitting and receiving antennas and three types of terrain (plains, hills, or mountains). In cases of uncertainty as to whether a link should be classified as being in a plains or hilly area, the mean value of the coefficients C_0 for these two types of area should be employed. Similarly, in cases of uncertainty as to whether a link should be classified as being in a hilly or mountainous area, the mean value of the coefficients C_0 for these two types of area should be employed. Links traversing plains at one end and mountains at the other should be classified as being in hilly areas. For the purposes of deciding whether a partially over water path is in a largely plains, hilly, or mountainous area, the water surface should be considered as a plain.

For planning purposes where the type of terrain is not known, the following values of the coefficient C_0 in Equation (2) should be employed:

C_0 = 1.7	for lower-altitude antenna in the range 0-400 m above mean sea level
C_0 = 4.2	for lower-altitude antenna in the range 400-700 m above mean sea level
C_0 = 8	for lower-altitude antenna more than 700 m above mean sea level

The coefficient C_{Lat} in Equation (2) of latitude ξ is given by:

C_{Lat} = 0	for 53?S ≥ ξ ≤ 53?N
C_{Lat} = -53 + ξ	for 53?N or S < ξ < 60?N or S
C_{Lat} = 7	for ξ ≥ 60?N or S

and the longitude coefficient C_{Lon}, by:

$C_{Lon} = 3$ for longitudes of Europe and Africa
$C_{Lon} = -3$ for longitudes of North and South America
$C_{Lon} = 0$ for all other longitudes

The value of the climatic variable P_L in Equation (2) is estimated by taking the highest value of the -100 N units/km gradient exceedance from the maps for the four seasonally representative months of February, May, August and November shown in Figure (11), Figure (12), Figure (13) and Figure (14). These correspond to Figures 7-10 of Recommendation ITU-R P.453. An exception to this is that only the maps for May and August should be used for latitudes greater than 60? N or 60? S.

Coastal links over/near large bodies of water

If measured data for K are not available for coastal links (see Note 2 for definition) over/near large bodies of water (see Note 3 for definition of large bodies of water), K can be estimated from:

$$\begin{aligned}
K_{cl} &= 2.3\cdot 10^{-4}\cdot 10^{-0.1 C_0 - 0.011|\varepsilon|} \\
\textit{if} \quad & K_{cl} \geq K_i \\
K &= 10^{(l-r_c)\cdot\log_{10}(K_i)+r_c\cdot\log_{10}(K_{cl})} \\
\textit{if} \quad & K_{cl} < K_i \\
K &= K_i
\end{aligned} \qquad \textbf{(3)}$$

where r_c is the fraction of the path profile below 100 m altitude above the mean level of the body of water in question and within 50 km of the coastline, but without an intervening height of land above 100 m altitude, K_i is given by the expression for K in Equation (2) with C_0 given in Table 1. Note that the condition $K_{cl} < K_i$ in Equation (3) occurs in a few regions at low and mid latitudes.

Coastal links over/near medium sized bodies of water

If measured data for *K* are not available for coastal links (see Note 2 for definition) over/near medium-sized bodies of water (see Note 3 for definition of medium-sized bodies of water), *K* can be estimated from:

$$
\begin{aligned}
K_{cm} &= 10^{0.5\cdot(\log_{10}(K_i)+\log_{10}(K_{cl}))} \\
\mathit{if} \quad & K_{cm} \geq K_i \\
K &= 10^{(1-r_c)\cdot\log_{10}(K_i)+r_c\cdot\log_{10}(K_{cm})} \\
\mathit{if} \quad & K_{cl} < K_i \\
K &= K_i
\end{aligned}
\qquad \textbf{(4)}
$$

with K_{cl} given by Equation (3). Note that the condition $K_{cm} < K_i$ in Equation (4) occurs in a few regions at low and mid latitudes.

NOTE 1 - Inland links are those in which either the entire path profile is above 100 m altitude (with respect to mean sea level) or beyond 50 km from the nearest coastline, or in which part or all of the path profile is below 100 m altitude for a link entirely within 50 km of the coastline, but there is an intervening height of land higher than 100 m between this part of the link and the coastline. Links passing over a river or a small lake should normally be classed as passing over land. For links in a region of many lakes, see Note 4.

NOTE 2 - The link may be considered to be crossing a coastal area if a fraction rc of the path profile is less than 100 m above the mean level of a medium-sized or large body of water and within 50 km of its coastline, and if there is no height of land above the 100 m altitude (relative to the mean altitude of the body of water in question) between this fraction of the path profile and the coastline.

NOTE 3 - The size of a body of water can be chosen on the basis of several known examples: Medium-sized bodies of water include the

Bay of Fundy (east coast of Canada) and the Strait of Georgia (west coast of Canada), the Gulf of Finland, and other bodies of water of similar size. Large bodies of water include the English Channel, the North Sea, the larger reaches of the Baltic and Mediterranean Seas, Hudson Strait, and other bodies of water of similar size or larger. In cases of uncertainty as to whether the size of body of water in question should be classed as medium or large, *K* should be calculated from:

$$K = 10^{(l-r_c)\cdot\log_{10}(K_i)+0.5\cdot r_c\cdot(\log_{10}(K_{cm})+\log_{10}(K_{cl}))} \quad \textbf{(5)}$$

NOTE 4 - Regions (not otherwise in coastal areas) in which there are many lakes over a fairly large area are believed to behave somewhat like coastal areas. The region of lakes in southern Finland provides the best known example. Until such regions can be better defined, *K* should be calculated from:

$$K = 10^{0.5\left[(2-r_c)\log K_i + r_c \log K_{cm}\right]} \quad \textbf{(6)}$$

Path inclination

From the antenna heights h_t and h_r (m above sea level or some other reference height), calculate the magnitude of the path inclination $|\varepsilon_p|$ (mrad) from:

$$\varepsilon = 1000\cdot\operatorname{atan}\left(\frac{|\mathrm{h}_t - h_r|}{1000\cdot d}\right)\text{milliradians} \quad \textbf{(7)}$$

where *d*, is the path length (km).

Equation (1) was derived from fading data on paths with lengths in the range 7-95 km, frequencies in the range 2-37 GHz, path inclinations for the range 0-24 mrad, and grazing angles in the range 1-12 mrad. Checks using several other sets of data for paths up to 237 km in length and frequencies as low as 500 MHz suggest, however, that it is valid for larger ranges of path length and frequency. The results of a semi-empirical analysis indicate that the lower frequency limit of validity is inversely proportional to path length. A rough estimate of this lower frequency limit, f_{min}, can be obtained from:

$$f_{min} = \frac{15}{d} \text{ GHz} \qquad \textbf{(8)}$$

Recommendation ITU-R P.530-9/10/11/12

The ITU-R P.530-9 prediction for single frequency or narrow band fading distribution at large fade depths in the average worst month in any part of the world is defined in the following steps. Note that only the detailed link design method has been implemented in the Pathloss program

Step 1

Calculate the geoclimatic factor *K* for the average worst month from Equation (1) below

$$K = 10^{-3.9-0.003dN_1} \cdot s_a^{-0.42} \qquad (1)$$

where

dN_1 is the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year. Data for dN_1 is provided on a 1.5 grid in latitude and longitude in Recommendation ITU-R P.453. This data has been incorporated into the Pathloss program. The value at the latitude and longitude of the centre of the path is determined by bilinear interpolation of the four closest grid points.

s_a is the area terrain roughness. This is defined as the standard deviation of terrain heights (m) within a 110 km by 110 km area with a 1 kilometer resolution. The area is aligned about the center of the path.

Step 2

Calculate the path inclination ε_p using equation Equation (2) below

$$\varepsilon_p = \left| \operatorname{atan} \frac{h_r - h_e}{d \cdot 1000} \right| \tag{2}$$

where

h_r and h_e antenna heights in meters above sea level
d path length in kilometers

Step 3

For detailed link design applications, calculate the percentage of time p_W that fade depth A (dB) is exceeded in the average worst month from Equation (3)

$$p_w = K \cdot d^{3.2} \cdot \left(1 + \left|\varepsilon_p\right|\right)^{-0.97} \cdot 10^{0.032 f - 0.00085 h_L - \frac{A}{10}} \tag{3}$$

where

f frequency in GHz
h_L altitude of the lower antenna (i.e. the smaller of h_r and h_e)
K geoclimatic factor from Equation (1)

KQ factor

The fade probability (Reference (2)) is given by:

$$P = K \cdot Q \cdot f^{b} \cdot d^{c} \cdot 10^{-\frac{A}{10}} \quad \textbf{(1)}$$

d path length in kilometers
f frequency in GHz
b, c factors to account for regional effects
A effective fade margin in dB

Typical values of *KQ* and the frequency - distance exponents *b* and *c* are given in Table 1.

Table 1: KQ Factors

		Japan	N.W. Europe	USSR
b(f^b)		1.2	1.0	1.5
c(d^c)		3.5	3.5	2.0
K-Q	maritime temperature, Mediterranean, coastal or high humidity and temperature climatic regions			$2 \cdot 10^{-5}$
	continental temperature climates or mid latitude inland climatic regions with	10^{-9}	$1.4 \cdot 10^{-8}$	$4.1 \cdot 10^{-6}$

	average rolling terrain			
	temperature climates, coastal regions with fairly flat terrain	$9.9 \cdot 10^{-8} / H$		$2.3 \cdot 10^{-5}$ to $4.9 \cdot 10^{-5}$

(2) $$H = \sqrt{h_1 + h_2}$$

h_1 and h_2 are the antenna heights in meters above ground level

K-Q Factor including terrain roughness

The fade probability (Reference (2)) is given by:

$$P = \frac{K \cdot Q}{S^{1.3}} \cdot f^{b} \cdot d^{c} \cdot 10^{-\frac{A}{10}} \qquad (1)$$

d path length in kilometers

f frequency in GHz

S terrain roughness in meters

A effective fade margin in dB

Table 1 shows typical values of the K-Q factors using frequency and distance exponents of 1 and 3 respectively. This is equivalent to the Vigants Barnett method described above.

Table 1: K-Q Factors Including Terrain Roughness

$b(f^{b})$		1.0
$c(d^{c})$		3.0
KQ	maritime temperate, Mediterranean, coastal or high humidity and temperature climatic regions	$4.1\,10^{-5} S^{-1.3}$

	maritime subtropical climate regions	$3.110^{-5}S^{-1.3}$
	continental temperate climates or mid latitude inland climatic regions with average rolling terrain	$2.110^{-5}S^{-1.3}$
	high dry mountainous climatic regions	$10^{-5}S^{-1.3}$

S is the terrain roughness in meters ($6 < S < 42$)

Fade probability for small fade margins

The multipath fade probability algorithms presented in the previous paragraphs are applicable for small time percentages which corresponds to large fade margins. This section is taken from paragraph 2.3.2 of ITU-R P.530-11

The method given below for predicting the percentage of time that any fade depth is exceeded combines the deep fading distribution given in the preceding section and an empirical interpolation procedure for shallow fading down to 0 dB.

Step 1: Calculate the fade probability (multipath occurrence factor, *P* (i.e., the intercept of the deep-fading distribution with the percentage of time-axis):

Step 2: Calculate the value of fade depth, A_t, at which the transition occurs between the deep-fading distribution and the shallow-fading distribution as predicted by the empirical interpolation procedure:

$$A_t = 25 + 1.2\log_{10}(P) \quad \textbf{(1)}$$

The procedure now depends on whether *A* is greater or less than A_t.

Step 3a: If the required fade depth, *A*, is equal to or greater than A_t:

Calculate the percentage of time that *A* is exceeded in the average worst month:

$$P_w = P \times 10^{-\frac{A}{10}} \quad \textbf{(2)}$$

Step 3b: If the required fade depth, *A*, is less than A_t:

Calculate the percentage of time, P_t, that A_t is exceeded in the average worst month:

$$P_t = P \times 10^{-\frac{A_t}{10}} \quad \textbf{(3)}$$

Calculate q'_a from the transition fade A_t and transition percentage time P_t:

$$q'_a = -20 \log_{10}\left(-\ln\left(\frac{100-P_t}{100}\right)\right) \Big/ A_t \quad \textbf{(4)}$$

Calculate q_t from q'_a and the transition fade A_t:

$$q_t = \left(q'_a - 2\right) \Big/ \left[\left(1+0.3\times10^{-A/20}\right)10^{-0.016A}\right] - 4.3\left(10^{A/20} + A/800\right) \quad \textbf{(5)}$$

Calculate q_a from the required fade A:

$$q_a = 2 + \left[1+0.03\times10^{-A/20}\right]\left[10^{-0.016A}\right]\left[q_t + 4.3\left(10^{A/20} + A/800\right)\right] \quad \textbf{(6)}$$

Calculate the percentage of time, P_w, that the fade depth A (dB) is exceeded in the average worst month:

$$P_w = 100\left[1-\exp\left(10^{-q_a A/20}\right)\right]\% \quad \textbf{(7)}$$

Frequency diversity

North American Standards

The frequency diversity improvement factor, I_{fd}, is based on Reference (4) and given by:

$$
\begin{aligned}
I_{fd} &= 50 \cdot \frac{\Delta f}{f^2 \cdot d} \cdot 10^{\frac{A}{10}} \\
&\text{d in miles} \\
I_{fd} &= 80.5 \cdot \frac{\Delta f}{f^2 \cdot d} \cdot 10^{\frac{A}{10}} \\
&\text{d in kilometers}
\end{aligned}
\tag{1}
$$

Df effective frequency spacing in GHz

f frequency in GHz

d path length

A effective fade margin in dB

Equation (1) is applicable to analogue, narrow band digital and wide band digital radio systems. The fade probability for a frequency diversity system, P_{fd}, is given by:

$$P_{fd} = \frac{P}{I_{fd}} \tag{2}$$

The above applies to a one for one frequency diversity system. In the case of a one for *N* switching system, the equivalent channel spacing as defined in Reference (6) must be used as follows:

$$\Delta f = \frac{N}{\sum_k \left(\frac{1}{\Delta f_k} \right)} \tag{3}$$

Note that the above factors are the same for selective and non selective fades.

ITU 530 Frequency Diversity

The non selective frequency diversity improvement is essentially the same as the North American formula:

$$I_{fdns} = \frac{80}{f \cdot d} \cdot \frac{df}{f} \cdot 10^{\frac{A}{10}} \tag{4}$$

The ITU method calculates the selective outage exactly as in the case of space diversity described in the following paragraphs using $I_{comb} = 0$ and $L_{comb} = 1$.

Space diversity - baseband switching

The space diversity improvement factor, I_{sd}, is based on Reference (4) and given by:

$$
\begin{aligned}
I_{sd} &= 7 \cdot 10^{-5} \cdot \frac{f}{d} \cdot s^2 \cdot v^2 \cdot 10^{\frac{A}{10}} \\
& \quad \text{s in feet} \\
& \quad \text{d in miles} \\
I_{sd} &= 1.2 \cdot 10^{-3} \cdot \frac{f}{d} \cdot s^2 \cdot v^2 \cdot 10^{\frac{A}{10}} \\
& \quad \text{s in meters} \\
& \quad \text{d in kilometers} \\
v_{dB} &= 20 \cdot \log(v)
\end{aligned}
\tag{1}
$$

s vertical spacing of the receiving antennas
f frequency in GHz
d path length
v_{dB} difference between the main and diversity received signals in dB

The fade probability P_{sd}, for space diversity systems is given by:

$P_{sd} = \frac{P}{I_{sd}}$ Experience with space diversity on wide band digital radio systems has led to the following observations:

- The space diversity improvement factor, for the dispersive component of the fade margin, is independent of the vertical antenna separation for spacings greater than 10 feet. As the antenna separation is reduced below 10 feet, the improvement factor increases rapidly.
- The space diversity improvement factor for the dispersive component of the fade margin can be equated to a fixed value of vertical antenna spacing.

- The space diversity improvement factor for the flat component of the fade margin is proportional to the square of the antenna separation.
- To account for these observations, two methods are used to calculate the space diversity improvement factor as currently used by two major microwave radio manufacturers.

Method 1 (Nortel)

The fade probability is expressed in general terms as follows:

$$
\begin{aligned}
P &\propto 10^{-\frac{A}{10}} \\
I_{sd} &\propto s^2 \cdot 10^{\frac{A}{10}} \\
P_{sd} &\propto \left(\frac{10^{-\frac{A}{10}}}{s} \right)^2 \\
{}_{sd} &\propto \left(\frac{10^{-\frac{A_f}{10}}}{s} + \frac{R_d \cdot 10^{-\frac{A_d}{10}}}{s} \right)^2
\end{aligned}
\qquad (2)
$$

The vertical antenna spacing, *s*, is replaced with a fixed value s_d for the dispersive component. The default value of s_d is 8.5 meters based on Reference (7). The result is given below:

$$
P_{sd} \propto \left(\frac{10^{-\frac{A_f}{10}}}{s} + \frac{R_d \cdot 10^{-\frac{A_d}{10}}}{s_d} \right)^2 \qquad (3)
$$

Method 2 Alcatel (USA)

This method treats the flat and dispersive components separately as shown below:

$$
\begin{aligned}
P_{sd} &= \frac{P_f}{I_{sd\_flat}} + \frac{P_d}{I_{sd\_disp}} \\
I_{sd\_disp} &= 0.09 \cdot \frac{f}{d} \cdot 10^{\frac{A_d}{10}}
\end{aligned}
\qquad (4)
$$

where:

I_{sd_flat} is given by Equation (1)
f frequency in GHZ
d path length in miles

Space diversiy - IF combining

In an IF combining system, the main and diversity received signals are combined in an intermediate frequency combiner. In this configuration, the combined thermal fade margin, A_c, is given by:

$$\begin{aligned} A_c &= A_t + 2.6 + 20 \cdot \log\left(\frac{l+v}{2}\right) \\ v_{dB} &= 20 \cdot \log(v) \end{aligned} \quad (1)$$

where:

A_t greater of the main and diversity thermal fade margins
v_{dB} difference between the main and diversity received signals in dB

In this case, the flat fade margin, A, becomes:

$$A = -10 \cdot \log\left(10^{-\frac{A_c}{10}} + 10^{-\frac{A_{ac}}{10}} + 10^{-\frac{A_{ex}}{10}}\right) \quad (2)$$

To account for the effects of IF combining, the space diversity improvement factor given in Equation (55) is modified as follows:

$$I_{sd} = 7 \cdot 10^{-5} \cdot \frac{f}{d} \cdot s^2 \cdot \frac{16 \cdot v^2}{(1+v)^4} \cdot 10^{\frac{A}{10}}$$

s in feet
d in miles

$$I_{sd} = 1.2 \cdot 10^{-3} \cdot \frac{f}{d} \cdot s^2 \cdot \frac{16 \cdot v^2}{(1+v)^4} \cdot 10^{\frac{A}{10}} \quad (3)$$

s in meters
d in kilometers

$$v_{dB} = 20 \cdot \log(v)$$

s vertical antenna spacing

f frequency in GHz

d path length

v_{db} difference between the main and diversity received signals in dB

As in the case of space diversity on baseband switching systems, the independence of the dispersive component of the fade margin to the vertical antenna spacing is accounted for by the methods given above.

ITU 530 frequency diversity

The non selective frequency diversity improvement is essentially the same as the North American formula:

$$I_{fdns} = \frac{80}{f \cdot d} \cdot \frac{df}{f} \cdot 10^{\frac{A}{10}} \qquad (1)$$

The ITU method calculates the selective outage exactly as in the case of space diversity described in the following paragraphs using $I_{comb} = 0$ and $L_{comb} = 1$.

ITU space diversity

The non selective space diversity improvement factor is given by:

$$I_{sdns} = \left[1-\exp\left(-3.34\cdot 10^{-4}\cdot S^{0.87}\cdot f^{-0.12}\cdot d^{0.48}\cdot P_o^{-1.04}\right)\right]\cdot 10^{\frac{A-dG+I_{comb}}{10}} \qquad (1)$$

where

P_0 fade occurrence factor

dG absolute value of the difference of the main and diversity antenna gains

A flat fade margin

S vertical separation between main and diversity antennas (m center to center)

d path length (km)

I_{comb} IF combiner gain dB (0 for baseband switching applications)

The selective outage probability is calculated as follows:

Calculate the square of the non selective correlation coefficient, k_{ns}

$$K_{ns}^2 = 1-\frac{I_{ns}\cdot P_{ns}}{n} \qquad (2)$$

where

I_{ns} non selective space diversity improvement factor

P_{ns} probability of a non selective outage

n multipath activity factor

Calculate the square of the selective correlation coefficient, k_S

$$
\begin{aligned}
k_s^2 &= 0.8238 \quad \text{for} \quad r_w \le 0.5 \\
k_s^2 &= 1 - 0.195 \cdot (l - r_w)^{0.109 - 0.13 \cdot \log_{10}(l - r_w)} \ \text{for} \quad 0.5 < r_w \le 0.9628 \\
k_s^2 &= 1 - 0.3957 \cdot (l - r_w)^{0.5136} \ \text{for} \quad r_w > 0.9628 \\
r_w &= 1 - 0.9746 \cdot \left(1 - k_{ns}^2\right)^{2.170} \ \text{for} \quad k_{ns}^2 \le 0.26 \\
r_w &= 1 - 0.6921 \cdot \left(1 - k_{ns}^2\right)^{1.034} \ \text{for} \quad k_{ns}^2 \le 0.26
\end{aligned}
\tag{3}
$$

The non selective outage probability is given by:

$$p_{sdns} = \frac{P_{ns}}{I_{sdns}} \tag{4}$$

The selective outage probability is given by:

$$P_{sds} = \frac{\left(\dfrac{P_s}{L_{comb}}\right)^2}{n \cdot \left(1 - k_s^2\right)} \tag{5}$$

where *comb* is the selective improvement factor due to the combiner.

The total outage probability is then given by:

$$P_{sd} = \left(P_{sdns}^{0.75} + P_{sds}^{0.75}\right)^{1.33} \tag{6}$$

ITU Quad Diversity Improvement

The non selective quad diversity improvement factor is the sum of the space and frequency diversity factors:

$$I_{qdns} = I_{sdns} + I_{fdns} \tag{1}$$

The square of the non selective correlation coefficient is given by:

$$K_{ns} = K_{nssd} \cdot k_{nsfd} \tag{2}$$

The selective outage is calculated exactly as in the case of space diversity using

$$I_{comb} = 0 \ and \ L_{comb} = 1 \tag{3}$$

for baseband switching applications.

Angle diversity

Angle diversity can be specified at either or both sites using a space diversity antenna configuration. Angle diversity cannot be combined with hybrid diversity. The implementation of angle diversity is based on the following observations:

- For antenna separations greater than 10 feet, the dispersive fading improvement factor is independent of the spacing. As the spacing is reduced below 10 feet, the improvement factor increases rapidly.
- Large improvement factors to dispersive fading occur when the main and diversity antennas are mounted next to each other, with the antennas slightly offset from each other horizontally.
- Angle diversity antennas approximate the above arrangement and achieve large dispersive improvement factors.
- The improvement to the flat component of the fade margin with angle diversity is not clear at present.

Angle diversity improvement is calculated by assigning a fixed vertical antenna spacing of 9.1 meters (30 feet). The angle diversity improvement for the flat fade margin is ten percent of the value calculated for conventional space diversity up to a maximum of 20. The angle diversity improvement for the dispersive fade margin is the same as that for conventional space diversity.

Free space path loss

The free space path loss between two isotropic radiators is given by the equation:

$$A = 92.4 + 20 \cdot \log(f) + 20 \cdot \log(d)\ dB \tag{1}$$

f frequency in GHz

d path length in kilometers

$$A = 96.6 + 20 \cdot \log(f) + 20 \cdot \log(d)\ dB \tag{2}$$

f frequency in GHz *d* path length in miles

If a path profile exists, the path length is calculated as the slant distance d_S shown in Equation (3).

$$\begin{aligned} d_s &= \sqrt{e_1^2 + e_2^2 - 2e_1e_2\cos(\Theta)} \\ e_1 &= h_1 + Kr_e \\ e_2 &= h_2 + Kr_e \\ \Theta &= \frac{d_p}{Kr_e} \end{aligned} \tag{3}$$

where

$h_{1/2}$ antenna heights above sea level

K earth radius factor

r_e earth radius d_p path length taken from the path profile

Atmospheric absorption

Atmospheric Absorption is the sum of the specific absorption of oxygen and water vapour and is based on Reference (9).

Oxygen Absorption

The specific attenuation of oxygen, g_O, is given by the equation:

$$\gamma_0 = \left[7.19 \cdot 10^{-3} + \frac{6.09}{f^2 + 0.227} + \frac{4.81}{(f-57)^2 + 1.50}\right] \cdot f^2 \cdot 10^{-3}\ dB/km$$

$$\text{for } f < 57GHz \tag{1}$$

$$\gamma_0 = \left[3.79 \cdot 10^{-7} + \frac{0.265}{(f-63)^2 + 1.59} + \frac{0.028}{(f-118)^2 + 1.47}\right] \cdot (f+198)^2 \cdot 10^{-3}\ dB/km$$

$$\text{for } f > 63GHz$$

where:

f frequency in GHz

Note that in the frequency range 57 to 63 GHz, Equation (1) is not defined due to the complicated spectrum structure which is height dependant. The program coding provides a uniform transition in this range with an attenuation of 15 dB /km at 60 GHz.

Water Vapour

The specific attenuation of water vapour, g_W, is given by the equation:

$$\gamma_w = \left[0.067 + \frac{3}{(f-22.3)^2 + 7.3} + \frac{9}{(f-183.3)^2 + 6} + \frac{4.3}{(f-323.8)^2 + 10}\right] \cdot f^2 \cdot \rho \cdot 10^{-4}\, dB/km \qquad (2)$$

for $f < 350 GHz$ and $\rho < 12 \frac{g}{m^3}$

where:

f frequency in GHz

r water vapour density in gm / m ^{3} at ground level and at a temperature of 15C.

Cochannel Operation

This paragraph describes the procedure to calculate the threshold degradation due to the cross polarized discrimination on radio links operating in a cochannel mode. The XPD will degrade under multipath fading and high intensity rain conditions.

XPD Degradation due to Multipath

The following 5 steps summarize the procedure given in ITU-R P.530.

Step 1. Calculate

$$\begin{aligned} XPD_0 &= XPD_g + 5 \ \ for\ XPD_g \leq 35 \\ XPD_0 &= 40 \ \ for\ XPD_g > 35 \end{aligned} \qquad (1)$$

where

XPD_g is the minimum value of the transmit and receive antenna *XPD* is measured on the boresight.

Step 2. Calculate the multipath activity parameter

$$\eta = 1 - e^{-0.2 \cdot P_0^{0.75}} \qquad (2)$$

where

P_0 is the multipath occurrence factor corresponding to the percentage of time that a fade greater than *0 dB* occurs in the average worst month.

Step 3. Calculate

$$Q = 10 \cdot \log_{10}\left(\frac{K_{XP} \cdot \eta}{P_0}\right) \tag{3}$$

where

$$K_{XP} = 0.7 \text{ for one transmit antenna} \tag{4}$$

$$K_{XP} = 1 - 0.3 \cdot \exp\left[-4 \cdot 10^{-6} \cdot \left(\frac{s_t}{\lambda}\right)^2\right] \text{for two transmit antennas} \tag{5}$$

S_t is the vertical separation between antennas and l is the carrier wavelength in meters.

Step 4. Calculate

$$C = XPD_0 + Q \tag{6}$$

Step 5 Calculate the probability of outage P_{XP} due to clear-air cross-polarization from

$$P_{xp} = P_o \cdot 10^{-\frac{M_{XPD}}{10}} \quad (7)$$

where

$$M_{XPD} = C - \frac{C_o}{I} + XPIF \quad (8)$$

Here, C_0 / I is the carrier-to-interference ratio for a reference BER, which can be evaluated either from simulations or from measurements.

XPIF is a laboratory-measured cross-polarization improvement factor that gives the difference in cross-polar isolation (XPI) at sufficiently large carrier-to-noise ratio (typically 35 dB) and at a specific BER for systems with and without cross polar interference canceller (XPIC). A typical value of XPIF is about 20 dB.

The specific implementation of Step 5 in the Pathloss program is given below using the methods used by Siemens Network Systems.

The carrier to cochannel interference ratio is given by:

$$\frac{C_0}{I_{coch\,mpth}} = -10 \cdot \log_{10}\left(10^{-\frac{XPD_{GTS}}{10}} + 10^{-\frac{XPD_{GRX}}{10}} + 10^{-\frac{(C\text{-}A)}{10}}\right) + 2 \quad (9)$$

for radios not equipped with an XPIC device and by the following equation for XPIC equipped radios.

$$\frac{C_0}{I_{coch\,mpth}} = -10 \cdot \log_{10}\left(10^{-\frac{XPD_{xpic}}{10}} + 10^{-\frac{XPD_{GTX}+XPIF}{10}} + 10^{-\frac{XPD_{GRX}+XPIF}{10}} + 10^{-\frac{(C+XPIF-A)}{10}}\right) \quad (10)$$

where

XPIF	improvement due to the XPIC device (dB)
XPD_G	cross polarized discrimination of the antennas (dB)
XPD_{xpic}	XPD of the XPIC device (dB). This term is not included for XPIC devices implemented in software

A fade margin including the effects of interference due to other transmitters (dB)

The 2 dB improvement in the non XPIC case is due to the Gaussian properties of the interfering crosspolar signal. This figure is included in the XPIF for XPIC equipped radios.

The interfering signal level due to the XPD degradation by multipath is then given by:

$$I_{coch\,mpth} = RX_{threshold} - \frac{C_0}{I_{coch\,mpth}} \tag{11}$$

This interfering signal level is used to calculate the threshold degradation and the cochannel fade margin.

XPD Degradation due to Rain

The XPD reduction factor due to high intensity rain is given by the equation:

$$\begin{aligned} XPD_{RAIN} &= 15 + 30 \cdot \log_{10}(f_{GHz}) - 12.8 \cdot f_{GHz}^{0.19} \cdot \log_{10}(A) \text{ for } f_{GHz} \leq 20GHz \\ XPD_{RAIN} &= 15 + 30 \cdot \log_{10}(f_{GHz}) - 22.6 \cdot \log_{10}(A) \text{ for } f_{GHz} > 20GHz \end{aligned} \tag{12}$$

The implementation in the Pathloss program follows the methodology used for multipath. The cross polarized signal is considered to be an interfering signal which degrades the receiver threshold. This is calculated as:

The corresponding carrier to cochannel interference ratio is then given by:

$$\frac{C_0}{I_{coch\,rain}} = -10 \cdot \log_{10}\left(10^{-\frac{XPD_{GTX}}{10}} + 10^{-\frac{XPD_{GRX}}{10}} + 10^{-\frac{XPD_{RAIN}}{10}}\right) + 2$$
$$\frac{C_0}{I_{coch\,rain}} = -10 \cdot \log_{10}\left(10^{-\frac{XP_{xpic}}{10}} + 10^{-\frac{XP_{GTX}+XPIF}{10}} + 10^{-\frac{XPD_{GRX}+XPIF}{10}} + 10^{-\frac{XPD_{RAIN}+XPIF}{10}}\right) \quad (13)$$

where the parameters are the same as those defined above for the multipath case.

ITU-T G.826 error performance objectives

ITU-T G.826 defines performance of SDH radio systems in terms of the following parameters.

- Severely Errored Seconds Radio (*SESR*)
- Background Block Error Rate (*BBER*)
- Errored Seconds Ratio (*ESR*)

This section describes the Pathloss implementation of this recommendation.

SESR Bit Error Rate

A modified bit error rate is first determined as follows:

$$BER_{SES} = \frac{0.458 \cdot a_1}{\text{bits per block}} \quad \textbf{(1)}$$

Table 1: BERses for various SDH paths and MS sections

Path type	***Bit rate***	***BERses (Notes 1 and 2)***	***Block per second (Note 2)***	***Bits per Block (Note 2)***
VC-11	1.5	5.4 ? $10^{-4}\alpha$	2000	832
VC-12	2	4.0 ? $10^{-4}\alpha$	2000	1120
VC-2	6	1.3 ? $10^{-4}\alpha$	2000	3424
VC-3	34	6.5 ? $10^{-5}\alpha$	8000	6120
VC-4	140	2.1 ? $10^{-5}\alpha$	8000	18792
STM-1	155	2.3 ? $10^{-5}\alpha$ 1.3 ? $10^{-5}\alpha$ + 2.2	8000 192000	19940 801

NOTE 1 - α = 1 indicates a Poisson distribution of errors.

NOTE 2 - The block/s are defined in ITU-T G.826 for SDH path, in ITU-T G.829 for SDH sections. Some STM-1 equipment might be designed with 8000 blocks/s (19940 bits/block), but ITU-T G.829 defines the block rate and size to be 192000 blocks/s and 801 bits/block, respectively.

The value of the BER_{SES} will lie between the 10^{-3} and 10^{-6} *BER*. Determine the RX threshold level at the BER_{SES} as follows:

$$
\begin{aligned}
m &= \frac{RXthreshold_{BER10^{-3}} - RXthreshold_{BER10^{-6}}}{3} \\
RXthreshold_{BER_{SES}} &= RXthreshold_{BER10^{-6}} + m \cdot \left(\log_{10}\left(BER_{SES}\right) + 6\right)
\end{aligned}
\qquad \textbf{(2)}
$$

Multipath

The severely errored seconds ratio is the worst month multipath fade probability at the BER_{SES} receiver threshold.

$SESR = P_{tSES} = P_t(BER_{SES})$ Determine the fade probability in the worst month at the residual bit error rate receive threshold level. The residual BER (*RBER*) is in the range from 1 ? 10^{-10} to 1 ? 10^{-13}.

$P_{tR} = P_t(RBER)$

Calculate the slope of the BER distribution curve on a log - log scale for BER in the range BER_{SES} to *RBER*

$$
m = \left| \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(P_{tR}) - \log_{10}(P_{tSES})} \right| \qquad \textbf{(3)}
$$

The background block error rate (*BBER*) is then given by:

$$BBER = SESR \cdot \frac{\alpha_1}{2.8 \cdot \alpha_2 \cdot (m-1)} + \frac{N_B \cdot RBER}{\alpha_3} \quad \textbf{(4)}$$

where

α_1	10 to 30, number of errors per burst for the BER in the range from 1_10^{-3} to BER_{SES}
α_2	1, number of errors per burst for the BER lower than *RBER*
α_3	1 to 10, number of errors per burst for the BER in the range from BER_{SES} to *RBER*
N_B	number of bits per block from the above table

The errored second ratio (*ESR*) is given by:

$$ESR = SESR + \sqrt[m]{n} + \frac{n \cdot N_B \cdot RBER}{\alpha_3} \quad \textbf{(5)}$$

where *n* is the number of blocks per second from the above table.

Rain

Calculate the unavailability due to rain, P_{aR} in the worst month at the BER_{SES} receiver threshold level. The BBER and ESR values for rain are obtained by substituting P_{aR} for SESR in the multipath calculation.

Effective radiated power

In microwave applications, the effective radiated power expressed in dBm is the power at the antenna terminals expressed in dBm plus the antenna gain expressed in dBi.

In land mobile applications, the effective radiated power expressed in dBm is the power at the antenna terminals expressed in dBm plus the antenna gain expressed in dBd.

The notation EIRP and ERP is used to distinguish between the two formats.

890 MHz is used as the separation frequency between dipole dBd and isotropic dBi.

Log normal fade probability

The log normal fade probability accounts for the location variability of the mobile. In a point to point link with well sited antenna, this term does not have any real significance. The fade probability is given by:

$$P = 100 - 50 \cdot erfc\left(\frac{A}{\sqrt{2} \cdot \sigma}\right)\% \qquad (1)$$

A fade margin in dB

s is the log normal standard deviation

erfc is the complimentary error function

The log normal standard deviation is set in the clutter category definition. The following default values are used:

Open land 4 dB
Agricultural 4 dB
Rangeland 4 dB
Water 1 dB
Forest land 6 dB
Wetland 2 dB
Residential 8 dB
Mixed urban/ buildings 10 dB
Commercial/ industrial 12 dB
Snow and ice 2 dB

Raleigh fade probability

The Raleigh fade probability represents the probability that the received signal will be less than the specified threshold level in a multipath fading environment. This probability is given by:

$$\mathrm{Pr} = 100 \cdot \left(1 - e^{\left(-10^{-\frac{A}{10}} \right)} \right) \quad \textbf{(1)}$$

Field strength

Field strength expressed in microvolts / meter is defined in ITU recommendation ITU-R PN.525-2 as shown in the equation below:

$$e = \sqrt{\frac{377 \cdot p}{4\pi d^2}} = \frac{\sqrt{30 \cdot p}}{d} \qquad \textbf{(1)}$$

e rms field strength in volts per meter.
p equivalent isotropically radiated power in the direction of the receive location.
d distance from the transmitter to the receive location in meters.

Antenna response

Antenna data files (*.asd) are used to determine the response to an incoming signal with horizontal and vertical angles, θ_H and θ_V relative to the mechanical boresight of the antenna.

In land mobile applications, it is assumed that the antenna is always physically mounted vertically (i.e. the mechanical boresight is horizontal). Therefore, a non zero vertical angle will produce an orientation loss. In the absence of electrical downtilt, the electrical and mechanical boresight are the same.

In microwave applications, it is assumed that the antenna is always vertically orientated.

In the following descriptions, the horizontal and vertical patterns are denoted by $G_H(\theta)$ and $G_V(\theta)$ respectively.

Mechanical downtilt

In the pathloss program, the sign convention for vertical angles is positive for angles above the horizon and negative for angles below the horizon. A positive downtilt, however, means that the antenna boresight is pointing down to the ground.

The effects of mechanical downtilt are accounted for by modifying the vertical angle q_V. The effect is to increase the vertical angle at the front of the antenna and decrease the vertical angle at the rear. At 90º off of boresight, (V = 90º) mechanical down tilt has no effect. The modification is given by the following equation.

$$
\begin{aligned}
\Delta\theta &= \frac{\theta_{MD}}{90}\cdot(90-\theta_H)\ \ for\ 0_H \le \theta \le 180 \\
\Delta\theta &= \frac{\theta_{MD}}{90}\cdot(-270+\theta_H)\ \ for\ 180 \le \theta_H \le 360 \\
\theta_{V\,\mathrm{mod}} &= \theta_V + \Delta\theta
\end{aligned}
\tag{1}
$$

where:

θ_{Vmod} is the modified vertical angle
$\Delta\theta$ is the correction to the vertical angle
θ_{MD} is the mechanical downtilt angle (positive down)
θ_H is the azimuth angle relative to the antenna boresight

Note that on directional / sectorized antennas, mechanical downtilt may degrade the horizon pattern of the antenna due to the sidelobe structure in the E plane.

Omnidirectional antennas

It is assumed that the vertical pattern of an omnidirectional is rotationally symmetric. The response, R_{dB} is given by:

$$
\begin{aligned}
R_{dB} &= G_h(\theta_h) + G_v(\theta_v) \\
G_h(\theta_h) &= 0 \text{ for an omnidirectional antenna}
\end{aligned}
\tag{2}
$$

Directional antennas

The situation in a directional antenna is more complex and assumes that the field distributions are separable into two orthogonal components. The response, R_{dB} is given by Equation (3) below:

$$
\begin{aligned}
\Omega &= \sin^{-1}\left(\cos\left(\theta_h\right)\cdot\sin\left(\theta_v\right)\right) \\
R_{dB} &= G_H\left(\theta_h\right) + G_v\left(\Omega\right)
\end{aligned}
\tag{3}
$$

In Equation (3), an effective vertical angle, Ω is first determined. The vertical response is read from the antenna data file E plane data at the angle Ω.

References

1. Bell Communications Research Advisory - TA-TSY-000236

    Issue 1 December 1984
    Preliminary Addendum to 4, 6, and 11 GHz Digital Radio Systems Requirements and Objectives

2. Recommendation ITU-R P.530-6

3. Recommendation ITU-R P.530-5

4. Space Diversity Engineering - A. Vigants
    Bell System Technical Journal - January 1975

5. Multipath Propagation at 4, 6, and 11 GHz - W.T. Barnett
    Bell System Technical Journal - February 1972

6. Transmission Unavailability of Frequency Diversity Protected Microwave FM Radio Systems Caused by Multipath Fading - A. Vigants and M.V. Pursley
    Bell System Technical Journal - October 1979

7. Northern Telecom - Practice 415-3041-150 Issued 87 12 22

8. Kazuo Morita - Review of the Electrical Communication Laboratory
    Volume 18, Numbers 11-12, November, December 1970

9. Propagation in Non Ionized Media - Report 719-2
    Recommendations and Reports of the CIR - Volume V

10. Engineering Considerations for Microwave Communication Systems
    GTE Lenkurt Incorporated

11. Digital Line of Sight Radio Links - A. A. R. Townsend
    Prentice Hall

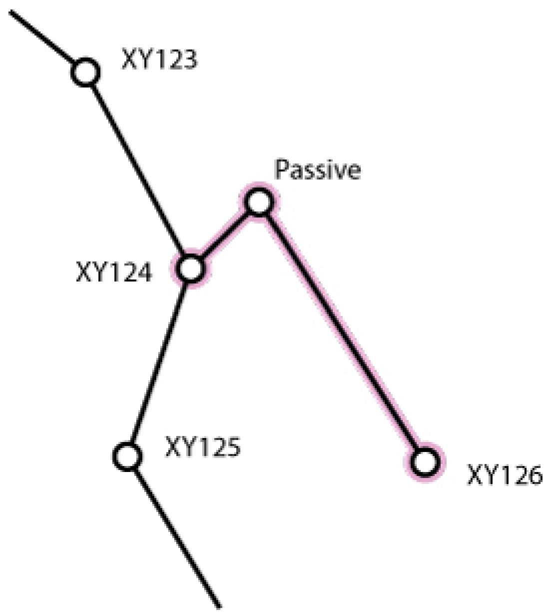
12. Handbook of Land-Mobile Radio System Coverage
Garry C. Hess
Artech House Publishers

Overview

A complete transmission path design can be carried out using the following types of passive repeaters:

- single rectangular passive
- close coupled double rectangular passive
- back to back antennas

A path can include up to three passive repeaters using any combination of the above types.



A passive repeater is created from pl5 files - one file for each passive link. These files must share a common end point with the same elevation and coordinates. Each file must include a path profile and a complete design must be carried out prior to combining the files into a passive file. It is assumed that the all aspects of the path design have been carried out including path clearance, reflection analysis and diffraction fading analysis. In the case of a single rectangular passive the same antenna height must be used in both pl5 files at the passive site.

In the case of a path with one passive repeater, the pl5 link selection can be carried out either in the Network display or in the pl50l transmission analysis section. On paths with more than one passive repeater, the link selection must be carried out in the pl50l transmission analysis section.

The calculations for single and close coupled double rectangular passive repeaters are based on the Microflect Passive Repeater Engineering manual (Reference 1).

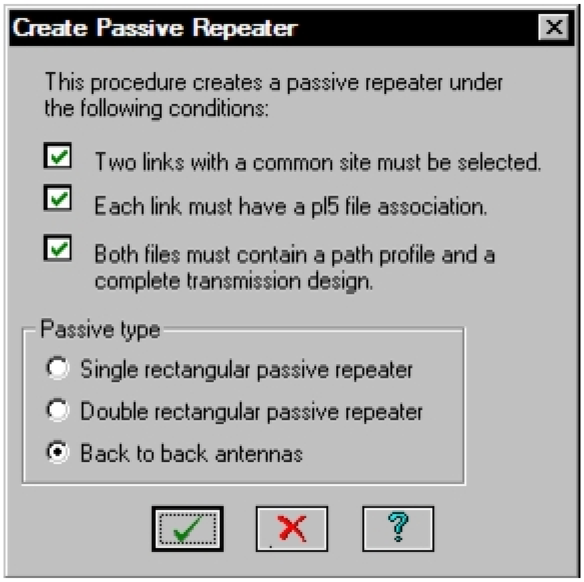
Path profiles

A path can include up to three passive repeaters using any combination of the above types.

A passive repeater is created from pl5 files - one file for each passive link. These files must share a common end point with the same elevation and coordinates. Each file must include a path profile and a complete design must be carried out prior to combining the files into a passive file. It is assumed that the all aspects of the path design have been carried out including path clearance, reflection analysis and diffraction fading analysis. In the case of a single rectangular passive the same antenna height must be used in both pl5 files at the passive site.

In the case of a path with one passive repeater, the pl5 link selection can be carried out either in the Network display or in the pl50l transmission analysis section. On paths with more than one passive repeater, the link selection must be carried out in the pl50l transmission analysis section.

Creating a single passive in the Network display



A passive link design will normally start in the Network display. Select the links to be incorporated into the passive and then use the "Design links" feature to carry out the design. This will ensure the same design criteria are used on these links. Once the individual link designs have been reviewed, select Operations - Create passive repeater. The passive link design requirements and their status is show. Select the type of passive. At the present time it is not possible to change the type of passive once the initial selection has been made.

Click the OK button and the two links

will be combined into the passive design and the results are displayed in the transmission analysis module. The following points are to be noted.

- The passive link is displayed

  as two separate paths each with their own parameters (free space loss, atmospheric absorption loss, fade probability..).

- Note that there is no

  pl5 file name associated with this new passive path. The pl5 file must be saved in order to register the passive with the Network display.

  Otherwise the Network display will continue to show the two links as separate entities.

- In the Design menu, the

  terrain data, antenna heights, diffraction and multipath-reflection sections are inactive

- A left click, on one of

  the paths brings up the Path profile data entry form for the specific pl5 file associated with that path.

- A right click on one of

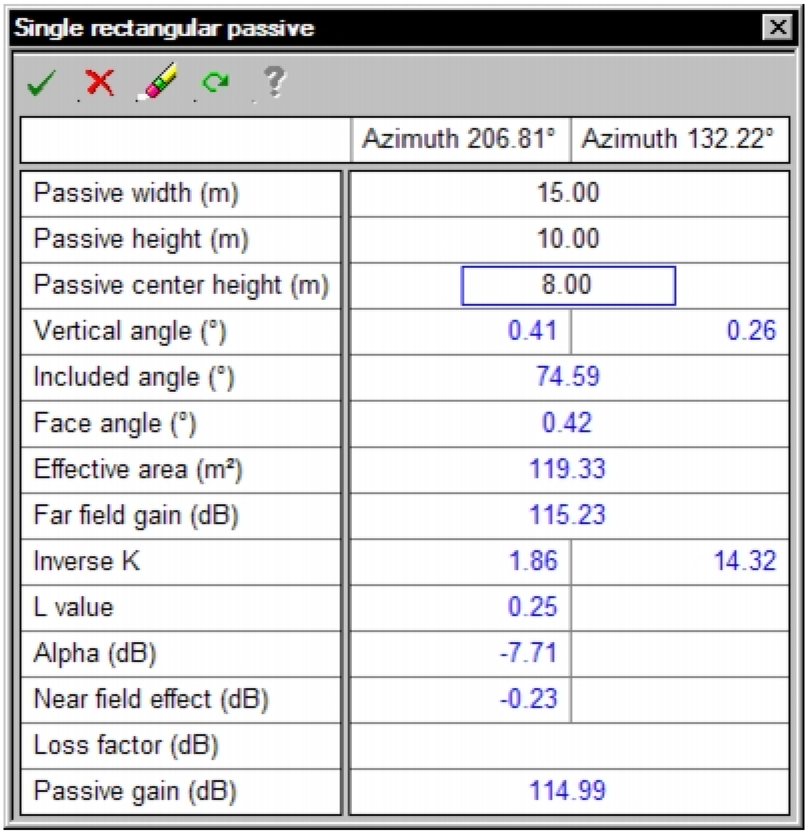
  the paths brings up a design menu to access the terrain data, antenna heights, diffraction and multipath-reflection sections using the pl5

  file for that path.

- Left click on the passive

  icon to bring up the passive repeater data entry form for the selected type.

Single rectangular passive repeater



Single rectangular passive

	Azimuth 206.81°	Azimuth 132.22°
Passive width (m)	15.00	
Passive height (m)	10.00	
Passive center height (m)	8.00	
Vertical angle (°)	0.41	0.26
Included angle (°)	74.59	
Face angle (°)	0.42	
Effective area (m²)	119.33	
Far field gain (dB)	115.23	
Inverse K	1.86	14.32
L value	0.25	
Alpha (dB)	-7.71	
Near field effect (dB)	-0.23	
Loss factor (dB)		
Passive gain (dB)	114.99	

The initial data entry display shows the included angle, the passive face angle and the vertical angles to the coordinating sites. These have been calculated from the coordinates and site elevations. The azimuths to the coordinating sites are used as the titles.

The passive width and height must be entered.

The loss factor represents the effect of the passive surface imperfections. Refer to the manufacturer's specifications for the loss factor at the design frequency.

The passive center height is the distance from ground level to the center of the passive and is set to the value of the antenna height at the passive site in the intermediate pl5 file. Note that the preliminary link design must used this value in both pl5 files used to create the passive file.

Close coupled double rectangular passive repeater

Double rectangular passive

	Azimuth 206.81°	Azimuth 48.83°
Passive width (m)	10.00	10.00
Passive height (m)	6.00	6.00
Passive center height (m)	5.00	8.00
Included angle (°)	60.00	60.00
Distance between passives (m)	25.00	
Vertical angle (°)	0.41	-0.13
Face angle (°)	4.18	-4.02
Effective area (m²)	51.91	51.90
Close coupling loss (dB)	-1.00	
Far field gain (dB)	108.00	
Inverse K²	4.24	29.52
L value		
Alpha (dB)		
Near field effect (dB)		
Loss factor (dB)		
Passive gain (dB)	107.00	

The included angle is automatically calculated for single rectangular passive repeaters based on the coordinates. In the case of double passives, there is not enough information available to calculate these angles and the user must determine the required geometry and included angles. Only the vertical angles are calculated. The required entries are:

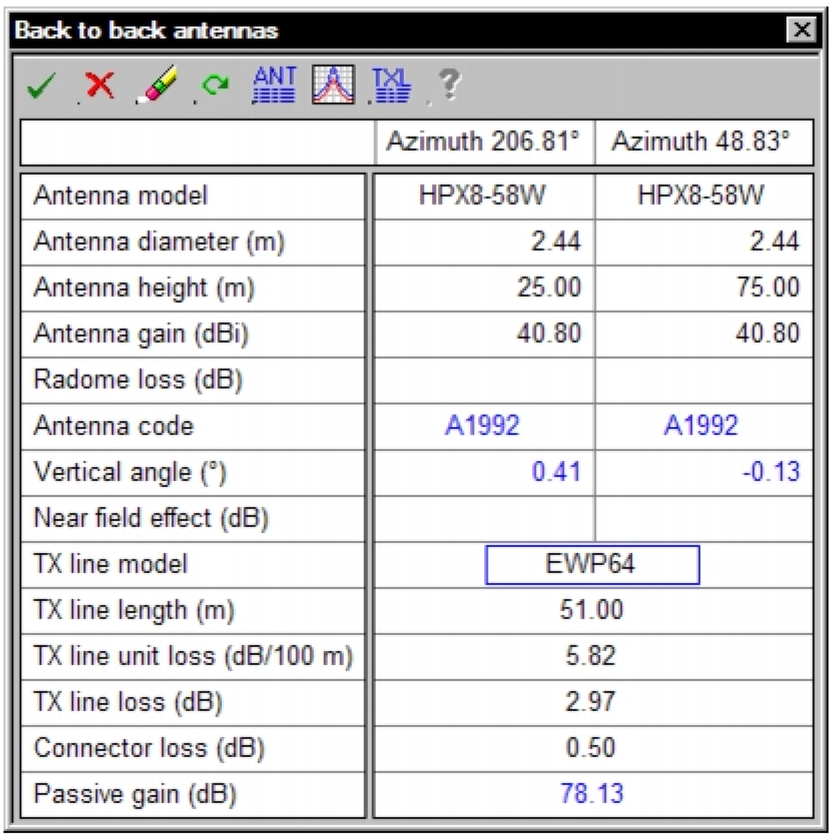
- passive widths and heights
- included angles
- distance between the passives

The passive center height is the distance from ground level to the center of the passive.

The loss factor represents the effect of the passive surface imperfections. Refer to the manufacturer's specifications for the loss factor at the design frequency.

Back to back antennas

The passive gain of back to back antennas is calculated as the sum of the antenna gains minus the transmission line and connector loss. The vertical angle is shown for reference only. The antenna and transmission line data used in the preliminary path designs are used for the default passive repeater values.


Back to back antennas

	Azimuth 206.81°	Azimuth 48.83°
Antenna model	HPX8-58W	HPX8-58W
Antenna diameter (m)	2.44	2.44
Antenna height (m)	25.00	75.00
Antenna gain (dBi)	40.80	40.80
Radome loss (dB)		
Antenna code	A1992	A1992
Vertical angle (°)	0.41	-0.13
Near field effect (dB)		
TX line model	EWP64	
TX line length (m)	51.00	
TX line unit loss (dB/100 m)	5.82	
TX line loss (dB)	2.97	
Connector loss (dB)	0.50	
Passive gain (dB)	78.13	

Create multiple passives in the transmission analysis section

A complete design must be carried out for each link of the passive including a path profile, transmission design and performance calculation. Each design is saved as a pl5 file.

If you are using the standalone PL50L program, open one of the pl5 link files in the transmission analysis section.

In the Network display, left click on one of the links in the passive path and select the transmission analysis menu item Select Operations - Create passive repeater and then select the type of passive. This will bring up a standard file open dialog box. Select a pl5 file which will be attached to the exiting file. The file is loaded and the display is reformatted to show the passive. Repeat this procedure for each additional pl5 link on the overall passive path Complete the passive data entry as described in the previous section.

Editing Passive Data

Once the passive has been created, you cannot access the terrain data, antenna heights, multipath - reflection or the diffraction design sections from the Design menu selection. Also note that the site data entry form does not allow changes to the coordinates.

- It will be necessary to recreate the passive path if any of the following changes are required:
- the wrong passive type has been selected
- it is necessary to move a site as this would invalidate one or two profiles
- the path profile elevations or structures have been edited

The path profile displayed in the transmission analysis section is divided into the individual links comprising the passive path. Left click on one of these paths to bring up the Path profile data entry form. The parameters affecting the multipath fade probability for this link can be entered here.

Right click on a path to bring up the design menu for that path. This feature allows access to the design features and is intended to review the basic designs. Any changes which affect the fade probability such as path inclination will be updated in the overall passive path.

Note that you must return to the transmission analysis section to update the passive path calculations.

Antenna configurations on passive paths

Normally a passive design will start with TR-TR antenna combinations. You can switch to the space diversity combination TRDR-TRDR at any time. If TXRX-TXRX antenna configurations area required, you must design the individual links with this antenna combination. You can then switch to the diversity antenna configuration TXRXDR-TXRXDR at any time

Interference calculations on paths with passive repeaters

An interference calculation involving a passive repeater models the passive with virtual transmitter - receiver pairs. The associated transmit and receive losses are defined in Figure (1).

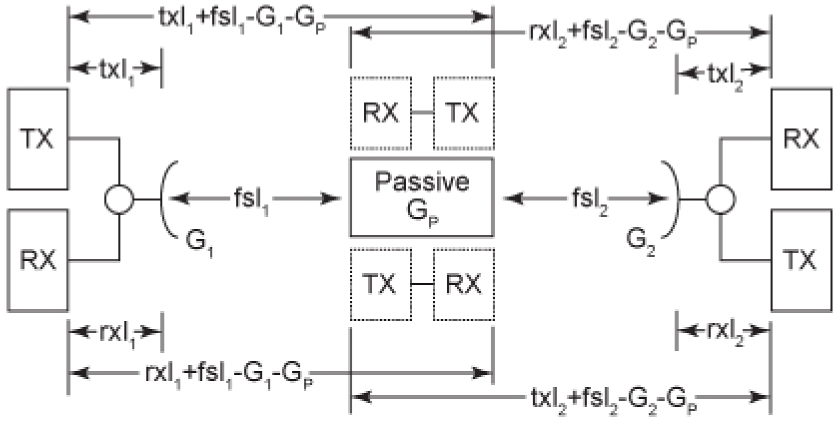


Figure (1): Passive repeater - interference virtual TX-RX losses

where:

$rxl_{1/2}$	transmitter losses at site 1/2 due to ACU and transmission line - connector losses
$rxl_{1/2}$	receiver losses at site 1/2 due to ACU and transmission line - connector losses
$G_{1/2}$	antenna gain at site 1/2
G_p	passive gain
$fsl_{1/2}$	free space and atmospheric absorption loss on link 1/2

Note that it is possible to run an interference calculation on a single passive path. This is an important design step to verify that self interference does not occur on a passive design. The interference paths on a single passive repeater path are shown in Figure (2). The direct path between the end sites is usually the most critical path.

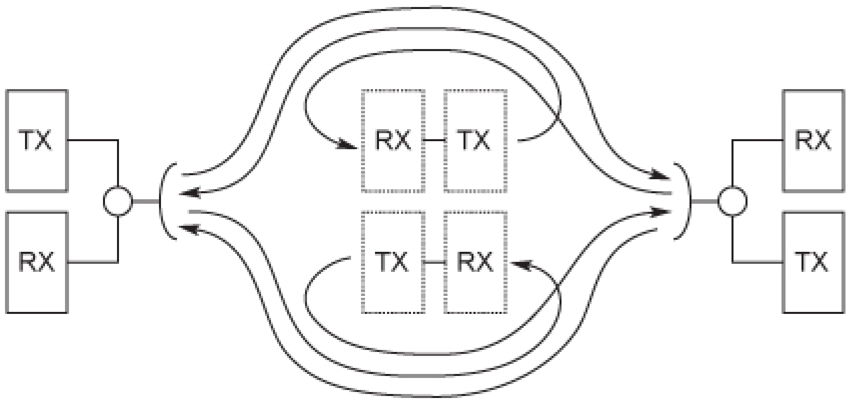


Figure (2): Passive repeater - interference paths

Rectangular passive repeater radiation pattern

Figure (3) shows the passive radiation pattern used for interference calculations and the definition of discrimination angle Θ

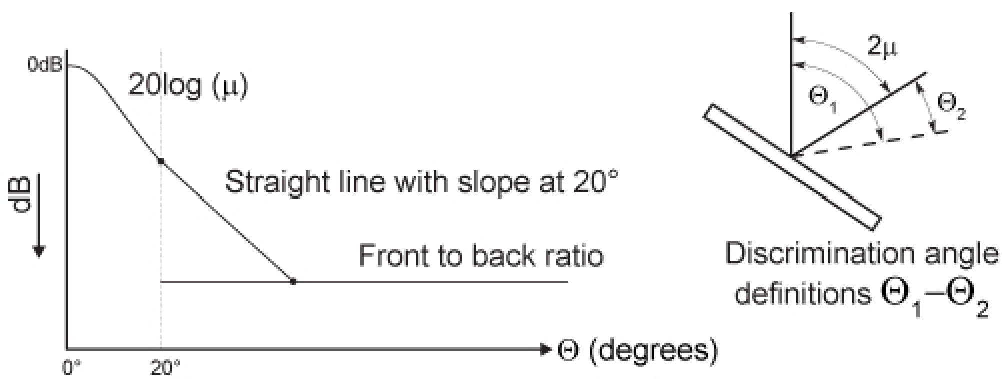


Figure (3): Rectangular passive radiation pattern

In the range 0 < Θ < 20 degrees, the discrimination is given by Equation (1)

$$\mu = \frac{\pi a \sin \theta}{\lambda} \tag{1}$$

At 20 degrees the curve follows the slope at 20 degrees until it reaches the front to back ratio of the passive given by Equation (2)

$$\text{front to back} = 10\log \frac{4\pi a \cos(\propto)}{\lambda^2} \tag{2}$$

Propagation Reliability Calculations on Passive Repeaters

Multipath fading

The fade probability *P* is a function of frequency (*f*), path length (*d*) and the fade margin (*A*) and is given by the general equation:

$$P = C \cdot f^a \cdot d^b \cdot 10^{\frac{-A}{10}} \qquad (1)$$

Where *a* and *b* are constants for the specific method used.

The passive repeater effectively divides the path up into segments and the overall fade probability is the sum of the fade probabilities for each segment. For a single passive with link path lengths d_1 and d_2, the fade probability is given by:

$$P = (C_1 \cdot f^a \cdot d_1^b + C_2 \cdot f^a \cdot d_2^b) \cdot 10^{\frac{-A}{10}} \qquad (2)$$

Equation (2) can be extended for any number of passives. If the Vigants-Barnett or ITU-530-6 methods are used to calculate propagation reliability, the factors $C_1 .. C_n$ are different for each segment and it is necessary to calculate the terrain roughness or grazing angle for each passive link on the profile. When a passive is created in the Microwave Worksheet, the path icon is divided into segments at the passive location(s). The terrain roughness / grazing calculation is applicable to the selected segment.

Rain attenuation

The total path length (the sum of the individual link path lengths) is used in the rain performance analysis.

Comparison of results

The following points should be noted when comparing the results of the passive repeater calculations with the Microflect examples:

- A direct comparison with the Microflect results cannot be made on near field paths due to differences in the format. The receive signals must be compared in these cases.
- Atmospheric absorption loss is always included in the Pathloss calculation.
- Vertical angles in the Pathloss program are calculated using an effective earth radius of K=4/3.

Rectangular passive gain

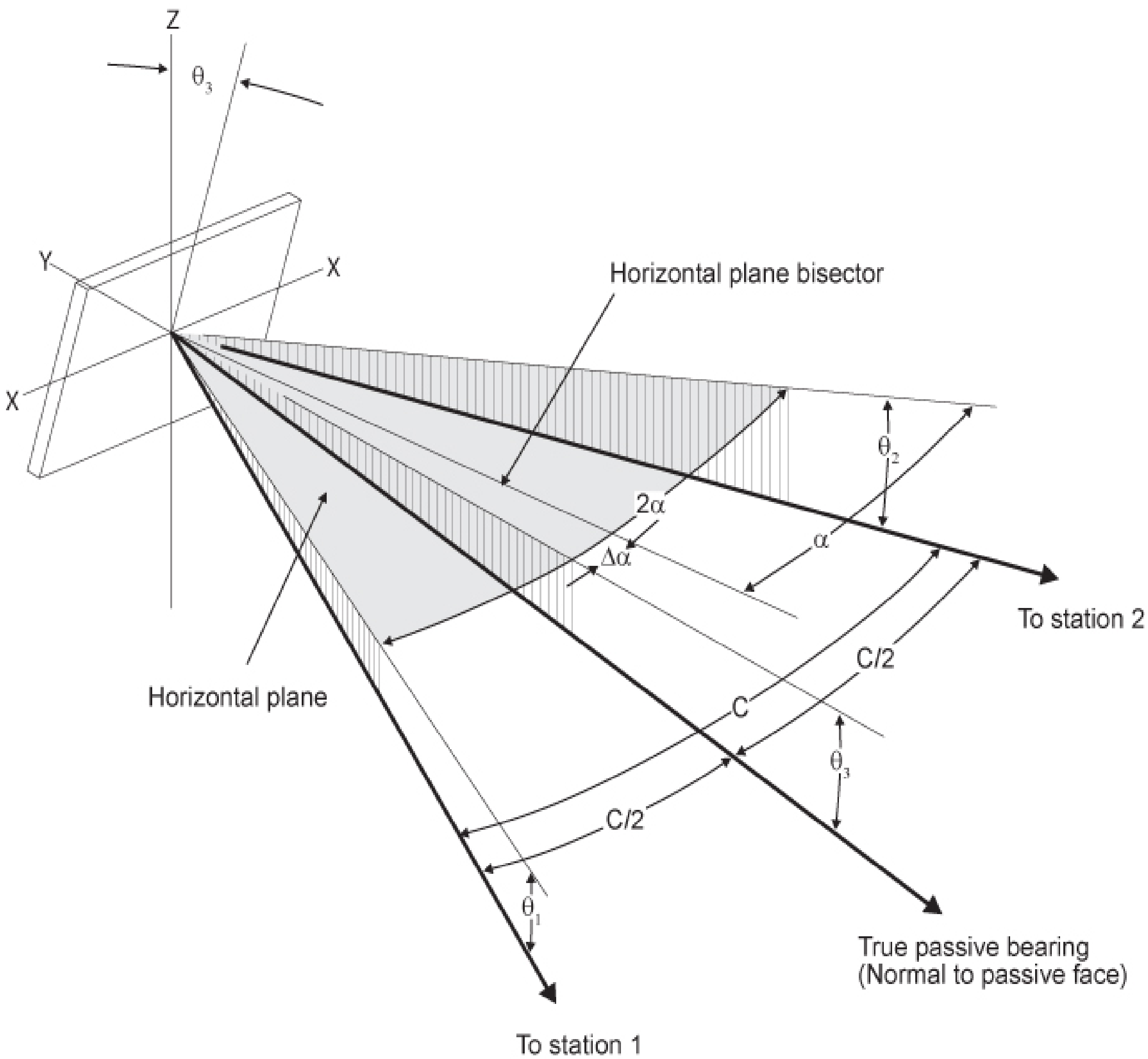


Figure (1): Passive repeater geometry

The theoretical gain of a rectangular passive repeater is given by:

$$G = 20 \cdot log_{10} \left(\frac{4 \cdot \Pi \cdot a \cdot cos\left(\frac{C}{2}\right)}{\lambda^2} \right) \quad (1)$$

$$cos\left(\frac{C}{2}\right) = \frac{sin(\theta_1) + sin(\theta_2)}{2 \cdot sin(\theta_3)}$$

θ_1 is the least vertical angle from the passive center to Site1 / Site 2

θ_2 is the greatest vertical angle from the passive center to Site1 / Site 2

θ_3 is the passive vertical face angle and is calculated by Equation (2)

$$tan(\Delta a) = \frac{tan(\alpha) \cdot (cos(\theta_1) - cos(\theta_2))}{cos(\theta_1) + cos\theta_2} \quad (2)$$

$$tan\theta_3 = \frac{cos(\Delta\alpha) \cdot (sin(\theta_1) + sin(\theta_2))}{cos(\alpha) \cdot (cos(\theta_1) + cos(\theta_2))}$$

α is the horizontal included angle

Near field loss - gain

The near field loss-gain (*αn*) is determined from Figure (1) using the parameters and *L* given by the equations below:

$$\frac{1}{K} = \frac{\Pi \cdot \lambda \cdot d}{4 \cdot a^2} \tag{1}$$

where:

d distance between the antenna and the passive

λ wavelength

a^2 effective area of the passive

All of the above parameters must be in the same units.

$$L = D\sqrt{\frac{\Pi}{4 \cdot a^2}} \tag{2}$$

where:

D antenna diameter

a^2 effective area of the passive

All of the above parameters must be in the same units.

If $\frac{1}{K} > 3$, then the passive is in the far field and *L* and *αn* are not calculated.

Note that in the Microflect format, *αn* effectively replaces the passive gain and the free space loss between the antenna and the near field passive. In the Pathloss program the passive gain is modified by the term "near field effect" defined as follows:

near field effect = free space loss + *αn -G*

The passive gain including the near field effect is equal to the far field gain (*G*) + near field effect.

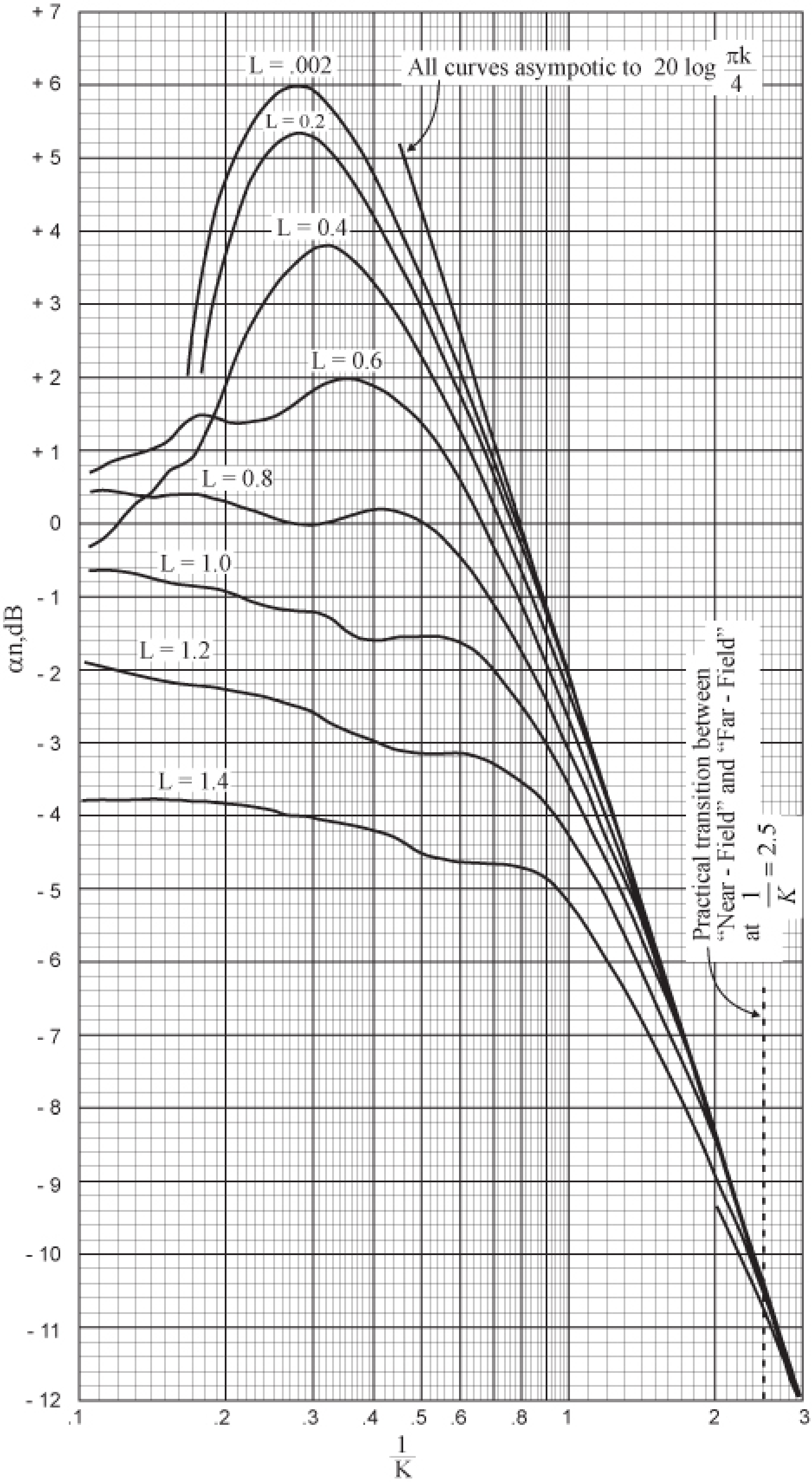

L = .002
L = 0.2
L = 0.4
L = 0.6
L = 0.8
L = 1.0
L = 1.2
L = 1.4
All curves asympotic to 20 log $\frac{\pi k}{4}$
Practical transition between "Near - Field" and "Far - Field" at $\frac{1}{K} = 2.5$
αn,dB
$\frac{1}{K}$
+ 7
+ 6
+ 5
+ 4
+ 3
+ 2
+ 1
0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
.1
.2
.3
.4
.5
.6
.8
1
2
3

Figure (1): Near field loss - gain

Close coupling loss - double passives

The close coupling loss a*p* on double passive repeaters is determined from Figure (3) with the parameters: $\frac{1}{K^2}$ *and* $\frac{b}{a}$ defined as follows:

$$\frac{1}{K^2} = \frac{2 \cdot \lambda \cdot d}{a^2} \qquad (1)$$

$$\frac{b}{a} = \sqrt{\frac{b^2}{a^2}}$$

where:

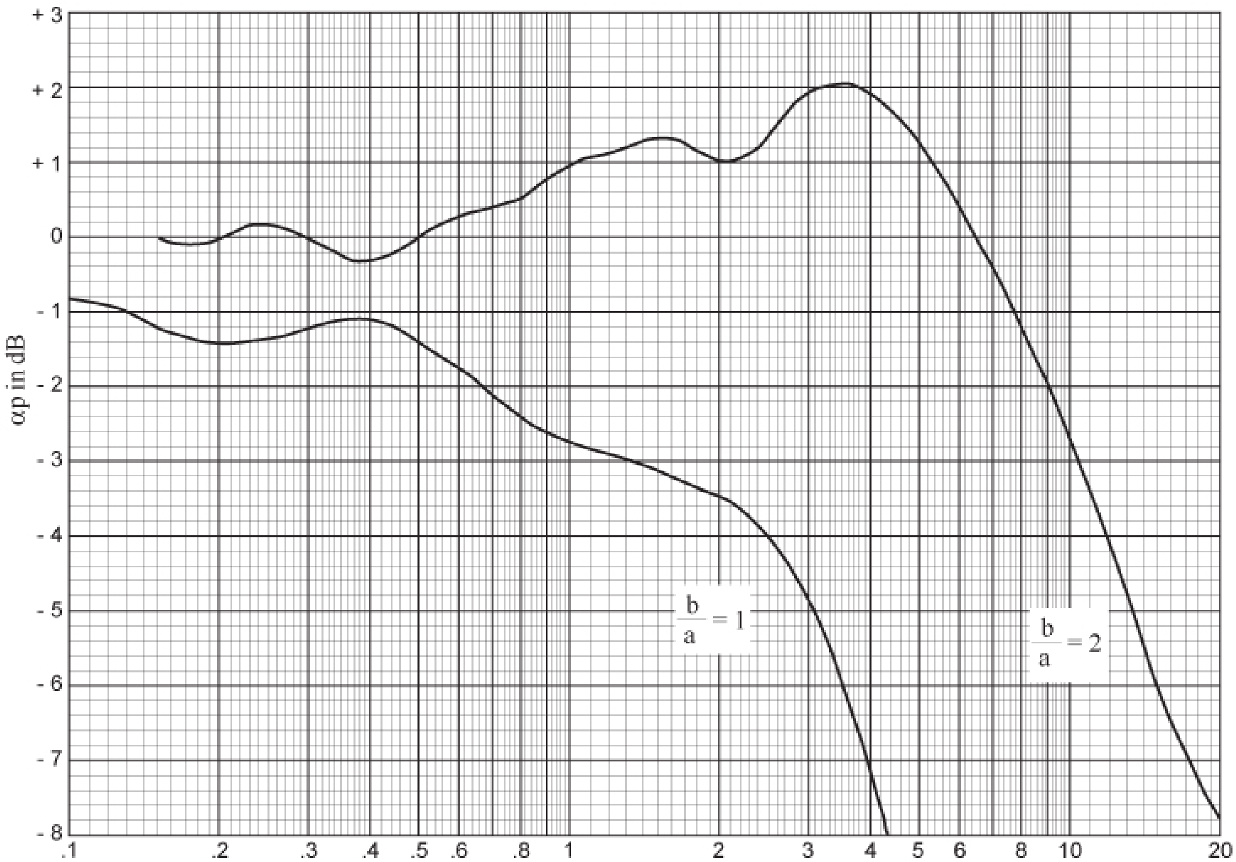
d distance between passives

a^2 smaller effective area of the two passives

b^2 larger effective area of the two passives

λ wavelength

The same units must be used for all parameters.



$$\frac{1}{K^2} = \frac{2 \cdot \lambda \cdot d}{a^2}$$

Figure (3): Double Passive Repeater Close Coupling Loss

References

1. Passive Repeater Engineering
Microflect Manual No. 161