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1 Overview

This technical note details microwave link planning calculations. Microwave link planning features conform to relevant ITU recommendations and cover the following areas:

- Propagation models and losses
- Calculating unavailability and error performance
- Calculating interference
- Generating profiles

2 Propagation models and losses

The aim of a propagation model is to predict the behavior of radio wave propagation in the atmosphere. In the case of microwave link planning, models predict the pathloss along a link.

When you use the microwave link planning features, you can access the following propagation models:

- Free Space
- ITU-R P.452
- General Diffraction Model
- P3M

Each of these models has its own way to predict pathloss values but they also use common methods to predict losses. Before looking at the characteristics of each model, consider the following phenomena that generate losses:

- Loss due to gases
- Loss due to diffraction

These phenomena can be used with some of the propagation models that are available.

2.1 Losses

2.1.1 Loss due to gases

Several methods are available to determine losses due to gases, ITU P676: P676-3, P676-5 and P676-7. The calculation of losses due to gases relies on measurements of atmospheric conditions. The more recent the release, the more precise the evaluation will be. ITU P767-7 is not the latest standard published but no method update was implemented in ITU P767-8.

Losses due to gases are accounted for as per the ITU recommendation (i.e., ITU-P R.676-5). As per ITU-R P.452, there are several models to assess gas attenuation. To ensure conformity with the calculation method described in the 2001 Vienna Agreements, the model described in P676-3 is required.

Total gas absorption involves lineic losses $\gamma_0$ from dry air, and $\gamma_w$ from water vapour. Depending on the hop length $d$ (km), loss is given as

$$A_g = \left[\gamma_0 + \gamma_w(\rho)\right]d$$

Equation 1

Where

$\rho$ is the water vapor concentration (g/m$^3$) (user-defined or computed from the ITU files).

For calculating $\gamma_0$ and $\gamma_w$ (dB/km), the following values are used in the formulas described below:

- $f$ (GHz) is the frequency
p (hPa) is the pressure defined on the Microwave Models/Propagation Models/General panel in the Atmospheric parameters /Pressure section of the project settings.

\( t (°C) \) is the temperature Project Settings dialog box, on the Microwave Models/Propagation Models/General panel in the Atmospheric parameters /Temperature Section.

\[
\begin{align*}
p_p &= p/1013 \\
rt &= 288/(273 + t)
\end{align*}
\]

Three gas attenuation models are used to fine-tune diffraction results:

- **ITU-R P.676-3**—provides methods to estimate the attenuation of atmospheric gases on terrestrial and slant paths using:
  - an estimate of gaseous attenuation computed by the summation of individual absorption lines that are valid for the frequency range 1-1,000 GHz, and
  - a simplified approximate method to estimate gaseous attenuation that is applicable in the frequency range 1-350 GHz.

- **ITU-R P.676-5**—includes updated formulas with four frequency ranges (f <=54 GHz, 54<f<66, 66<=f<120, 120 <=f<350 GHz). For more information, refer to the ITU Recommendation for detailed formulas specific to the frequency range.

- **ITU-R P.676-7**—includes updated formulas with six frequency ranges (f < =54 GHz, 54<f<60, 60<f<62, 62<f<66, 66<=f<120, 120 <=f<=350 GHz). For more information, refer to the ITU Recommendation for detailed formulas specific to the frequency range.

**NOTE:** These are successive versions of methods of attenuation by atmospheric gases. To benefit from the latest empirical considerations, it is recommended that you use the latest method, ITU-R P.676-7.

### 2.1.1.1 Lineic attenuation \( \gamma_0 \) from dry air

**Dry air (P676-3 and Appendix VA01)**

\[
\gamma_o = \begin{cases} 
\frac{7.27r_t}{f^2 + 0.351r_p^2 r_t^2} + \frac{7.5}{(f - 57)^2 + 2.44r_p^2 r_t^2} \times 10^{-3} & \text{for } f \leq 57 \text{ GHz} \\
2 \times 10^{-4} r_t^{1.5} \left(1 - 1.2 \times 10^{-5} f^{1.5}\right) + \frac{4}{(f - 63)^2 + 1.5r_p^2 r_t^2} + \frac{0.28r_t^2}{(f - 118.75)^2 + 2.84r_p^2 r_t^2} \times 10^{-3} & \text{for } 63 \text{ GHz} \leq f \leq 350 \text{ GHz}
\end{cases}
\]

Equation 2
2.1.1.1 Dry air (P676-5)

\[
\gamma_o = \left[ \frac{7.34 r_p^2 r_i^3}{f^2 + 0.36 r_p^2 r_i^2} + \frac{0.3429 b \gamma_o'(54)}{(54 - f)^d + b} \right] f^2 \times 10^{-3}
\]

for \( f \leq 54 \text{ GHz} \)

\[
\gamma_o = \exp \{[54^N \ln(\gamma_o(54)) (f - 57) (f - 60) (f - 63) (f - 66)/1944
- 57^N \ln(\gamma_o(57)) (f - 54) (f - 60) (f - 63) (f - 66)/486
+ 60^N \ln(\gamma_o(60)) (f - 54) (f - 57) (f - 63) (f - 66)/324
- 63^N \ln(\gamma_o(63)) (f - 54) (f - 57) (f - 60) (f - 66)/486
+ 66^N \ln(\gamma_o(66)) (f - 54) (f - 57) (f - 60) (f - 63)/1944] f^N \}
\]

for \( 54 \text{ GHz} < f < 66 \text{ GHz} \)

\[
\gamma_o = \left[ \frac{0.2296 d \gamma_o'(66)}{(f - 66)^c + d} + \frac{0.286 r_p^2 r_i^{3.8}}{(f - 118.75)^2 + 2.97 r_p^2 r_i^{1.6}} \right] f^2 \times 10^{-3}
\]

for \( 66 \text{ GHz} < f < 120 \text{ GHz} \)

\[
\gamma_o = \left[ 3.02 \times 10^{-4} r_p^2 r_i^{3.5} + \frac{1.5827 r_p^2 r_i^3}{(f - 66)^2} + \frac{0.286 r_p^2 r_i^{3.8}}{(f - 118.75)^2 + 2.97 r_p^2 r_i^{1.6}} \right] f^2 \times 10^{-3}
\]

for \( 120 \text{ GHz} \leq f \leq 350 \text{ GHz} \)

with:

\[
\gamma_o'(54) = 2.128 r_p^{1.4954} r_i^{-1.6032} \exp \left[ -2.5280 (1 - r_i) \right]
\gamma_o(54) = 2.136 r_p^{1.4975} r_i^{-1.5852} \exp \left[ -2.5196 (1 - r_i) \right]
\gamma_o(57) = 9.984 r_p^{0.9313} r_i^{-2.6732} \exp \left[ 0.8563 (1 - \eta_i) \right]
\gamma_o'(60) = 15.42 r_p^{0.8595} r_i^{3.6178} \exp \left[ 1.1521 (1 - r_i) \right]
\gamma_o(60) = 10.63 r_p^{0.9298} r_i^{2.3284} \exp \left[ 0.6287 (1 - \eta_i) \right]
\gamma_o(63) = 1.944 r_p^{1.6673} r_i^{-3.3583} \exp \left[ -4.1612 (1 - \eta_i) \right]
\gamma_o'(66) = 1.935 r_p^{1.6657} r_i^{-3.3714} \exp \left[ -4.1643 (1 - r_i) \right]
\]

\[
a = \ln(\eta_2 / \eta_1) / \ln 3.5
b = 4^d / \eta_1
\eta_1 = 6.7665 r_p^{-0.5050} r_i^{0.5106} \exp \left[ 1.5663 (1 - r_i) \right]^{-1}
\eta_2 = 27.8843 r_p^{-0.4908} r_i^{0.8491} \exp \left[ 0.5496 (1 - r_i) \right]^{-1}
c = \ln(\xi_2 / \xi_1) / \ln 3.5
d = 4^c / \xi_1
\xi_1 = 6.9575 r_p^{-0.3461} r_i^{0.2535} \exp \left[ 1.3766 (1 - r_i) \right]^{-1}
\xi_2 = 42.1309 r_p^{-0.3068} r_i^{1.2023} \exp \left[ 2.5147 (1 - r_i) \right]^{-1}
N = 0 \text{ for } f \leq 60 \text{ GHz} \text{ and } N = -15 \text{ for } f > 60 \text{ GHz}
\]

Equation 3


2.1.1.1.2 Dry air (P676-7)

For $f \leq 54$ GHz:

$$\gamma_o = \left[ \frac{7.2}{f^2} + 0.34 \frac{r_i^{2.8}}{r_f^{1.6}} + \frac{0.62}{(54 - f)^{1.16 \xi_1}} + 0.83 \xi_2 \frac{r_i^{2}}{r_f^{1.6}} \right] \times 10^{-3}$$

For $54$ GHz $< f \leq 60$ GHz:

$$\gamma_o = \exp \left[ \frac{\ln \gamma_{54}}{24} (f - 58)(f - 60) - \frac{\ln \gamma_{58}}{8} (f - 54)(f - 60) + \frac{\ln \gamma_{60}}{12} (f - 54)(f - 58) \right]$$

For $60$ GHz $< f \leq 62$ GHz:

$$\gamma_o = \gamma_{60} + (\gamma_{62} - \gamma_{60}) \frac{f - 60}{2}$$

For $62$ GHz $< f \leq 66$ GHz:

$$\gamma_o = \exp \left[ \frac{\ln \gamma_{62}}{8} (f - 64)(f - 66) - \frac{\ln \gamma_{64}}{4} (f - 62)(f - 66) + \frac{\ln \gamma_{66}}{8} (f - 62)(f - 64) \right]$$

For $66$ GHz $< f \leq 120$ GHz:

$$\gamma_o = \left\{ \frac{3.02 \times 10^{-4} r_i^{3.5} + 0.283 r_i^{3.8} (f - 118.75)^2 + 2.91 r_i^{2.1} (f - 66)^{1.434 \xi_4} + 1.15 \xi_5}{(f - 118.75)^2 + 2.91 r_i^{2.16}} \right\} \times 10^{-3}$$

For $120$ GHz $< f \leq 350$ GHz:

$$\gamma_o = \left[ \frac{3.02 \times 10^{-4}}{1 + 1.9 \times 10^{-5}} \right] + \frac{0.283 r_i^{0.3}}{(f - 118.75)^2 + 2.91 r_i^{2.16}} \times 10^{-3} + \delta$$

with:

$$\xi_1 = \varphi(r_p, r_f, 0.0717, -1.8132, 0.0156, -1.6515)$$

$$\xi_2 = \varphi(r_p, r_f, 0.5146, -4.6368, -0.1921, -5.7416)$$

$$\xi_3 = \varphi(r_p, r_f, 0.3414, -6.5851, 0.2130, -8.5854)$$

$$\xi_4 = \varphi(r_p, r_f, 0.0112, 0.0092, -0.1033, -0.0009)$$

$$\xi_5 = \varphi(r_p, r_f, 0.2705, -2.7192, -0.3016, -4.1033)$$

$$\xi_6 = \varphi(r_p, r_f, 0.2445, -5.9191, 0.0422, -8.0719)$$

$$\xi_7 = \varphi(r_p, r_f, -0.1833, 6.5589, -0.2402, 6.131)$$

$$\gamma_{54} = 2.192 \varphi(r_p, r_f, 1.8286, -1.9487, 0.4051, -2.8509)$$

$$\gamma_{58} = 12.59 \varphi(r_p, r_f, 1.0045, 3.5610, 0.1588, 1.2834)$$
\[ \gamma_{60} = 15.0 \varphi(r_p, r_t, 0.9003, 4.1335, 0.0427, 1.6088) \]

\[ \gamma_{62} = 14.28 \varphi(r_p, r_t, 0.9886, 3.4176, 0.1827, 1.3429) \]

\[ \gamma_{64} = 6.819 \varphi(r_p, r_t, 1.4320, 0.6258, 0.3177, -0.5914) \]

\[ \gamma_{66} = 1.908 \varphi(r_p, r_t, 2.0717, -4.1404, 0.4910, -4.8718) \]

\[ \delta = -0.00306 \varphi(r_p, r_t, 3.211, -14.94, 1.583, -16.37) \]

\[ \varphi(r_p, r_t, a, b, c, d) = r_p^a r_t^b \exp[c(1 - r_p) + d(1 - r_t)] \]

Equation 4

## 2.1.1.2 Lineic attenuation \( \gamma_w \) due to water vapour

**Water vapor (P676-3 and Appendix VA01)**

\[
\gamma_w = \begin{bmatrix}
3.27 \times 10^{-2} r_t + 1.67 \times 10^{-3} \frac{\rho r_t^7}{r_p} + 7.7 \times 10^{-4} f^{0.5} + \frac{3.79}{(f - 22.235)^2 + 9.81 r_p^2 r_t} \\
11.73 r_t + 4.01 r_t \\
(f - 183.31)^2 + 11.85 r_p^3 r_t + (f - 325.153)^2 + 10.44 r_p^3 r_t
\end{bmatrix} f^2 \rho r_p r_t \times 10^{-4}
\]

for \( f \leq 350 \text{ GHz} \)

Equation 5
### 2.1.1.2.1 Water vapor (P676-5)

\[
\gamma_w = \left\{ \begin{array}{l}
3.13 \times 10^{-2} r_p r_t^2 + 1.76 \times 10^{-3} \rho r_t^{8.5} + r_t^{2.5} \left[ \frac{3.84 \xi_{w1} g_{22} \exp(2.23 (1 - r_t))}{(f - 22.235)^2} + 9.42 \xi_{w1}^2 \right] \\
+ \frac{10.48 \xi_{w2} \exp(0.7 (1 - r_t))}{(f - 183.31)^2} + 9.48 \xi_{w2}^2 \\
+ \frac{3.76 \xi_{w4} \exp(1.6 (1 - r_t))}{(f - 325.153)^2} + 9.22 \xi_{w4}^2 \\
+ \frac{17.87 \xi_{w5} \exp(1.46 (1 - r_t))}{(f - 448)^2} \\
+ \frac{302.6 \xi_{w5} g_{752} \exp(0.41 (1 - r_t))}{(f - 752)^2} \right\} f^2 \rho \times 10^{-4} \\
\end{array} \right.
\]

for \( f \leq 350 \text{ GHz} \)

with:

\[
\begin{align*}
\xi_{w1} &= 0.9544 r_p r_t^{0.69} + 0.0061 \rho \\
\xi_{w2} &= 0.95 r_p r_t^{0.64} + 0.0067 \rho \\
\xi_{w3} &= 0.9561 r_p r_t^{0.67} + 0.0059 \rho \\
\xi_{w4} &= 0.9543 r_p r_t^{0.68} + 0.0061 \rho \\
\xi_{w5} &= 0.9555 r_p r_t^{0.68} + 0.006 \rho \\
g_{22} &= 1 + (f - 22.235)^2 / (f + 22.235)^2 \\
g_{557} &= 1 + (f - 557)^2 / (f + 557)^2 \\
g_{752} &= 1 + (f - 752)^2 / (f + 752)^2
\end{align*}
\]

Equation 6
2.1.1.2.2 Water vapor (P676-7)

\[
\gamma_w = \left\{ \frac{3.98\eta_1 \exp[2.23(1-r_t)]}{(f - 22.235)^2 + 9.42\eta_1^2} g(f,22) + \frac{11.96\eta_1 \exp[0.7(1-r_t)]}{(f - 183.31)^2 + 11.14\eta_1^2} \right\} \\
+ \left\{ \frac{0.081\eta_1 \exp[6.44(1-r_t)]}{(f - 321.226)^2 + 6.29\eta_1^2} + \frac{3.66\eta_1 \exp[1.6(1-r_t)]}{(f - 325.153)^2 + 9.22\eta_1^2} \right\} \\
+ \left\{ \frac{25.37\eta_1 \exp[1.09(1-r_t)]}{(f - 380)^2} + \frac{17.4\eta_1 \exp[1.46(1-r_t)]}{(f - 448)^2} \right\} \\
+ \left\{ \frac{844.6\eta_1 \exp[0.17(1-r_t)]}{(f - 557)^2} g(f,557) + \frac{290\eta_1 \exp[0.41(1-r_t)]}{(f - 752)^2} g(f,752) \right\} \\
+ \frac{8.3328 \times 10^4 \eta_2 \exp[0.99(1-r_t)]}{(f - 1780)^2} g(f,1780) \right\} f^2 r_t^{2.5} \rho \times 10^{-4}
\]

with:

\[\eta_1 = 0.955 r_p r_t^{0.68} + 0.006 \rho\]

\[\eta_2 = 0.735 r_p r_t^{0.5} + 0.0353 r_t^4 \rho\]

\[g(f, f_i) = 1 + \left( \frac{f - f_i}{f + f_i} \right)^2\]

Equation 7
2.1.2 Loss due to diffraction

In order to model microwave link behavior in the real world, you need to consider the impact of obstacles on the line-of-sight and account for diffraction. Diffraction attenuation for microwave link planning results from the combination of several diffraction methods including Single Knife-Edge Obstacle, Bullington, Epstein and Peterson, Deygout, ITU R P.527-5, ITU-R .526-11, Durkin and Triple Peak. A maximum of three edges is considered.

- **Single Knife Edge Obstacle**—using this method all geometrical parameters are combined in a single dimensionless parameter.

Where

- $H$ is the height of the top of the obstacle above the line of sight
- $d_1$ and $d_2$ are the distances of the two ends of the path from the top of the obstacle
- $\lambda$ is the wavelength

For $\nu$ greater than -0.78 the diffraction loss is:

$$J(\nu) = 6.9 + 20\log\left(\frac{\sqrt{(\nu - 0.1)^2 + 1 + \nu - 0.1}}{\nu}ight) \text{ dB}$$

**NOTE:** $\nu$ is the relative penetration of the obstacle in the Fresnel zone

- **Bullington**—using this method an equivalent single knife edge is constructed at the intersection of Tx/Rx “horizons” and a loss is calculated.

Where

- Tx is the transmitter
- Edge 1 is the first edge
- Edge 2 is the second edge
- Rx is the receiver
• **Delta Bullington**—using this method, you can correct the underestimation of loss calculated when using the Bullington Diffraction model. This method was introduced in ITU Recommendation P526 Release 13. With this method, the following three calculations are performed:
  1. Compute loss \( L_{ba} \) using Bullington method over the actual profile.
  2. Compute loss \( L_{bs} \) using Bullington method over a smooth profile. The same extremities are used, the antenna heights have the same height above the smooth profile than with actual profile.
  3. Compute loss \( L_{sph} \) using the spherical earth model.

The diffraction loss for the path is then computed as:

\[
L = L_{ba} + \max\{ L_{sph} - L_{bs} , 0 \} \quad \text{dB}
\]

**NOTE:** When required to be ITU compliant, use the Delta-Bullington method.

- **Epstein-Peterson**—using this method the loss for each single edge is calculated using the height above the dotted line as the effective height of the edge. The total loss is the sum of individual losses. Calculations begin at the transmitter or previous obstacle.

- **Deygout**—using this method the link path is divided into segments. The method begins by determining the longest edge (i.e., the principle edge “v”).

Beginning at the principle edge (P), a new reference plane is created and \( v \) is calculated for the intermediate edge based on the height above the reference plane.

This intermediate edge will have a lower value of \( v \) and becomes the principle edge for the path from Tx to P. The process is recursive for multiple intermediate edges and is repeated until all edges are considered. The method ignores any edges with 1st Fresnel zone clearance. The same process is used along the path from P to the receiver. The losses calculated for each edge are added together.
• **ITU-R P.526-5**—using this method the calculations follow Deygout methods along three edges (principal edge (p), the edge between the transmitter and the principal edge (t), and the edge between the principal edge and the receiver (r)). The following correction is made to Deygout’s method:

\[ L = J(v_p) + T \left[ J(v_t) + J(v_r) + C \right] \]

Where C is the empirical correction and \( C = 8.0 + 0.04D \) (D being the total path length). This is further corrected by:

\[ T = \frac{J(v_p)}{6} \text{ for } J(v_p) \leq 6 \]

\[ T = 1 \text{ for } J(v_p) > 6 \]

• **ITU-R P. 526-11**—using this method the same methodology as ITU-R P.526-5 is used along with:

\[ C = 10.0 + 0.04D \]

And

\[ T = 1.0 - \exp \left[ -J(v_p)/6.0 \right] \]

• **Durkin**—using this method the Epstein-Peterson method is used when there are three real edges. When there are more than three real edges, the first and the last main edges are kept and a fictitious edge is calculated using the Bullington model.

• **Triple Peak**—this method is a successive loss calculation based on single knife-edge method. It is split in three steps:

1. The first one is to get the largest knife edge loss by considering each peak separately (which is similar to Deygout method). Once the obstacle leading to largest loss has been found, the profile is split at this location into two separate sub-profiles and the obstacle is considered as a common antenna along the partial paths.

2. The second step is to determine the highest knife edge loss value of these two partial paths. As in the first step, the partial path with the worst obstacle is split in sub-profiles.

3. Using the same method, the last step is to find the highest loss by considering the partial path found in step 2.

The total obstruction loss is finally obtained by adding the three loss contributions:

\[ A_H = A_1 + A_2 + A_3 \]

### 2.1.2.1 Knife-edge merging distance

All the propagation models that use knife-edge diffraction (i.e., General Diffraction Model, ITU-R P.452 and P3M) have a knife-edge merging distance.

| Knife edge merging distance (m) | 10 |

Valid values for the knife-edge merging distance range between 0 and 100 meters. Very close diffraction edges for which the distance is lower than the merging distance are merged into a single edge.

The effect of merging very close diffraction edges is a lower diffraction loss value. If the merging distance is zero, edges are not merged.
2.1.3  Loss due to foliage

Foliage is defined either by a vector, a clutter class, or user-defined obstacle when using a link user profile. For vector data and user-defined obstacles, the associated obstacle type must be set to Tree. For clutter data, the foliage clutter class must be associated with the ground type Tree.

After you have defined the obstacle or ground type, ensure the appropriate geodata is selected in the profile sources.

2.1.3.1.1  CCIR

The CCIR model is an empirical model that enables one to predict foliage losses based on the frequency used and the foliage depths that impact line of sight.

Distance is calculated as follows:

\[ L_{\text{db}} = 0.2 f^{0.3} R^{0.6} \]

Equation 8  Foliage loss calculation

**NOTE**: Foliage loss is only available for General Diffraction Model.
2.2 Propagation Models

2.2.1 Free Space

The Free Space propagation model is the most basic model available as it does not account for the terrain. You should use it when the link is in line-of-sight, when the first Fresnel zone is completely clear (i.e., without obstruction) and when it is not necessary to account for other propagation phenomena (e.g., reflections/ducts/etc.). Free space losses may be written as (ITU-R P.525-2):

\[ A_{\text{freeSpace}} = 32.4 + 20 \cdot \log_{10}(d) + 20 \cdot \log_{10}(f) \]

Equation 9

Where

- \( d \) (km) is the distance
- \( f \) (MHz) is the frequency

**NOTE:** It is possible to include absorption losses with the Free Space Model.

2.2.2 ITU-R P.452

The ITU-R P.452 propagation model conforms to the prediction procedures for evaluating interference between sites as per the ITU-R P.452 recommendation.

2.2.2.1 Site angle and angular distance for transhorizon paths

The angle from horizon of the site of the transmission antenna (mrad) is given by:

\[ \theta_i = \theta_{\text{max}} = \max_{i=1}^{n-1} \left( \frac{h_i - h_{ts}}{d_i} - \frac{10^3 d_i}{2a_e} \right) \]

Equation 10

The site angle of reception antenna horizon (mrad) is given by:

\[ \theta_r = \max_{j=1}^{n-1} \left( \frac{h_j - h_{ts}}{d - d_j} - \frac{10^3 (d - d_j)}{2a_e} \right) \]

Equation 11

The angle of transhorizon broadcasting (see Example of a transhorizon path profile) is calculated according to:

\[ \theta = \frac{10^3 d}{a_e} + \theta_i + \theta_r \]

Equation 12

In these equations, all distances are in kilometres and all height values are in meters.

\( a_e = k_{50} \cdot a_0 \) is the terrestrial radius equivalent with \( a_0 = 6371 \text{ km} \).
Example of a path profile (transhorizon)

Note 1 – The $\theta_r$ value thus represented is negative.
### 2.2.2.2 Classification of paths

The various classifications to consider when dealing with different path types are shown in Table 1.

**Table 1: Classification and relevant model**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Propagation Model To Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct visibility, with first Fresnel zone clear</td>
<td>▪ Direct visibility</td>
</tr>
<tr>
<td></td>
<td>▪ Attenuation by groups of obstacles</td>
</tr>
<tr>
<td>Direct visibility with diffraction by obstacles located under the path (path incursion in the first Fresnel zone)</td>
<td>▪ Direct visibility</td>
</tr>
<tr>
<td></td>
<td>▪ Diffraction</td>
</tr>
<tr>
<td></td>
<td>▪ Attenuation by groups of obstacles</td>
</tr>
<tr>
<td>Transhorizon</td>
<td>▪ Diffraction</td>
</tr>
<tr>
<td></td>
<td>▪ Duct phenomena/reflection on layers</td>
</tr>
<tr>
<td></td>
<td>▪ Tropospheric broadcasting</td>
</tr>
<tr>
<td></td>
<td>▪ Attenuation by groups of obstacles</td>
</tr>
</tbody>
</table>

The classification of paths is performed according to the following method:

1. If $\theta_{\text{max}} > \theta_{\text{id}}$
   - Yes $\Rightarrow$ Transhorizon Path
2. If $\theta_{\text{f max}} > \theta_{\text{id}}$
   - Yes $\Rightarrow$ Path with diffraction by obstacles under the path
   - No $\Rightarrow$ Path has direct visibility
\[
\theta_{\text{max}} = \max_{i=1}^{n-1} \left( \theta_i \right) = \max_{i=1}^{n-1} \left( \frac{h_i - h_{ni}}{d_i} - \frac{10^3 d_i}{2a_e} \right) \quad \text{(mrad)}
\]

\[
\theta_{\text{max}}' = \max_{i=1}^{n-1} \left( \theta_i' \right) = \max_{i=1}^{n-1} \left( \frac{(h_i + R) - h_{ni}}{d_i} - \frac{10^3 d_i}{2a_e} \right) \quad \text{(mrad)} \text{ with } R = 17.392 \sqrt{\frac{d_j (d_i - d_j)}{d_i}}
\]

\[
\theta_y = \frac{h_n - h_{ni}}{d} - \frac{10^3 d}{2a_e} \quad \text{(mrad)}
\]

\[
a_e = 6371k_{\beta_0} = \frac{6371 \cdot 157}{157 - \Delta N} \text{ (km)}
\]

Equation 13

with \(\Delta N\) (N/km units) refractivity gradient.

2.2.2.3 Radio-meteorological data

This forecasting procedure uses three radio-meteorological parameters to describe the variability of normal and abnormal propagation conditions at different locations around the globe:

- \(\Delta N\) (N/km units), average refractivity gradient in the first kilometre of the atmosphere, is used to determine the equivalent radius of the earth to use in the analysis of the path profile and diffraction due to obstructions. It should be noted that \(\Delta N\) is a positive value.

- The parameter \(\beta_0\) (%) represents the percentage of time, for the lowest 100 meters of the atmosphere, that a decay gradient greater than 100 units N/km in the refraction index may be expected. This parameter is used to estimate, for the latitude considered, the relative incidence of totally abnormal propagation. The value to use for \(\beta_0\) is the value corresponding to the latitude of the middle point of the path.

- The parameter \(N_0\) (N units), a sea level co-index, is used exclusively in the tropospheric diffusion model as a measure of the variation of this mechanism as a function of the location. The correct values of \(\Delta N\) and \(N_0\) are those corresponding to the middle point in the path and are provided by the appropriate maps.

2.2.2.3.1 Value of the \(\beta_0\) parameter

The point incidence of normal propagation, \(\beta_0\)%, at the middle point of a path has the expression:

\[
\beta_0 = \begin{cases} 
0.015 |\phi| + 1.67 & \text{for } |\phi| \leq 70^\circ \\
4.17 \mu_i \mu_4 & \text{for } |\phi| > 70^\circ 
\end{cases}
\]

\(\phi\): latitude of the middle point of the path
The parameter $\mu_1$ depends on the proportion of path trunks located respectively above land (on land and/or coastal areas) and above water bodies. This parameter is expressed as:

$$\mu_1 = \left[ \frac{-d_{lm}}{16.68} + \left[ 10^{-0.496 + 0.354r_1} \right]^5 \right]^{0.2}$$

where the value of $\mu_1$ must be $\leq 1$,

$$\tau = \left[ 1 - e^{-\left( 4.12 \times 10^{-4} \times d_{lm}^{2.441} \right)} \right]$$

Where

$d_{lm}$ is the length of the longest continuous terrestrial trunk (within land masses and coastal areas) of the path on the plane of the great circle (km) (see Radio-climatic zones)

$d_{im}$ is the length of the longest continuous terrestrial trunk (within land masses) of the path on the plane of the great circle (km) (see Radio-climatic zones)

$$\mu_4 = \begin{cases} 
10^{-0.935 + 0.0170\varphi \log_{10} \mu_1} & \text{for } |\varphi| \leq 70^\circ \\
10^{0.3 \log_{10} \mu_1} & \text{for } |\varphi| > 70^\circ 
\end{cases}$$

2.2.2.3.2 Radio-climatic zones

Table 2 provides information about radio-climatic zones.

<table>
<thead>
<tr>
<th>Type of Zone</th>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal zone</td>
<td>A1</td>
<td>Coastal and shoreline zones, this zone covers land adjacent to the sea up to an altitude of 100 m above sea or water level, but limited to a distance of 50 km from the nearest maritime expanse.</td>
</tr>
<tr>
<td>Land zone</td>
<td>A2</td>
<td>All land, other than the &quot;coastal zones&quot; and shorelines in the meaning of Zone A1 above.</td>
</tr>
<tr>
<td>Sea</td>
<td>B</td>
<td>Seas, oceans and large water expanses (i.e., covering a circle of at least 100 km in diameter).</td>
</tr>
</tbody>
</table>

2.2.2.4 Additional loss due to diffraction

Additional loss due to $L_d (p)$ diffraction is calculated by the method described at 2.1.2, using a log-normal distribution of the loss between 50% and $\beta_0$:

- for $p = 50\%$, $L_d (50\%)$ is calculated using the method described in Recommendation UIT-R P.526 for the median value of the terrestrial radius equal to (50%) 
- for $p \leq \beta_0$, $L_d (\beta_0)$ is calculated using the method described in Recommendation UIT-R P.526 for the terrestrial radius equal to ($\beta_0$) using the knife edges identified for 50% of cases (median)

- for $\beta_0 < p < 50 \%$, $L_d (p)$ is provided by:

$$L_d (p) = L_d (50\%) - F_i (p) [L_d (50\%) - L_d (\beta_0)]$$

Equation 14

Where

$$F_i = I(p/100)/I(\beta_0/100)$$

The value of the equivalent terrestrial radius that should be used in calculations of diffraction is the following:

$a(p) = 6.371 \cdot k(p)$ (km$^2$/F)

- $k (50\%)$ is given by Equation 13
- \( k (\beta_0) = 3 \)

An acceptable approximation of \( I(x) \) for \( x < 0.5 \) given by:

\[
I(x) = \xi(x) - T(x)
\]

\[
T(x) = \sqrt{-2 \ln(x)}
\]

\[
\xi(x) = \frac{[(C_2 \cdot T(x) + C_1) \cdot T(x)] + C_0}{[(D_3 \cdot T(x) + D_2) \cdot T(x) + D_1]^{T(x)+1}}
\]

\[
C_0 = 2.515516698, \ C_1 = 0.802853, \ C_2 = 0.010328
\]

\[
D_1 = 1.432788, \ D_2 = 0.189269, \ D_3 = 0.001308
\]

### 2.2.2.5 Loss due to tropospheric propagation

Loss (dB) due tropospheric propagation is equal to:

\[
L_{\text{ts}}(p) = 190 + L_f + 20\log_{10}(d) + 0.573\theta - 0.15N_0 + L_e + A_g - 10.1 \left[ -\log_{10} \left( \frac{p}{50} \right) \right]^{0.7}
\]

Equation 15

**Where**

\[
L_f = 25 \cdot \log_{10}(\frac{f}{2}) - 2.5 \left[ \log_{10} \left( \frac{f}{2} \right) \right]^2
\]

(dB) loss as a function of the frequency

\[
L_e = 0.05 \cdot 10^{0.05 \cdot (G_e - G_s)}
\]

(dB) loss from coupling between the beginning and the middle where \( G_t \) and \( G_r \) are respectively, in dBi, the antenna gains for transmission and reception in the direction toward the horizon along the interference path along the great circle.

\( N_0 \) refractivity at ground normalized to sea level

\( A_g \) absorption by gases (with \( \rho = 3 \text{ g/m}^3 \) for the entire length of the path)

\( \theta \) (mrad) is the angular distance of the path
2.2.2.6 Loss due to abnormal propagation (ducts/reflection on layers)

2.2.2.6.1 Plane earth model and equivalent antenna heights

A linear approximation of terrain height above average sea level is calculated as:

$$ h_{SI} = h_{ST} + m \cdot d $$

- $h_{SI}$ is the height a-dnm (m) of a surface adjusted by least-squares method for a $d_i$ (km) from the source of interference
- $h_{ST}$ is the height a-dnm (m) of the surface of the plane Earth from the beginning of the path, that is for the interfering station
- $m$ is the slope (m/km) of the surface adjusted by the least-squares method, compared to the sea level.

For profiles of regularly-spaced points:

$$ m = \frac{\sum_{i=0}^{n} (h_i - h_a) \left( d_i - \frac{d}{2} \right)}{\sum_{i=0}^{n} \left( d_i - \frac{d}{2} \right)^2} $$

$$ h_a = \frac{1}{n+1} \sum_{i=0}^{n} h_i $$

For any other profile:

$$ m = \left( \frac{1}{d^3} \right) \sum_{i=1}^{n} 3 (d_i - d_{i-1}) (d_i + d_{i-1} - d) (h_i + h_{i-1} - 2h_a) + (d_i - d_{i-1})^2 (h_i - h_{i-1}) $$

$$ h_a = \left( \frac{1}{2d} \right) \sum_{i=1}^{n} (d_i - d_{i-1}) (h_i + h_{i-1}) $$

$h_I$ is the true height a-dnm (m) of the $i$th point of the land

$h_a$ is the average of real heights a-dnm on the path, bases $h_0$ and $h_n$ included, provided by:

The height $h_{ST}$ of the surface of the plane Earth, at the position of the interfering station, is given by:

$$ h_{ST} = h_a - m \frac{d}{2} $$

It follows that the height $h_{SR}$ of the surface of the plane Earth, at the position of the station receiving interference, is given by:

$$ h_{SR} = h_{ST} + m \cdot d $$

A correction should be made if the plane Earth heights are greater than the real heights:

$$ h_{ST} = \min (h_{ST}, h_0) $$

$$ h_{ST} = \min (h_{ST}, h_0) $$

If one or both of the two heights have been corrected then the slope value $m$ must also be corrected using the following formula:

$$ m = \frac{h_{SR} - h_{ST}}{d} $$

The parameter for terrain irregularity, $h_m$ (m), is the maximum height of terrain above the surface of the plane Earth for the section of the path between the two included horizon:

$$ h_m = \max_{i_{lr}} \left[ i_{lr} \left( h_i - (h_{ST} + m \cdot d_i) \right) \right] $$

Where $i_{lt}$ is the index of the profile point at a distance $d_{lt}$ from the transmitter

$i_{lr}$ is the index of the profile point at a distance $d_{lr}$ from the receiver
Example of Plane Earth surface and terrain irregularity parameter

The equivalent heights $h_{te}$, $h_{tr}$ of the antennas above the average terrain may be deduced:

$h_{te} + h_{st} = h_{ts} = \text{Altitude of point of transmission} + \text{Height above ground of transmitting antenna}$

$h_{te} + h_{sr} = h_{ts} = \text{Altitude of point of reception} + \text{Height above ground of receiving antenna}$

**2.2.2.6.2 Loss as a function of percentage of time and angular distance**

Loss (dB) is given by:

$$A_f = 102.45 + 20 \log_{10}(f) + 20 \log_{10}(d_p + d_v) + A_{ct, cr} + A_{ct, tr} + A_{tr} + A_{sr}$$

**Equation 16**

**Where**

- $A_{ct}$ = diffractive loss due to terrain screening for the transmitting station, respectively:

  $$A_{st, sr} = \begin{cases} 
  20 \log_{10} \left[ 1 + 0.361 \theta'' \left( f \cdot d_{lt, lr} \right)^{1/2} \right] + 0.264 \theta'' \left( f \cdot d_{lt, lr} \right)^{1/3} \text{ dB for } \theta'' > 0 \text{ mrad} \\
  0 \text{ dB for } \theta'' \leq 0 \text{ mrad}
  \end{cases}$$

  **Where**

  $$\theta'' = \theta_{lx} - 0.1 d_{lt, lr} \text{ mrad}$$

- $A_{ct, cr}$ corrections to account for coupling of surface ducts above bodies of water for the transmitting station and the receiving station, respectively:

  $$A_{ct, cr} = \begin{cases} 
  -3 e^{-0.2s d_{ct, lr}} \left[ 1 + \tgh \left( 0.07 (50 - h_{st, r}) \right) \right] \text{ (dB) for } w \geq 0.75, d_{ct, lr} \leq d_{lt, lr} \text{ and } d_{ct, lr} \leq 5 \text{ km} \\
  0 \text{ (dB) in all other cases}
  \end{cases}$$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d$</td>
<td>Length of path on great circle (km)</td>
</tr>
<tr>
<td>$d_{lt}, d_{lr}$</td>
<td>Distance between transmission and reception antennas and their respective horizons (km)</td>
</tr>
<tr>
<td>$\theta_t, \theta_r$</td>
<td>Angles of elevation from the horizon at transmission and at reception (mrad)</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Angular distance of path (mrad)</td>
</tr>
<tr>
<td>$h_{ts}, h_{rs}$</td>
<td>Height of center of antennas above the average sea level (m)</td>
</tr>
<tr>
<td>$h_{te}, h_{re}$</td>
<td>Antenna equivalent height above ground (m)</td>
</tr>
<tr>
<td>$d_{ct}(1)$</td>
<td>Distance between the first terminal station (interference source) and the coast, along the path of interference in the great circle plane (km)</td>
</tr>
<tr>
<td>$d_{cr}(1)$</td>
<td>Corresponding distance for the second station (station receiving interference) (km)</td>
</tr>
</tbody>
</table>

(1) These parameters should be included only for paths that include one or several trunks passing above bodies of water.

The exact values of $d_{ct}$ and $d_{cr}$ are significant only when $d_{ct}$ and $d_{cr} \leq 5$ km. If, for either one of these parameters or both, the distances are clearly greater than 5 km, you have to account for the condition $> 5$ km. There are a few interference paths that require detailed evaluation of these parameters.

### 2.2.2.6.3 Fixed loss per linkage

This loss (dB) is given by:

$$A_s(p) = \gamma_d \delta + A(p)$$

Equation 17

**Where**

$$\gamma_d = 5.10^{-3} \alpha f^{\frac{1}{2}}$$

linear attenuation in dB/mrad

$$\delta = 10^{\frac{d}{a_s}} + \theta_t + \theta_r$$

corrected angular distance or $\theta_{ct}$, $\theta_{cr}$

$$A(p) = -12 + (1.2 + 3.7 \times 10^{-3} d) \log_{10} \left( \frac{p_{t}}{p_{b}} \right) + 12 \left( \frac{p_{t}}{p_{b}} \right)$$

variation in percentage of time that:

$$\Gamma = \frac{1.076}{(2.0058 - \log_{10} \beta)^{1.012}} \times e^{-\left(9.51 - 4.8 \log_{10} \beta + 0.198 (\log_{10} \beta)^2\right) \times 10^{-6} \cdot d^{1.13}}$$

$$\beta = \beta_0 \cdot \mu_2 \cdot \mu_3$$

% (see definition of radio-meteorological parameters for $\beta_0$)
\( \mu_2 \): correction term to account for path geometry:

\[
\mu_2 = \left[ \frac{500}{a_e} \frac{d^2}{\left(\sqrt{h_e} + \sqrt{h_{re}}\right)^2} \right]^\alpha
\]

The \( \mu_2 \) value should not be greater than 1.

\[
\alpha = -0.6 - 3.5 \cdot 10^{-9} \cdot d^{3.1} \cdot \tau
\]  
(25a)

where: \( \varepsilon = 3.5 \)

\( \tau \): see definition of radio-meteorological parameters

\( \alpha \) must always be greater than or equal to \(-3.4\)

\( \mu_3 \) is a correction term to account for terrain irregularity:

\[
\mu_3 = \begin{cases} 
1 & \text{for } h_e \leq 10 \text{ m} \\
\exp \left[ -4.6 \times 10^{-5} (h_e - 10) (43 + 6d) \right] & \text{for } h_e > 10 \text{ m}
\end{cases}
\]

with \( d_i = \min(d - d_{lt} - d_{lr}, 40) \) km

2.2.2.6.4 Duct phenomena/reflection on layers

Loss (dB) during periods of abnormal propagation (ducts or reflection) is:

\[
L_{ba}(p) = A_f + A_d(p) + A_g
\]

Equation 18

Where

\( A_f \): total absorption by gases

\( A_d \): loss as a function of the percentage of time and angular distance, inside the abnormal propagation phenomena (Equation 16)

\( A_g(p) \): total value of losses by coupling between antennas and the structure of abnormal propagation in the atmosphere (Equation 17)

2.2.2.7 Loss due to groups of obstacles

Additional loss due to the protection against the effects of local groups of obstacles is expressed:

\[
A_h = 10.25 \times e^{-d_i} \left[ 1 - \tgh \left[ 6 \left( \frac{h}{h_o} - 0.625 \right) \right] \right] - 0.33
\]

Equation 19

Where

\( d_k \) is the distance (km) between the nominal position of the group of obstacles and the antenna (see Fig. 3)

\( h \) is height of the antenna (m) above local terrain

\( h_o \) is the nominal height of the group of obstacles (m) above the local terrain.

In the microwave planning features, this correction is included when the profile already uses clutter to analyse obstructions and in calculations of diffractive attenuation. Moreover, it is possible to specify a minimum distance, by type of clutter, beyond which this correction could not be integrated into the propagation loss.
2.2.2.8 Calculating losses

The losses to consider for a link are the sum of all the phenomena studied above. Recommendation ITU-R P452 states several methods for the overall prediction: V10, V12 and V13

2.2.2.8.1 ITU-R P452-10: methods of deriving overall predictions

<table>
<thead>
<tr>
<th>Path type</th>
<th>Action required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line-of-sight</td>
<td>The prediction is obtained by summing the losses given by the line-of-sight and clutter loss models, i.e.:</td>
</tr>
<tr>
<td></td>
<td>[ L_b(p) = L_{b0}(p) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td></td>
<td>where:</td>
</tr>
<tr>
<td></td>
<td>( L_{b0}(p) ): predicted basic transmission loss not exceeded for ( p % ) of time given by the line-of-sight model</td>
</tr>
<tr>
<td></td>
<td>( A_{ht}, A_{hr} ): appropriate additional losses due to height-gain effects in local clutter</td>
</tr>
<tr>
<td>Line-of-sight with sub-path diffraction</td>
<td>The prediction is obtained by summing the losses given by the line-of-sight and (sub-path) diffraction models and clutter models, i.e.:</td>
</tr>
<tr>
<td></td>
<td>[ L_b(p) = L_{b0}(p) + L_{ds}(p) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td></td>
<td>where ( L_{b0} )</td>
</tr>
<tr>
<td></td>
<td>( L_{ds}(p) ): prediction for ( p % ) of time given by the sub-path diffraction loss element of the diffraction model</td>
</tr>
<tr>
<td></td>
<td>( A_{ht}, A_{hr} ): appropriate additional losses due to height-gain effects in local clutter</td>
</tr>
<tr>
<td>Trans-horizon</td>
<td>The overall prediction can be obtained by applying the following ancillary algorithm:</td>
</tr>
<tr>
<td></td>
<td>[ L_b(p) = -5 \log \left( 10^{-0.2L_{bs}} + 10^{-0.2L_{bd}} + 10^{-0.2L_{ba}} \right) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td></td>
<td>where ( L_{bs}(p), L_{bd}(p) ) and ( L_{ba}(p) ): individual predicted basic transmission loss for ( p % ) of time given by the troposscatter, diffraction and ducting/layer reflection propagation models respectively.</td>
</tr>
<tr>
<td></td>
<td>NOTE: Where a model has not been proposed for a path (because the conditions given in Table 1 were not met), the appropriate term should be omitted from trans-horizon equation.</td>
</tr>
</tbody>
</table>
### 2.2.2.8.2 ITU-R P452-12: methods of deriving overall predictions

<table>
<thead>
<tr>
<th>Path type</th>
<th>Action required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Line-of-sight</strong></td>
<td>The prediction is obtained by summing the losses given by the line-of-sight and clutter loss models, i.e.:</td>
</tr>
<tr>
<td></td>
<td>[ L_b (p) = L_{b0} (p) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td><strong>where</strong></td>
<td>[ L_{b0} (p) : ] predicted basic transmission loss not exceeded for ( p )% of time given by the line-of-sight model</td>
</tr>
<tr>
<td></td>
<td>[ A_{ht}, A_{hr} : ] appropriate additional losses due to height-gain effects in local clutter</td>
</tr>
<tr>
<td><strong>Line-of-sight with sub-path diffraction</strong></td>
<td>The prediction is obtained by summing the losses given by the line-of-sight and (sub-path) diffraction models and clutter models, i.e.:</td>
</tr>
<tr>
<td></td>
<td>[ L_b (p) = L_{b0} (p) + L_{ds} (p) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td><strong>where</strong></td>
<td>[ L_{ds} (p) : ] prediction for ( p )% of time given by the sub-path diffraction loss element of the diffraction model</td>
</tr>
<tr>
<td><strong>Trans-horizon</strong></td>
<td>The overall prediction is obtained in three stages:</td>
</tr>
<tr>
<td></td>
<td>The unmodified ducting/layer reflection loss ( L_{ba} ) is obtained using Equation 18</td>
</tr>
<tr>
<td></td>
<td>The modified ducting/layer reflection model loss, ( L_{bam} (p) ), is found by application of the algorithm in § 4.7.1.</td>
</tr>
<tr>
<td></td>
<td>The overall prediction can then be obtained by applying the following ancillary algorithm:</td>
</tr>
<tr>
<td></td>
<td>[ L_b (p) = -5 \log (10^{-0.2L_{bs}} + 10^{-0.2L_{bd}} + 10^{-0.2L_{bam}}) + A_{ht} + A_{hr} ] dB</td>
</tr>
<tr>
<td><strong>where</strong></td>
<td>( L_{bs} (p) ) and ( L_{bd} (p) ): individual predicted basic transmission loss for ( p )% of time given by the troposcatter and diffraction propagation models respectively.</td>
</tr>
<tr>
<td></td>
<td>( L_{bam} (p) ) is the modified ducting/layer reflection loss</td>
</tr>
<tr>
<td><strong>NOTE 1</strong></td>
<td>– Where a model has not been proposed for a path (because the conditions given in Table 1 were not met), the appropriate term should be omitted from trans-horizon equation.</td>
</tr>
</tbody>
</table>
2.2.2.8.3 ITU-R P452-13: methods of deriving overall predictions

The basic transmission loss due to free-space propagation and attenuation by atmospheric gases is given by:

\[ L_{bfsg} = 92.5 + 20 \log f + 20 \log d + A_g \]  
\text{dB}  
\text{Equation 20}

The corrections for multipath and focusing effects at \( p \) and \( \beta_0 \) percentage times are given by:

\[ E_{sp} = 2.6 \left[ 1 - \exp\left(-0.1 \{d_h + d_l\}\right) \right] \log (p/50) \]  
\text{dB}  
\text{Equation 21}

The basic transmission loss not exceeded for time percentage, \( p\% \), due to LoS propagation:

\[ L_{b0p} = L_{bfsg} + E_{sp} \]  
\text{dB}  
\text{Equation 22}

The basic transmission loss associated with diffraction not exceeded for \( p\% \) time is given by:

\[ L_{bd} = L_{b0p} + L_{dp} \]  
\text{dB}  
\text{Equation 23}

The final basic transmission loss not exceed for \( p\% \) time, \( L_b \) (dB), as given by:

\[ L_b = -5 \log \left( 10^{-0.2 L_{b0}} + 10^{-0.2 L_{pam}} \right) + A_{ht} + A_{hr} \]  
\text{dB}  
\text{Equation 24}

\text{Where}  
\( A_{ht, hr} \): additional losses to account for clutter shielding the transmitter and receiver. These should be set to zero if there is no such shielding.

Loss accounting for phenomena specific to each kind of path is given in the following equations. The percentage \( p\% \) is an interface parameter used to correct calculations performed for \( p = 50\% \).

2.2.2.8.4 Direct visibility path, first free Fresnel zone

\[ L_b(p) = L_{b0}(p) + A_{ht} + A_{hr} \]  
\text{Equation 25}

\text{Where}  
\( L_{b0}(p) = 92.5 + 20 \log_{10}(f) + 20 \log_{10}(d) + E_s(p) + A_s \)

- \( E_s(p) \): Correction due to multipath and focalisation effects given by
  \[ E_s(p) = 2.6 \left[ 1 - e^{-\frac{d}{10}} \right] \log_{10} \left( \frac{p}{50} \right) \]

- \( A_s = [\gamma_o + \gamma_s(p)]d \) (See \textit{Section 2} concerning attenuation by gases.)

- \( A_{ht, hr} \) calculated according to Equation 19
NOTE: \( E_s(p) = 0 \) for \( p = 50\% \)

2.2.2.8.5 Line-of-sight path, diffraction by obstacles located under the path

\[
L_b(p) = L_b0(p) + L_d(p) + A_{ht} + A_{hr}
\]

Equation 26

Where

- \( L_b0(p) \) is given by Equation 21
- \( L_d(p) \) is given by Equation 14
- \( A_{ht} \) and \( A_{hr} \) calculated according to Equation 19

2.2.2.8.6 Transhorizon path

\[
L_b(p) = -5 \log_{10} \left( 10^{-0.2L_b0(p)} + 10^{-0.2L_d(p)} + 10^{-0.2L_{bs}(p)} \right) + A_{ht} + A_{hr}
\]

Equation 27

Where

- \( L_b0(p) \) is given by Equation 15
- \( L_d(p) \) is given by Equation 14
- \( L_{bs}(p) \) is given by Equation 18
- \( A_{ht} \) and \( A_{hr} \) are calculated according to Equation 19

2.2.3 General Diffraction Model

The General Diffraction Model is a simplified model that takes into account free space losses, diffraction losses and optionally absorption losses. Therefore, losses computed with this model can be described with the following formula:

\[
A_{\text{pathloss}} = A_{\text{freespace}} + A_{\text{diffraction}} + A_{\text{gaz}} + A_{\text{foliage}}
\]

Equation 28

NOTE: See propagation losses and free space section for calculation details.
2.2.4 P3M propagation model

P3M is the result of intensive research activities in the field of propagation modeling. It supports frequencies between 100 MHz and 60 GHz and encompasses an in-building penetration algorithm. While its 3D capabilities make it a perfect solution for urban and dense urban environments, it supports all environments and various cell types (e.g., macro cells, micro cells, and pico cells). You can model meteorological conditions using P3M including atmospheric and rain attenuation as well as water concentration.

Figure 1: P3M predictions at ground height (1.5m)

Figure 2: P3M predictions in-building, visualized in the 3D Viewer

With the P3M propagation model, you can generate predictions at multiple heights simultaneously, which improves the performance of the prediction generation process in urban areas. At the model height, which is assumed to be the ground height, predictions are generated both indoors and outdoors. At higher heights, only indoor predictions are generated inside buildings.
2.2.4.1 Path loss reciprocity

While it may sound like an obvious requirement, many propagation models do not return the same calculated path loss when the transmitter and the receiver are inverted. This is the unfortunate consequence of the assumptions that those models are based on, such as the height of the transmitting antenna (not lower than X meters) and the height of the receiving antenna (not higher than Y meters).

The P3M model was built with 3D and dense urban environments in mind. As a result, it cannot assume that the receiving antenna is located at the street level. With small cell deployments, it cannot assume either that transmitting antennas are placed at a reasonable height. To deal with these realities, the path loss calculation in P3M is fully reciprocal (from transmitter to receiver and vice versa), which enables predictions to be generated in conditions where other propagation models fail.

2.2.4.2 Radial versus bin

Instead of laying out path profiles in a pixel-based manner, the P3m propagation model creates profiles along radials that terminate at the edge of the prediction area, as shown in the figure below. Due to the nature of radio waves and in particular the width of their propagation path, this method proves to be at least as accurate as the pixel-based approach where profiles are created for each pixel of the path loss grid. In addition, the radial-based method brings significant gains in terms of computation time.
The optimal number of radials to use is automatically calculated depending on the resolution of the prediction as well as the maximum propagation distance. With large propagation distances, this can result in a large number of radials, which impacts calculation times. To mitigate this issue, you can define a dual resolution so that the number of radials is computed according to the user-defined Inner Area Radius value rather than the entire propagation distance. The P3M propagation model generates predictions at a number of points along each radial. It then performs bi-linear interpolation to build the final path loss grid, as shown in the figure below.

Figure 5: Radial-to-pixel interpolation

Points are uniformly spaced along each radial. Consecutive points are separated by a distance that corresponds to the prediction resolution. However, when using a dual resolution, the spacing used in the outer area (beyond the defined inner area radius) corresponds to the user-defined outer area resolution. The dual calculation resolution and the outer area resolution settings are defined in the P3M propagation model settings.

2.2.4.3 Geodata and profile extraction

P3M relies on the following geographical data:
- Digital Elevation Models (DEMs), also referred to as Height grids, which represent the height of the terrain above sea level.
- Land-use information, also referred to as Clutter grids, which classify the type of terrain (i.e., vegetation, trees, man-made structures, etc.).
- Building and vegetation heights, also referred to as Clutter Height grids, which specify the mean height above ground level of the clutter specified in the clutter grid. This information is useful in all environments, particularly in urban areas to describe the height of buildings.
- 3D building or vegetation outlines, also referred to as polygons, which detail the height and contour of each building or of the vegetation.

Figure 6: Examples of the various types of geodata

While the elevation data is mandatory, terrain data is optional. When extracting geographical data along a particular radial, the height is calculated as the sum of the elevation (altitude above sea
level) and the above ground height. If several sources of data are available to represent the terrain, the model automatically selects the most appropriate data source by order of priority:

1. For all locations inside the 3D Area, building polygons are considered, as well as clutter classifications marked as "Forest". This is because forests have a non-negligible impact on propagation losses. However, if a vegetation polygon ("Forest") is used, polygons inside the polygon area are considered while the Forest clutter type is considered outside the vegetation polygon area.

2. For all locations outside the 3D area but within the extent of at least one clutter height grid, the clutter height grid with the best resolution is considered.

3. For all locations outside the 3D area that are not covered by any clutter Height grid, the clutter grid with the best resolution is considered.

Figure 7: Illustration of how profiles are determined

Buildings are considered to have a flat rooftop. As a result, the height of building walls is automatically adjusted so that the rooftop height above the ground corresponds to the reported building height at the center of the building, as shown in the figure below.

Figure 8: Illustration of how building rooftops are dealt with

See section 5.1.6 for flat rooftop option.

2.2.4.4 Diffraction

Propagation losses that occur along a vertical profile largely depend on the obstructions between the transmitter and the receiver. The model estimates diffraction losses based on a number of parameters:

- The terrain heights along the profile
- The height and width of every obstacle along the profile
- The transmitter antenna height and the receiver antenna height
- The frequency used
  The P3M propagation model relies on the Epstein-Peterson multiple knife-edge diffraction method. It considers in sequence a number of edges and sums up the associated losses.
  - The first edge (E1) is the edge with the largest positive angle from the transmit antenna.
  - The last edge (E2) is the edge with the largest positive angle from the receive antenna.
  - The second edge (E3) is the edge with the largest positive angle from edge E1.
  - The second last edge (E4) is the edge with the largest positive angle from edge E2.
  - Edges E3 and E4, provided they both exist, are merged into a single edge (E5) as shown in the illustration above.
  - Similarly, if two edges are closer than the user-defined knife-edge merging distance, they are automatically merged into a single edge.
  - The diffraction loss associated with edge E1 (L1) is computed according to the distance between E1 and the straight line between the transmit antenna and edge E5. The loss is based on the amount of the first Fresnel zone that is obstructed as shown in the illustration below. When there is full clearance, there is no diffraction loss.
  - The diffraction losses associated with edges E2 and E5 are calculated in a similar manner.
  - Finally, the total diffraction loss is calculated as the sum of L1, L2 and L3.

![Figure 9: Multiple Edges (Epstein-Peterson)](image1)

![Figure 10: Illustration of the Fresnel Zone clearance](image2)
It is possible to change the diffraction model in Ellipse. See the Epstein-Peterson model description in section 2.1.2.

### 2.2.4.5 In-building penetration

The P3M propagation model includes an in-building penetration algorithm, which relies on the availability of building polygons and which predicts propagation losses both outdoors and indoors. The predicted path loss is first calculated close to the building, at the receiver height. A one-time penetration loss is applied at the main building wall. An additional loss is included, based on the distance traveled by the wave inside the building. This loss is meant to account for the presence of indoor separations, which obstruct typically less than building walls, as well as for locations and wall thickness values that are unknown to the network planner.

![Figure 11: Illustration of the in-building penetration algorithm at work](image)

While polygon IDs are unique, it is possible that two polygons share the same block ID. This happens, for example, when adjacent building polygons share a common wall. In this case, P3M considers the wall as an indoor wall in its in-building calculations.

![Figure 12: Illustration of how polygon IDs, building IDs, and block IDs are used.](image)
NOTE: The Polygon_ID column must contain unique integers.

2.2.4.6 Meteorological conditions

You can account for environmental conditions such as fog or rain by defining meteorological properties for the P3M model. This is particularly important when using super or extremely high frequencies (i.e., SHF 3 Hz-30 GHz r EHF 30 GHz-300 GHz). Losses incurred due to atmospheric or rain attenuation tend to increase at the mmWave wavelengths.

![Figure 13: Meteorological conditions and wave characteristics](image)

2.2.4.6.1 Atmospheric attenuation

Atmospheric attenuation is based on the ITU Recommendation ITU-P676 and includes:
- pressure
- temperature
- water concentration
You can define these values or they can be automatically calculated for you based on the location of the base station and the ITU classification by region.

2.2.4.6.2 Rain attenuation

Rain attenuation at certain mmW frequencies impacts the accuracy of predictions. For this reason, the P3M model now takes rain attenuation into account. Rain attenuation (A_r) is calculated as:

\[ A_r [dB] = \gamma_r \times d \]

Where

- \( d \) is the path length in kilometers (km)
- \( \gamma_r \) is the lineic attenuation (dB/km) due to rain

And, as with atmospheric attenuation, you can:
- define the rain rate, or
- automatically calculate an appropriate value based on the ITU Recommendation ITU-P838 (Release 3, 03/2005)
2.2.4.6.3 User-defined rain rate

When the rain rate R is a user-defined value in mm/h, the lineic attenuation in dB/km is based on the coefficients k and α listed in the coefficient table of the recommendation as a function of frequency and polarization, as defined in the ITU Recommendation ITU-P838.3:

\[ \gamma_r = k \times R^\alpha \]

2.2.4.7 Calculated rain rate

When the rain rate R is defined as the rainfall rate exceeded of the average year (p%) , the rain rate \( R_p \) in mm/h is automatically derived based on the transmitting location as specified in the ITU Recommendation ITU-R P.837-6 (02/2012). The calculated rain rate decreases when the percentage of time defined for Rainfall Rate Exceeded increases. The figure below displays an example of the rain rate variation according to the time exceedance in India.

<table>
<thead>
<tr>
<th>Rainfall rate exceeded for (%) of the time</th>
<th>Rain Rate Fall (mm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>112</td>
</tr>
<tr>
<td>0.01</td>
<td>60</td>
</tr>
<tr>
<td>0.1</td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

*Figure 14: Rain rate calculation example*

2.2.4.8 Foliage Loss

The P3M propagation model not only supports polygon files for buildings but also polygon files representing vegetation, such as Forest. To more closely model the impact of vegetation, a foliage loss (in dB/m) has been introduced, which is impacted by the distance the signal travels through the foliage as well as the frequency.

*Figure 15: Illustration of foliage loss where d=the signal path distance through foliage.*
As the signal travels through foliage, a loss is incurred as shown in the graph below.

![Signal degradation through foliage](image)

**Figure 2**  Signal degradation through foliage.

**NOTE**: Foliage loss will be available in Ellipse 8.7.

### 2.2.4.9 Defining vegetation data

To define the building polygons, open the Project Settings dialog box. On the GIS/Data Sources pane, select the Clutter layer and click the **Layer Settings** button.

![Layer Settings - Clutter](image)

**Figure 3**  Layer Settings - Clutter.

In the Other Scales section, select Ground Type and click Edit. Scroll down to “forest” and, from the associated list, select “tree”. 
For more information, see "Loss due to foliage".

**NOTE**: Vegetation clutter classes (such as Forest and Trees) should be assigned to the Tree clutter type, which is then used over the extents of the predictions. In this way, the foliage loss is accounted for in calculations; otherwise, no foliage loss is applied and vegetation is treated as any other obstacles.

### 2.2.4.10 P3M calculation parameters

The clutter calibration scale is defined in the clutter layer settings dialog.
3 Calculating Unavailability and error performance

Unavailability and error performance objectives are part of several ITU-R and ITU-T recommendations. The following paragraphs provide an insight into the ITU methods used in the software.

3.1 Calculating received power

The received power calculation takes into consideration main feeder loss values. When a diversity feeder is defined, an additional feeder loss value is considered. This is not taken into account for the link availability calculation.

Received power is determined using the following equation:

\[ P_{RX} = P_{TX} - \sum L_{feederTX} - \sum L_{deviceTX} - L_{slotTX} - L_{otherTX} + G_{TX} \\
- L_{pathloss} + G_{RX} - L_{otherRX} - L_{slotRX} - \sum L_{deviceRX} - \sum L_{feederRX} \]

Equation 29

Where

- \( P_{TX} \) (dBm) is the power used by equipment, defined per slot (in the Link Editor on the Channel tab (Slot configuration))
- \( L_{feederTX/RX} \) (dB) is the insertion losses linked to feeders (defined in the Link Editor on the Description tab, Coupling Device section)
- \( L_{deviceTX/RX} \) (dB) is the insertion losses linked to devices (defined in the Link Editor on the Description tab, Coupling Device section)
- \( L_{otherTX/RX} \) (dB) is the other insertion losses (defined in the Link Editor on the Description tab in the Antenna System section (Rx-Tx losses + radome loss))
- \( L_{slotTX/RX} \) (dB) is the losses specific to the channel used, defined per slot (defined in the Link Editor on the Description tab, in the Microwave Radio section (Losses For Attenuator and Splitters))
- \( G_{TX/RX} \) (dBi) is the antenna gain in the direction of the other extremity

3.1.1 Feeder losses

Using the Feeder Editor, you can define the name, manufacturer, and model of the feeder cables you want to account for in microwave link planning.

\[ L_{feeder} = A_{feeder} \cdot l + A_{other} \]

Equation 30

Where

- \( A_{feeder} \) (dB/m) is the lineic feeder loss (provided in dB/100m)
- \( l \) (m) is the length of feeder
- \( A_{other} \) (dB) is the additional feeder loss 1 and 2
3.1.2 Device losses

Using the Device Editor, you can define the name, type (attenuator, splitter or coupler), manufacturer, and model of the device you want to account for in microwave link planning.

\[ L_{device} = A_{device} + A_{other} \]

Equation 31

Where

- \( A_{device} \) (dB) is the device loss
- \( A_{other} \) (dB) is the additional device loss 1 and 2

3.1.3 Slot losses

Slot losses are calculated for microwave equipment.

3.1.3.1 Standard System

In a standard system, the losses observed at the channel level equal the attenuator loss values.

\[ L_{slot} = A_{attenuator} \]

Equation 32
3.1.3.2 Branching System

\[ L_{\text{slot}}(x) = A_{\text{attenuator}}(x) + A_{\text{split}}(x) + \sum_{i=0}^{x-1} A_{\text{split}}(i) \]

Equation 33

3.1.4 Antenna masking method

Antenna gain is calculated using the antenna model associated with points at each end of the microwave link. The antenna gain definition is contained in the antenna (.paf) file. You define the azimuth and elevation on the Description tab/Antenna System panel in the Link Editor.

**NOTE:** The transmitter gain is not necessarily equal to the maximum antenna gain.

3.1.4.1 Method 1

Using method 1, the antenna gain is calculated described in the equation below.

\[ G(\theta, \phi, \beta) = G_{\text{max}} - G_H(\theta) - G_V(\beta - \alpha) \]

Equation 34

**Where**

- \( \theta \) is the horizontal angle between the antenna azimuth and the receiver azimuth
- \( \phi \) is the tilt of the transmitter antenna
- \( \alpha \) is the tilt angle perceived by the receiver

\[ \alpha = a \tan(\tan(\phi) \cos(\theta)) \]

Equation 35
$\beta$ is the path elevation between the transmitter and the receiver

$G_{\text{max}}$ (dBi) is the maximum antenna gain

$G_{\text{hi}}$ (dB) is the horizontal cross-section antenna diagram, with $G_{\text{hi}}(0) = 0$

$G_{\text{V}}$ (dB) is the vertical cross-section antenna diagram, with $G_{\text{V}}(0) = 0$

### 3.1.4.2 Method 5

Method 5 gives identical, or nearly identical results, when compared with a simple antenna model for the most common interference scenarios (i.e., when either the azimuth separation or the tilt is small). A genuine antenna model simply extracts antenna gain based on the interference signal angle and adds the gain from each cut to the others. These models give significantly different results for scenarios with both a large azimuth separation and a large tilt separation. In these cases, a genuine model would give strongly over-optimistic predictions of interference (i.e., the antenna decoupling previsions would be much too large). Method 5, on the other hand, produces realistic predictions throughout calculations.

Differences occur in a small number of interference scenarios; this may be why these issues are often overlooked. When differences occur, though, they tend to be large and grow larger with increasing azimuth separation and/or tilt separation. InfoVista recommends choosing Method 5 for antenna gain calculations in scenarios with large differences. The choice of antenna model is of utmost importance.

Method 5 uses the following formulas.

**If both an H and a V diagram/cut exists (“model 5”):**

$$G = G_{\text{max}} + \left( w_{\text{H}} \cdot G_{\text{H}}(a_{T}) + w_{\text{V}} \cdot G_{\text{V}}(a_{T}) \right) / \left( w_{\text{H}} + w_{\text{V}} \right)$$

Where

- $w_{\text{V}} = V$ weight factor [deg]
  
  $$= \frac{180}{\pi} \cdot \arctan \left( \frac{|a_{\text{V}}|}{|a_{\text{H}}|} \right)$$

- $w_{\text{H}} = H$ weight factor [deg]
  
  $$= 90 - w_{\text{V}}$$

- $a_{T} = \text{total angle} \ [\text{deg}]$

  $$= \sqrt{\sqrt{a_{\text{H}}^2} + \sqrt{a_{\text{V}}^2}}$$

**If only a H diagram exist (“model 5”):**

$$G = G_{\text{max}} + G_{\text{H}}(a_{\text{H}})$$

Where

- $H = \text{horizontal}$
- $V = \text{vertical}$
- $a_{\text{H}} = H$ angle [deg]
- $a_{\text{V}} = V$ angle [deg]

$G_{\text{max}}$ = maximum (boresight) gain for the antenna [dBi]

$G_{\text{H}}(a)$ = gain/offset from H diagram/cut for specified angle “a” [dB] (linear interpolation from H diagram/cut)

$G_{\text{V}}(a)$ = gain/offset from V diagram/cut for specified angle “a” [dB] (linear interpolation from V diagram/cut)

$G = \text{total antenna gain for angle } a_{\text{H}} \text{ and } a_{\text{V}}$ [dBi]

$\arctan$ = the arctangent function

$\sqrt{\ }$ = the square-root function

$sqr$ = the square function

$\pi$ = the real number “pi”
3.1.5 Propagation losses

The propagation losses computed depend on the propagation model selected in the project settings. These losses are considered to be constant over time and statistically-defined phenomena such as rain or multipath are not included. These statistical phenomena are accounted for when evaluating link availability and quality.

**NOTE**: Propagation losses are described at section 2. Please refer to this section for calculation details.

3.2 Accounting for repeaters

3.2.1 Included in the link budget

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

\[
P = C f^a d^b 10^{-\frac{A}{10}}
\]

\( C, a \) and \( b \) are constants for the specific method used. The passive repeater effectively divided 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:

\[
P = (C_1 f^a d_1^b + C_2 f^a d_2^b) \times 10^{-A/10}
\]

For two passives with link path lengths \( d_1, d_2 \) and \( d_3 \), the fade probability is given by:

\[
P = (C_1 f^a d_1^b + C_2 f^a d_2^b + C_3 f^a d_3^b) \times 10^{-A/10}
\]

Power received is calculated according to the following formula:

\[
P_{RX} = P_{TX} - L_{feederTX} - L_{otherTX} - L_{slotTX} + G_{TX} - \sum L_{pathloss}(A \rightarrow R) + G_R - \sum L_{pathloss}(R \rightarrow B) + G_{RX} - L_{slotRX} - L_{otherRX} - L_{feederRX}
\]

Equation 36

This equation is similar to Equation 1; however:

- \( L_{pathloss}(A \rightarrow R) \) is the propagation losses between extremity A and the repeater
- \( L_{pathloss}(R \rightarrow B) \) is the propagation losses between the repeater and extremity B
- \( G_R \) is the repeater gain

Repeater gain is calculated based on the type of repeater: back-to-back or passive.

In the microwave link planning features, a repeater is created for a site by specifying the height of antennas or the repeater on the main tower of the site. Automatic antenna alignment is used to orient antennas of A and B toward the repeater based on its geographical location and its height.

3.2.2 Back-to-back repeaters

In the microwave planning features, a back-to-back repeater is defined directly by its gain.

It is not necessary to define the parts of the chain of reception-transmission (i.e., antennas, feeders, amplifiers) but it is necessary to subtract, from the gains of the chain of transmission, the possible losses due to near-field effects.
3.2.3 Passive repeaters

For passive flat reflector, the theoretical gain is given by:

\[ G = 20 \log_{10}(\frac{4\pi a \cos \frac{C}{2}}{\lambda^2}) \]

Where

\(a\): Effective area of the passive
\(\lambda\): Wavelength
\(C\): Horizontal angle between the two terminals

\textbf{NOTE:} It is not the direct distance between A and B that is accounted for.
3.3 Calculating margins

As per ITU recommendations, there are several margins that need to be correctly calculated in order to model microwave links effectively.

3.3.1 Thermal margins

In order for microwave links to operate correctly, the received power must be greater than the sensitivity threshold of the receiver. The thermal margin \( A_{\text{thermal}} \) is defined as:

\[
A_{\text{thermal}} (dB) = P_{\text{RX}} (dBm) - P_{\text{th}} (dBm)
\]

Equation 37

Where

- \( P_{\text{RX}} \) is the received power (see Equation 29)
- \( P_{\text{th}} \) is the receiver sensitivity for a given BER, as defined in the Equipment Settings (In the Project Data Explorer, edit a Radio)

Calculation results are limited to two decimal places for ease of comparison. In addition, the thermal margin is adjusted to account for outside factors (such as interference), factors related to equipment, or engineering margins.

NOTE: The margin represents the capacity of the link to “absorb” other statistical propagation losses (e.g., hydrometeors and multipath) that have not been included in calculations of received power. The margin is used as the basis for evaluating link quality and availability.

3.3.2 Additional engineering margins

You can reduce the calculated effective margin to account for reductions in the received field that result in an increase in the CNR (defined in the Project Settings dialog box on the Propagation Models/ General panel for the Multipath, Rain, and Refraction models).

\[
A'_{\text{thermal}} = A_{\text{thermal}} - A_{\text{user}}
\]

Equation 38

Calculation results are limited to two decimal places in order to facilitate comparisons outside of the tool.

3.3.3 Threshold deterioration due to interference / flat fade margin

When interference (I) impacts the microwave link, the signal-to-noise ratio (CINR) degrades as illustrated in the following equation.

\[
\frac{C}{I + N} = \frac{C}{N} \cdot \frac{1}{1 + I/N}
\]

(With C, I and N in W)

Equation 39

The presence of interference changes the CINR according to:

\[
\Delta(dB) = 10 \log_{10} \left( \frac{1}{1 + I/N} \right) = -10 \log_{10} \left( 1 + 10^{\frac{I(dBm)-N(dBm)}{10}} \right)
\]

Equation 40
The margin $M$ between the signal-to-noise ratio and the signal-to-threshold noise ratio, can be written as follows:

$$M = \frac{C}{N}(dB) + \Delta(dB) - CINR_{\text{threshold}}(dB)$$

Equation 41

Threshold degradation is defined as:

$$TD(dB) = -\Delta = 10 \log_{10} \left( 1 + \frac{I(dBm) - N(dBm)}{10} \right) = 10 \log_{10} \left( \frac{10^{N(dBm)/10} + 10^{I(dBm)/10}}{10^{I(dBm)/10}} \right) - N(dBm)$$

Equation 42

Where

$I (dBm)$ is the total interference level at receiver

$N (dBm)$ is the noise threshold of receiver

From margin $M$, the equation becomes:

$$M' = C(dB) + \Delta(dB) - 10 \log_{10} \left( N.CINR_{\text{threshold}} \right)$$

$$= C(dB) + \Delta(dB) - 10 \log_{10} \left( C_{\text{man}} \right)$$

$$= C(dB) - C_{\text{man}}(dB) - TD(dB)$$

Equation 43

The presence of interference reduces the thermal margin of the threshold degradation value. The flat fade margin can be defined as:

$$A_{\text{flat}} (dB) = A_{\text{thermal}} (dB) - TD(dB)$$

Equation 44

To account for $TD$, define a value in the Project Settings dialog box, on the Microwave Models/Propagation Models/General panel. Calculation results are limited to two decimal places in order to facilitate comparisons outside of the tool.

3.3.3.1 Noise calculation from noise factor

The noise threshold of the receiver is given by:

$$N(dBm) = 10 \log_{10}(k \cdot T \cdot B) + F + 30$$

Equation 45

Where

$k$ is the Boltzmann’s constant ($k = 1.38 \times 10^{-23}$ W/K/Hz)

$T$ is the standard temperature ($T=290K$).

$B$ (Hz) is the bandwidth

$F(dB)$ is the noise figure if the equipment

3.3.3.2 Noise calculation from T/I value

The threshold-over-interference (T/I) ratio provides information about the level of interference $I_{\text{obj}}$ that, located at T/I dB below the reception threshold $P_{\text{th}}$ leads exactly to a 1 dB degradation in the reception threshold. The T/I ratio combines the radio noise factor and the thermal noise.
From this definition and from Equation 44 with $T_{D0} = 1$ dB it can be deduced that:

$$N (dBm) = I_{obj} - 10 \cdot \log_{10} \left( \frac{1}{10^{10} - 1} \right) = P_{th} (dBm) - \left( \frac{T}{I} \right) + 5.868$$

Equation 46

Where

$P_{th}$ is the receiver sensitivity for a given BER (BER $10^{-6}$ defined for the equipment)

$T/I$ (dB) is the T/I co-channel ratio (Note that this parameter is defined for the equipment)

### 3.3.3.3 Determining the Noise factor

If available for the equipment, the parameters below are used to determine $N$ (in the following order):
1. The kTB value entered for the equipment.
2. The noise factor value and use of Equation 45.
3. The T/I value and the sensitivity threshold and the use of Equation 46.

### 3.3.4 Dispersive fade margin / effective margin (or composite)

Dispersive fade margin $A_{disp}$ is defined as the average depth of fading due to multipath that causes unavailability, independently of the thermal noise and interference. This is an equipment parameter that can be measured and applies only to digital links. The effective margin is defined as follows:

$$A_{effective} (dB) = -10 \cdot \log_{10} \left( \frac{-A_{disp} (dB)}{10} + 10 \cdot \frac{-A_{disp} (dB)}{10} \right)$$

Equation 47

Calculation results are limited to two decimal places in order to facilitate comparisons outside of the tool.

### 3.4 Determining link unavailability caused by hydrometeors

Several methods are available to determine link unavailability caused by hydrometeors as per recommendations P838-1, P838-2, P838-3. ITU P-838-3 is the latest version. Methods that were supported in previous versions of the standard are still available, for consistency purposes when you open a project created with previous versions of the software.

Methods to determine link unavailability caused by hydrometeors rely on empirical data, so the latest method is the more accurate. When you create a new project, Mentum recommends choosing ITU P-838-3. You define this value in the Project Settings dialog box. When you create a new project, we recommend you choose the ITU P838-3 in the Microwave Models/Availability/ Rain Models/\ITU-R P.530 7-14 panel, in the Models Settings section.

**NOTE:** In Ellipse 6.x, the only available method was ITU P838-1.

There are two ways to calculate unavailability due to hydrometeors (i.e., the outage probability). The percentages calculated for the different methods are annual percentages that may be later converted to worst month values.
3.4.1 ITU methods

Microwave link planning features respect the following ITU prediction methods for calculating unavailability due to rainfall.

3.4.1.1 Calculating rainfall intensity, $R_{0.01}$

This calculation is based on a rainfall intensity $R_{0.01}$ (mm/h) that is not exceeded more than 0.01% of the time. Attenuation $A_{0.01}$ due to rainfall in this case is given by:

$$A_{0.01} = \gamma d_e$$

Equation 48

Where

The lineic attenuation (dB/km) is based on coefficients $\alpha$ and $\beta$ with values as listed in Appendix B and as a function of frequency and polarisation according to:

$$\gamma = \alpha R_{0.01}^\beta$$

Equation 49

NOTE: $\beta$ coefficients are called $k$ in Appendix B

The effective length is a function of the real length and the rainfall intensity given by:

$$d_e = \frac{d}{1 + d/d_0}$$

Equation 50

With $d$ in kilometres and $d_0 = 35e^{-0.015 R_{0.01}}$

Values for $\alpha$ and $\beta$, which are untabulated frequency values, are determined using linear interpolation.

3.4.1.2 Calculating unavailability using the ITU-R P.530-7 method

When attenuation $A$ is exceeded for a certain amount of time 0.01%, unavailability is calculated using the following formula:

$$\frac{A}{A_{0.01}} = 0.12P^{-(0.546 + 0.043 \log_{10}(P))}$$

Equation 51

3.4.1.3 Calculating unavailability using the ITU-R P.530-8/13 method

Recommendation P530-8/13 also provides another formula applicable for latitudes less than 30° north or south. The formula from recommendation P530-7 remains applicable for latitudes between 30° north and 30° south.

$$\frac{A}{A_{0.01}} = 0.07P^{-(0.855 + 0.139 \log_{10}(P))}$$

Equation 52
### 3.4.1.4 Calculating unavailability using the ITU-R P.530-14/16 method

The technique used by Recommendation P530-14 and above for estimating rain attenuation is similar to previous versions. The effective path length is computed using the actual path length \( d \) by the following distance factor:

\[
r = \frac{1}{0.477 \cdot d^{0.633} \cdot R^{0.073 \cdot \alpha} \cdot f^{0.123} \cdot 10^{-0.579 \cdot (1 - \exp(-0.024 \cdot d))}}
\]

Equation 53

The formula used to compute attenuation is:

\[
\frac{A_p}{A_{0.01}} = C_1 \cdot P^{-(C_2 + C_3 \log_{10} P)}
\]

with:

\[
C_1 = \left(0.07 \cdot C_0\right) \cdot 0.12^{(1-C_0)}
\]

\[
C_2 = 0.855C_0 + 0.546(1-C_0)
\]

\[
C_3 = 0.139C_0 + 0.043(1-C_0)
\]

where:

\[
C_0 = \begin{cases} 
0.12 + 0.4 \log_{10} \left( \frac{f}{10} \right)^{0.8} & f \geq 10 \text{ GHz} \\
0.12 & f < 10 \text{ GHz}
\end{cases}
\]

Equation 54

### 3.4.1.5 Margins used in calculations

In the preceding equations, the attenuation \( A \) that is used to calculate \( P \) is known as the fade margin.

### 3.4.1.6 Calculating unavailability caused by rain and wet snow using the ITU-R P.530-12 and above

The ITU-R P 530-12 integrates a method to account for attenuation due to rain and wet snow to consider in high latitudes or high link altitudes. The incidence of the effect of melting ice particles or wet snow in the melting layer is determined by the height of the link in relation to the rain height, which varies with geographic location. The variation of zero-degree rain height is taken into account in the method by taking 49 height values relative to the median of the rain height, with a probability associated with each and given in Appendix C.

The absorption and scattering by rain, \( R \) is calculated and should be considered at frequencies where both rain attenuation and multipath fading must be taken into account.

The option to consider the combined method for rain and wet snow is available in the Project Settings, on the Microwave Models/Availability/Rain Models/ITU-R P.530 7-13 panel, in the Models Settings section.

\[
A_{r3} = A_p \cdot F
\]
Where

$A_{rs}$ is the combined attenuation due to rain and wet snow

$A_p$ is the attenuation exceeded for time percentage $p$ (valid only for link path through which only liquid rain falls)

$F$ is the probability factor given in Appendix C.

### 3.4.1.7 Calculating the latitude correction using IRU-R P 530-8 and above

The option to use latitude correction in the prediction method is available in the Project Settings, on the Microwave Models/Availability/Rain Models/ITU-R P.530 7-13 panel, in the Models Settings section.

### 3.4.2 Crane method

Crane statistics provide, for different regions of the world, rainfall intensity values not exceeded for different percentages of time. ITU recommendations also provide this type of information for various regions. This data can be used in calculations using the ITU method. In this case, only the value provided for 0.01% of the time for the selected region is used.

The crane method regions are available in the Project Settings dialog box, on the Microwave Models/Availability/Rain Models/Crane Method panel.

The Crane method uses the tabulated information on the rainfall intensity $R_p$ which produces attenuation equal to the fade margin. From a rainfall intensity value, the corresponding attenuation is given by:

\[
A = \alpha R_p \left( \frac{e^{\mu d} - 1}{\mu \beta} - \frac{b^\beta e^{c \beta d}}{c \beta} + \frac{b^\beta e^{\gamma \beta d}}{c \beta} \right) \quad \text{for} \quad d \leq D \leq 22.5 \text{ km}
\]

\[
A = \alpha R_p \left( \frac{e^{\mu D} - 1}{\mu \beta} \right) \quad \text{for} \quad D < d
\]

Equation 56

Where

\[
\mu = \ln(b e^{c d})/d
\]

\[
b = 2.3 R_p^{-0.17}
\]

\[
c = 0.026 - 0.031 \ln(R_p)
\]

\[
d = 3.8 - 0.61 \ln(R_p)
\]

If the length of a hop $d$ (km) is greater than 22.5 km the calculation is done using $d = 22.5$ km and the following correction is applied:

\[
P_{\text{modified}} = P \left( \frac{22.5}{d} \right)
\]

Equation 57

Linear interpolation is used to determine the percentage of unavailability $P$ corresponding to this attenuation (i.e., the rainfall intensity values are calculated for different time percentages).

### 3.4.3 Year to Worst Month conversion method

Both ITU and Crane methods provide an estimation of the annual unavailability due to hydrometeors. The conversion to worst month unavailability is done with Recommendation ITU-R P841-4.
3.5 Calculating link unavailability due to multipath

There are several models that you can use to calculate unavailability due to multipath propagation. Generally, fade-out probability \( p_w \) is a function of distance \( d \), frequency \( f \) and the fade out margin \( A \) according to:

\[
p_w(A) \propto f^b d^c 10^{\frac{A}{10}}
\]

Equation 58

The occurrence factor \( p_0 \) is defined as:

\[
p_0 = p_w(0)
\]

Equation 59

**NOTE:** \( p_w \) is a percentage, given for the worst month.

3.5.1 ITU methods

Microwave link planning features respect the following ITU prediction methods for calculating unavailability due to multipath.

3.5.1.1 Recommendation ITU-R P.530-7/8

The probability of unavailability due to multipath is:

\[
p_w = K \cdot d^{3.6} \cdot f^{0.89} (1 + \varepsilon_p)^{-1.4} 10^{\frac{A}{10}} \%
\]

Equation 60

**Where**

\( f \) (GHz) is the frequency  
\( d \) (km) is the distance  
\( A \) (dB) is the effective fade-out margin (or flat margin if signatures are used)  
\( K \) is the geo-climatic factor for the worst month  
\( \varepsilon_p \) (mrad) is the path incline (mrad) is:

\[
\varepsilon_p = 1000 \left| \frac{h_r - h_e}{1000d} \right| \approx \left| \frac{h_r - h_e}{d} \right|
\]

Equation 61

**Where**

\( h_r \) and \( h_e \) are the altitudes of transmission and reception antennas
3.5.1.2 Recommendation ITU-R P.530-9/12 and Recommendation ITU-R P530-13

ITU Recommendations P530-9/12 and P530-13 are virtually the same, with the exception of how $K$ and $pw$ are calculated. The recommendations deal specifically with the flat fade margin and the equipment signature.

3.5.1.2.1 Including a calculation of the geoclimatic factor

The geoclimatic factor is:

$$K = 10^{4.2 - 0.0029dN_1}$$

Equation 62

$$K = 10^{3.9 - 0.003dN_1} S^a^{-0.42}$$

Equation 63

Where

$dN_1$ is the refractivity gradient not exceeded for 1% of an average year in the first 65 meters of the atmosphere (illustrated in Figure 12 of the ITU-R P.453-9 recommendation).

You can define the value for $dN_1$ on the Microwave Models\Availability\Multipath Models \ITU-R P.530 13, ITU-R P.530 7-8 or ITU-R P. 530 9-12 panels, in the Geoclimatic Factor section. You can also use the values provided in the ITU recommendations available in the Project Settings dialog box, on the Microwave Models/ITU Tabulated Values panel.

You can define the value of $K$ in Microwave Models\Availability\Multipath Models \ITU-R P.530 13, ITU-R P.530 7-8 or ITU-R P. 530 9-12 panels, in the Geoclimatic Factor section.

The probability of unavailability due to multipath propagation is:

$$p_w = K d^{3.1} \left(1 + \left|\epsilon_p\right|\right)^{-1.29} f^{0.8} \times 10^{-0.00089 h_L - A/10} \%$$

Equation 64

Where

$K$ is the geoclimatic factor obtained using equation 72

$f$ (GHz) is the frequency

$d$ (km) is the distance

$A$ (dB) is the effective fade-out margin (or flat margin if signatures are used)

$\epsilon_p$ (mrad) is the path incline

$h_L$ (m) is the minimum altitude between $h_r$ and $h_e$
3.5.1.2.2 Calculating the geoclimatic factor to account for roughness

The geoclimatic factor is:

\[ K = 10^{-4.4 - 0.0027 dN_1 (10 + s_a)^{0.46}} \]

Equation 65

Where

\( dN_1 \) is the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year

\( s_a \) is the terrain roughness, defined as the standard deviation of terrain heights in a square 110 km by 110 km in size centered at the middle of the studied path, assuming a resolution of 30 arc seconds.

NOTE: The roughness calculation is performed using the standard deviation of terrain heights along the single path analysed (identical to the method for calculating unavailability using the KQ factor). You can also define a roughness factor in Microwave Models dialog box, in the Availability/Multipath Models/K.Q. Factor panel, in the Settings section.

The probability of unavailability due to multipath propagation is:

\[ p_w = K d^{3.4} (1 + |e_p|)^{-1.03} f^{0.8} \times 10^{-0.00076 h_L - A/10} \%
\]

Equation 66

Where

\( f \) is the frequency in GHz

\( h_L \) is the altitude of the lower antenna

The multiplying factor for index \( i \) is calculated by:

\[ \Delta F = \Gamma(\Delta h) P_i \]

Equation 67

Where

\( \Gamma(\Delta h) \) is a multiplying factor that takes account of differing specific attenuations according to height relative to the rain height, given by:

\[
\Gamma(\Delta h) = \begin{cases} 
0 & 0 < \Delta h \\
\frac{4(1-e^{\Delta h/70})^2}{1+\left(1-e^{-((\Delta h/600)^2)}\right)^2 \left(4(1-e^{\Delta h/70})^2-1\right)} & -1200 \leq \Delta h \leq 0 \\
1 & \Delta h < -1200 
\end{cases}
\]

And \( P_i \) is the probability that the link will be at \( \Delta h \).

\( \Delta F \) must then be added to the current value \( F \) as follows:

\[ F = F + \Delta F \] dB


3.5.2 Vigants-Barnett method

The probability of unavailability due to multipath propagation is:

\[ p_w = 6.0 \cdot 10^{-7} \cdot C \cdot f \cdot d^3 10^{\frac{-A}{10}} \, \text{(%)} \]

Equation 69

Where

- \( f \) (GHz) is the frequency
- \( d \) (km) is the distance
- \( A \) (dB) is the effective fade out margin
- \( C \) is the factor C

You can define the coefficient C or specify that it be calculated using geoclimatic factor \( c_t \) and terrain roughness \( S \) (calculated by the method above or user-defined) according to:

\[ C = c_f \left( \frac{S}{15.2} \right)^{-1.3} \]

Equation 70

These settings are available in Project Settings dialog box, on the Microwave Models\Availability\Multipath Models \Vigants-Barnett panel, in the C factor section.

3.5.3 K.Q factor method

3.5.3.1 K.Q factor method without accounting for roughness

The probability of unavailability due to multipath propagation is:

\[ p_w = K.Q \cdot f^b d^c 10^{\frac{-A}{10}} \, \text{(%)} \]

Equation 71

Where

- \( f \) (GHz) is the frequency
- \( d \) (km) is the distance
- \( A \) (dB) is the effective fade out margin
- \( b, c \) are user-defined factors that account for regional effects
- \( K.Q \) is a user-defined factor

3.5.3.2 K.Q factor method accounting for roughness

The probability of unavailability due to multipath is:

\[ p_w = \frac{K.Q}{S^1.5} \cdot f^b d^c 10^{\frac{-A}{10}} \, \text{(%)} \]

Equation 72

Where

- \( f \) (GHz) is the frequency
- \( d \) (km) is the distance
S(m) is the terrain roughness (calculated by the method above or user-defined)
A(dB) is the effective fade out margin

3.5.4 ETSI method (TR 101 016, Annex A)

This algorithm calculates flat fading (i.e., the probability that a specified fade margin is exceeded, due to flat
(non-selective) multipath propagation only) during a specified period of time (the worst month or year).

3.5.4.1 Worst month probability

The worst month flat fading probability is calculated according to the following steps:

*Step 1.* Calculate the geo-climatic factor $KQ$ as:

\[
KQ = KQ_{const} \cdot KQ_{func}
\]

and

\[
KQ_{func} = 1 \quad \text{<None>}
\]

\[
KQ_{func} = (h_A + h_B)^{-0.5} \quad \text{Antenna heights}
\]

\[
KQ_{func} = w^{-1.3} \quad \text{Terrain roughness}
\]

\[
KQ_{func} = s^{-1.4} \quad \text{Terrain slopes}
\]

where

- $KQ$ geo-climatic factor (1)
- $KQ_{const}$ $KQ$ constant (1)
- $KQ_{func}$ $KQ$ function
- $h_{A,B}$ station A|B antenna height (m AMSL)
- $w$ terrain roughness (m)
  (calculated from path profile, $\geq 1$ m)
- $s$ terrain slopes (mrad)
  (not yet supported)
Step 2. Calculate the multipath occurrence factor \( P_0 \) as:

\[
P_0 = KQ \cdot f^B \cdot d^C
\]

where

- \( P_0 \) multipath occurrence factor (1)
- \( f \) frequency (GHz)
- \( B \) frequency factor
- \( d \) path distance (km)
- \( C \) distance factor

Step 3. Calculate the worst month flat fading probability \( P_F \) as:

\[
P_F = P_0 \cdot 10^{\left(\frac{M}{10}\right)}
\]

Where

- \( P_F \) worst month flat fading probability (1)
- \( M \) fade margin (dB)

3.5.4.2 Shallow fading

The calculation above applies to the deep fading region ("small percentages of time"). For lower fade margins ("various percentages of time"), the shallow fading interpolation is used instead. The following division between deep and shallow fading applies:

- \( 35 \leq M \) Deep fading
- \( 25 \leq M < 35 \) Conditional
- \( M < 25 \) Shallow fading

3.5.5 Methods using signatures

3.5.5.1 ITU Multipath Method

ITU recommendation P.530 accounts for unavailability due to frequency-selective and frequency non-selective fading (i.e., flat fading). Flat fading is calculated using the equipment signature parameters required for transmission.
3.5.5.1.1 Calculating unavailability due to selective fading (ITU-R P.530)

According to the signature method described in recommendation P.530, the probability (between 0 and 1) of unavailability due to selective fading is:

\[ p_s = 2.15qW \frac{\tau_m^2}{\tau} \left( 10^{-B_M/20} + 10^{-B_{NM}/20} \right) \]

Equation 73

Where

\[ \tau_m = 0.7 \left( \frac{d}{50} \right)^{1.3} \] (ns) is the average temporal delay where d (km) is the path length

\[ W \] (GHz) is the signature width (defined in the radio configuration)

\[ \tau \] (ns) is the reference delay for obtaining the signature (defined in the radio configuration)

\[ \eta = 1 - e^{-10^{0.1} e^{\tau_m \eta}} \] is the activity factor where \( P_0 = p_0/100 \) is the occurrence factor

\[ B_M \] (dB) is the signature depth (minimum phase) (defined in the radio configuration)

\[ B_{NM} \] (dB) is the signature depth (non minimum phase) (defined in the radio configuration)

3.5.5.1.2 Calculating unavailability due to selective fading (ITU-R F.1093 method B)

According to the simplified method (ITU-R F.1093), the probability (between 0 and 1) of unavailability due to selective fading is given by:

\[ p_s = 4.32\eta \left( \frac{\tau_m^2}{T^2} \right) K_n \]

Equation 74

Where

\[ \tau_m = 0.7 \left( \frac{d}{50} \right)^{1.3} \] (ns) is the average temporal delay where d (km) is the path length

\[ \eta = 1 - e^{-10^{0.1} e^{\tau_m \eta}} \] is the activity factor where \( P_0 = p_0/100 \) is the occurrence factor

\[ K_n \] is the standardized signature parameter (defined in the radio configuration)

\[ T \] (ns) is the symbol duration of the system (defined in the radio configuration)

3.5.5.1.3 Calculating unavailability with selective and non-selective fading

Other than the use of diversity techniques, the probability (between 0 and 1) of total unavailability is given by:

\[ p_t = p_{ns} + p_s \]

Equation 75

Calculation of \( p_t \) is shown in the formulas described above. In the calculation of \( p_{ns} = p_{w}/100 \), \( p_{w} \) is equivalent to Equation 58 (ITU), Equation 60 (ITU), Equation 64 (ITU), Equation 69 (Vigants-Barnett Method), Equation 71 (K.Q factor method), or Equation 72 (K.Q method with roughness), using as reference the margin other than the dispersive fade margin of the equipment (i.e., a margin of protection against flat fading).

If you do not choose signature use, the total unavailability is calculated using the same equations although the effective calculated margin is used as a reference and may include the dispersive fade margin of the equipment.
3.5.5.2 ETSI method (TR 101 016, Annex A)

This algorithm calculates the selective fading (i.e., the probability that a specified fade margin is exceeded, due to frequency selective multipath propagation only) during a specified period of time (the worst month or the year).

3.5.5.2.1 Worst month probability

The worst month selective fading probability is calculated according to the following steps:

*Step 1.* Calculate the multipath activity parameter $\eta$ as:

$$\eta = 1 - e^{(-0.2 \cdot P_0^{0.75})}$$

where

$\eta$ multipath activity parameter (1)

$P_0$ multipath occurrence factor (1), from the worst month flat fading probability calculation

*Step 2.* Calculate the mean value of the time delay between the direct and indirect paths as:

$$\tau_m = 0.7 \cdot \left(\frac{d}{50}\right)^{1.3}$$

where

$\tau_m$ mean value of the time delay (ns)

$d$ path distance (km)

*Step 3.* Calculate the worst month selective fading probability $P_S$ as:

$$P_S = 2 \cdot 10^{-3} \cdot \eta \cdot W_{nm} \cdot 10^{\frac{B_{nm}}{20}} \cdot \left(\frac{\tau_m^2}{\tau_r}\right)$$

where

$P_S$ worst month selective fading probability (1)

$W_{nm}$ signature width (MHz) for non-minimum phase

$B_{nm}$ signature depth (dB) for non-minimum phase

$\tau_r$ reference time delay (ns) for signature measurement, typically 6.3 ns

3.5.6 Worst Month to Year conversion methods

The implementation of Year/Month conversion methods for attenuation due to multipath considers recommendation ITU-R P.841 and ITU RP530 Methods. The settings are available in multipath sections of the project settings.

NOTE: Please refer to section 3.9 for calculation details.
3.6 Diversity techniques against unavailability due to multipath

There are two methods for calculating the unavailability improvements gained by using diversity techniques.

3.6.1 ITU methods

Microwave link planning features respect the following ITU methods for calculating improvements gained from diversity techniques.

3.6.1.1 Improvement due to space diversity

The factor $I_{sdns}$ for improvement due to space diversity in the vertical plane and for narrow band signals is given in recommendation P.530 (for $43 \leq d \leq 240$ km, $2 \leq f \leq 11$ GHz, $3 \leq S \leq 23$ m) according to:

$$I_{sdns} = \left[ 1 - \exp\left(-0.04 \cdot S^{0.87} f^{-0.12} d^{0.48} p_0^{-1.04}\right) \right] \cdot 10^{\left(A-V+I_{comb}\right)/10}$$

Where

$$V = |G_1 - G_2|$$

Equation 76

Where

- $G_1$, $G_2$ (dBi) is the gain of the two antennas
- $S$(m) is the vertical separation (from center to center) between the reception antennas
- $f$(GHz) is the frequency
- $d$(km) is the length of the path
- $A$(dB) is the protection margin (effective) against fading
- $p_0$(%) is the multipath propagation occurrence factor
- $I_{comb}$ (dB) is the IF combiner gain (equipment parameter)

**NOTE:** Since it is not possible to use a different antenna for the two receiving antennas, $V=0$ is still valid.

3.6.1.2 Improvements due to frequency diversity

This method applies to 1+1 systems, the $I_{fdns}$ factor for improvement due to frequency diversity is given in recommendation P.530 (for $30 \leq d \leq 70$ km, $2 \leq f \leq 11$ GHz, $\Delta f/f \leq 5$ %) according to:

$$I_{fdns} = \frac{80}{f \cdot d} \left(\frac{\Delta f}{f}\right) 10^{\left(A/10\right)}$$

Equation 77

Where

- $\Delta f$(GHz) is the frequency difference: If $\Delta f > 0.5$ GHz, use $\Delta f = 0.5$
- $d$(km) is the length of the path
- $f$(GHz) is the frequency
- $A$(dB) is the protection margin (effective) against fading

**NOTE:** Improvements using angle diversity (as described in P.530-10) are not accounted for.
3.6.1.3 Calculating unavailability using frequency or space diversity techniques

Improvements gained through frequency and space diversity techniques are accounted for as follows. The term \( I_{ns} \) replaces both terms \( I_{dns} \) and \( I_{dns} \) calculated above.

From the activity factor defined from \( P_0 = \frac{p_0}{100} \) according to:

\[
\eta = 1 - e^{-0.2 \cdot 60^{0.75}}
\]

Equation 78

The square of the correlation coefficient of non-selective fading is calculated according to:

\[
k_{ns}^2 = 1 - \frac{I_{ns} \cdot p_{ns}}{\eta}
\]

Equation 79

The square of the correlation coefficient of selective fading is calculated according to:

\[
k_{s}^2 = \begin{cases} 
0.8238 & \text{for } r_w \leq 0.5 \\
1 - 0.195 \cdot (1 - r_w)^{0.109 - 0.130 \log_{10}(1 - r_w)} & \text{for } 0.5 < r_w \leq 0.9628 \\
1 - 0.3957 \cdot (1 - r_w)^{0.5136} & \text{for } r_w > 0.9628 
\end{cases}
\]

Equation 80

Where

\[
r_w = \begin{cases} 
1 - 0.9746 \left(1 - k_{ns}^2\right)^{2.170} & \text{for } k_{ns}^2 \leq 0.26 \\
1 - 0.6921 \left(1 - k_{ns}^2\right)^{0.034} & \text{for } k_{ns}^2 > 0.26 
\end{cases}
\]

The probability (between 0 and 1) of interruption due to non-selective fading is given by:

\[
p_{dns} = \frac{p_{ns}}{I_{ns}}
\]

Equation 81

The probability (between 0 and 1) of interruption due to selective fading is given by:

\[
p_{ds} = \frac{\left( \frac{p_s}{L_{comb}} \right)^2}{\eta(1 - k_{s}^2)}
\]

Equation 82

The total probability (between 0 and 1) of interruption is given by:

\[
p_d = \left( p_{dns}^{0.75} + p_{ds}^{0.75} \right)^{4/3}
\]

Equation 83

3.6.1.4 Calculating unavailability using frequency and space diversity techniques

In this case, the calculation is identical to the calculation described when using frequency or space:

\[
k_{ns,s+f} = k_{ns,s} \cdot k_{ns,f}
\]

Equation 84

The following can then be deduced (by neglecting second order terms), which is not provided in recommendation P.530:
\[ I_{ns,s+f} = I_{ns,s} + I_{ns,f} - \frac{P_{ns}}{\eta} I_{ns,s} I_{ns,f} \approx I_{ns,s} + I_{ns,f} \]

Equation 85

3.6.1.5 Calculating unavailability using diversity techniques without signature

The most basic scenario is when the probability of frequency-selective fading is not accounted for. The improvement factor defined according to equation 95 is used and the probability is given by:

\[ p_d = \frac{P_{ns}}{I_{ns,s} + I_{ns,f}} \]

Equation 86

3.6.2 Vigants-Barnett method

The Vigants-Barnet method is a classic method of microwave link prediction.

3.6.2.1 Improvements using space diversity (baseband switching systems)

The factor \( I_{sdns} \) for improvement due to space diversity is given by:

\[ I_{sd} = 1.2 \cdot 10^{-3} \cdot \frac{f}{d} S^2 \nu^2 \cdot 10^{\frac{A}{10}} \]

Equation 87

Where

- \( S(m) \) is the vertical separation (from centre to centre) between the receiving antennas
- \( f \) (GHz) is the frequency
- \( d \) (km) is the length of path
- \( A(dB) \) is the protection margin (effective) against fading
- \( \nu \) (dB) is the field difference (dB) between the main signal and the diversity signal (\( \nu = 1 \) if the signals are equal).

You can define this method in the Project Settings dialog box, on the Microwave Models/Availability/Multipath Models/ General panel, in the Default Space Diversity Settings section.

3.6.2.2 Improvements gained using space diversity (IF combining systems)

To account for the effects of intermediate frequency combination, the \( I_{sdns} \) factor for improvement due to space diversity is given by:

\[ I_{sd} = 1.2 \cdot 10^{-3} \cdot \frac{f}{d} S^2 \frac{16 \cdot \nu^2}{(1 + \nu)^4} \cdot 10^{\frac{A}{10}} \]

Equation 88

In this equation, the fade margin \( A \) is the combined thermal fade margin provided by:

\[ A = A_{thermal} + 2.6 + 20 \log_{10} \left( \frac{1 + \nu}{2} \right) \]

Equation 89
You can define this method in the Project Settings dialog box, on the Microwave Models/Availability/Multipath Models/General panel, in the Default Space Diversity Settings section.

### 3.6.2.3 Improvements gained using frequency diversity

This equation is similar to the one contained in recommendation ITU-R P.530.

\[
I_{\text{eqns}} = \frac{80.5}{f \cdot d \left( \frac{\Delta f}{f} \right)} 10^{\frac{A}{10}}
\]

Equation 90

You can define this method in the Project Settings dialog box, on the Microwave Models/Availability/Multipath Models/General panel, in the Diversity Method section.

### 3.6.2.4 Combining diversity values

There are several methods for combining improvement factors (i.e., sum, product, maximum, square root of sum of squares). You can also specify a maximum improvement factor.

### 3.6.3 ETSI method (TR 101 016, Annex A)

This algorithm calculates the total multipath fading with respect to diversity improvement (i.e., the probability that a specified fade margin is exceeded, due to multipath propagation (flat, selective, clear-air XPD) including the effects of diversity arrangements) during a specified period of time (the worst month or the year).

The following diversity arrangements are supported:

- Space diversity (SD)
- Frequency diversity (FD)
- Combined diversity (CD)
- Quadruple diversity (QD)

The following radio configurations are supported:

- N+0, no frequency diversity
- N+1, frequency diversity with a single diversity channel

#### 3.6.3.1 Unprotected multipath fading

The unprotected multipath fading probability (i.e., the total multipath fading probability without any diversity improvement) is calculated according to the following formula:

\[
P_U = P_F + P_S + P_{XPD}
\]

where

- \(P_U\) unprotected multipath fading probability (1)
- \(P_F\) flat fading probability (1)
- \(P_S\) selective fading probability (1)
- \(P_{XPD}\) clear-air XPD fading probability (1)
3.6.3.2 Diversity improved multipath fading

The diversity improved multipath fading probability (i.e., the total multipath fading probability considering the diversity improvement) is calculated according to the following steps:

**Step 1.** Calculate the space diversity correlation coefficient $k_{SD}$ as:

$$k_{SD} = \begin{cases} e^{-4 \cdot 10^{-4} \left( \frac{\Delta h}{\lambda} \right)^2} & \text{SD} \lor \text{CD} \lor \text{QD} \\ 1 & \text{otherwise} \end{cases}$$

where

- $k_{SD}$: space diversity correlation coefficient (1), $\leq 1$
- $\Delta h$: vertical separation (m) between primary and diversity antenna (centre-to-centre)
- $\lambda$: wavelength (m)

**Step 2.** Calculate the frequency diversity correlation coefficient $k_{FD}$ as:

$$k_{FD} = \begin{cases} e^{-0.89 \cdot \Delta f \cdot \tau_m} & \text{FD} \lor \text{CD} \lor \text{QD} \\ 1 & \text{otherwise} \end{cases}$$

where

- $k_{FD}$: frequency diversity correlation coefficient (1), $\leq 1$
- $\Delta f$: frequency separation (MHz) between operating and diversity channel (centre-to-centre)
- $\tau_m$: mean value of the time delay (ns), from the selective fading probability calculation

**Step 3.** Calculate the diversity improved multipath fading probability $P_D$ as:

$$P_D = \begin{cases} \frac{P_U^4}{\eta^3 \cdot (1 - k_{SD})^2 \cdot (1 - k_{FD})^2} & \text{QD} \\ \frac{P_U^2}{\eta \cdot (1 - k_{SD} \cdot k_{FD})} \cdot \frac{N + 1}{2} & \text{SD} \lor \text{FD} \lor \text{CD} \\ P_U & \text{otherwise} \end{cases}$$

where

- $P_D$: diversity improved multipath fading probability (1), $\leq P_U$
- $\eta$: multipath activity parameter (1), from the selective fading probability calculation
- $N$: number of operating channels in $N+1$ configuration, $\geq 1$, set to 1 in $N+0$ configuration
3.6.3.3 Diversity improvement factor

The improvement factor for the diversity improved multipath fading probability \( PD \) when compared to the unprotected multipath fading probability \( PU \) is calculated as:

\[
I = \frac{P_U}{P_D}
\]

Where

\( I \) diversity improvement factor (1), \( I \geq 1 \)

The improvement factor can be limited to a user-defined maximum value, in which case the software also adjusts the diversity improved multipath fading probability \( PD \) to adequately reflect this limitation.

3.6.3.4 Worst month probabilities

Worst month results are calculated by using worst month probabilities as input to sections 3.6.3.1 to 3.6.3.3 above.

3.7 Clear air XPD

3.7.1 ITU-R P.530

Recommendation ITU-R P.530 contains the procedure for calculating degradation due to crossed polarisation discrimination when the microwave link is operating in co-channel mode. The calculations involve the XPD antenna cross-polarisation factor, as well as the XPIF parameter of the interference canceller (XPIC) possibly available in the equipment.

3.7.1.1 Definition of total unavailability

The total probability of unavailability due to multipath propagation is:

\[
P_t = \begin{cases} 
  p_{ns} + p_s + p_{XP} & \text{with diversity} \\
  p_d + p_{XP} & \text{without diversity}
\end{cases}
\]

Equation 91

Where

\( p_d \) is the unavailability due to fading when diversity techniques are implemented, calculated from unavailability due to selective and non-selective frequency fading, \( p_s \) and \( p_{ns} \) respectively

\( p_{XP} \) is the probability of interruption due to cross polarisation in clear weather

The total probability of unavailability due to rainfall is:

\[
P_t = \max (p_{rain}, p_{XPR})
\]

Equation 92

Where

\( p_{rain} \) is the unavailability caused by rainfall

\( p_{XPR} \) is the probability of interruption due to cross polarisation during precipitation events
3.7.1.2 Calculation of $P_{XP}$

From the cross-polarisation factor $XPD_g$ guaranteed by the antenna manufacturer, it can be calculated:

$$XPD_g = \begin{cases} 
XPD_g + 5 & \text{for } XPD_g \leq 35 \\
40 & \text{for } XPD_g > 35 
\end{cases}$$

Equation 93

From the fade occurrence factor $P_0$ and the activity factor $\eta$, it can be calculated:

$$Q = -10 \log_{10} \left( k_{XP} \eta \right) \left/ P_0 \right.$$

Equation 94

Where

$$k_{XP} = \begin{cases} 
0.7 & \text{for a transmission antenna} \\
1 - 0.3 \exp \left[ -4 \times 10^{-6} \left( \frac{s_t}{\lambda} \right)^2 \right] & \text{for two transmission antennas}
\end{cases}$$

The probability of interruption can be expressed:

$$P_{XP} = P_0 \cdot 10^{-M_{XP} / 10}$$

Equation 95

Where

$$M_{XP} = \begin{cases} 
C - C_0 / I & \text{without XPIC} \\
C - C_0 / I + XPIF & \text{with XPIC}
\end{cases}$$

$C$ is $XPD_0 + Q$

$C_0 / I$ (dB) is the carrier/interference ratio for a reference BER. This ratio can be defined in the radio settings or is computed by the formula below

Recommendation P.530 does not provide specifications for evaluating $C_0 / I$. It should be noted that the carrier/interference ratio is calculated by:

$$\frac{C_0}{I_{carriers}} = \begin{cases} 
-10 \log_{10} \left[ 10 \left( \frac{XPD_{grx}}{10} \right) + 10 \left( \frac{XPD_{grx} + XPIF}{10} \right) + 10 \left( \frac{(C-A)}{10} \right) \right] + 2 & \text{w/o XPIC} \\
-10 \log_{10} \left[ 10 \left( \frac{XPD_{grx}}{10} \right) + 10 \left( \frac{XPD_{grx} + XPIF}{10} \right) + 10 \left( \frac{XPD_{grx} + XPIF}{10} + 10 \left( \frac{(C+XPIF-A)}{10} \right) \right) + 2 & \text{w/o XPIC}
\end{cases}$$

Where

$A$ is the fade margin including effects due to interference by other transmitters $XPD_{xpic}$ is the $XPD$ of the XPIC equipment (defined in the radio configuration)
### 3.7.1.3 Calculating $P_{XPR}$

In recommendation P.530, the XPD reduction in precipitation conditions is defined as:

$$XPD_{RAIN} = U - V(f) \log_{10}(CPA)$$

Equation 96

Where

$$U = U_0 + 30 \log_{10}(f)$$ \quad \text{where} \quad U_0 = 15 \text{ dB and} \quad f \text{ is the frequency in GHz}$$

$$V(f) = \begin{cases} 
12.8 f^{0.19} & \text{for} \ 8 \leq f \leq 20 \text{ GHz} \\
22.6 & \text{for} \ 20 < f \leq 35 \text{ GHz}
\end{cases}$$

Where CPA is the cumulative distribution of co-polar loss due to rainfall

Equivalent path loss (dB) is given by:

$$A_p (dB) = 10^{\frac{U - C_0}{V}}$$

Equation 97

NOTE: In the previous equations, XPIF = 0 when there is no XPIC equipment.

The probability of interruption can be expressed as:

$$P_{XPR} = 10^{(n-2)}$$

Equation 98

Where

$$n = \left( -12.7 + \sqrt{161.23 - 4m} \right) / 2$$

$$m = \begin{cases} 
23.26 \log_{10} \left( \frac{A_p}{0.12 \cdot A_{0.01}} \right) & \text{if} \ m \leq 40 \\
40 & \text{if} \ m \geq 40
\end{cases}$$

$A_{0.01}$ is the attenuation due to rainfall not exceeded more than 0.01% of the time

NOTE: The carrier/interference ratio is calculated as follows, using the reduction of XPD$_{RAIN}$ with CPA = A (fade margin including effects due to interference by other transmitters):

$$XPD_{RAIN} = \begin{cases} 
15 + 30 \log_{10} \left( f_{GHz} \right) - 12.8 f^{0.19} \cdot \log_{10}(A) & \text{for} \ 8 \leq f \leq 20 \text{ GHz} \\
15 + 30 \log_{10} \left( f_{GHz} \right) - 22.6 \cdot \log_{10}(A) & \text{for} \ f > 20 \text{ GHz}
\end{cases}$$

$$\frac{C_0}{I_{coch\text{nh}}} = \begin{cases} 
-10 \log_{10} \left( \frac{XPD_{GRX}^{10}}{10} + \frac{XPD_{GRX}^{10} + XPD_{XPIC}^{10}}{10} + 10 \right) + 2 & \text{w/out XPIC} \\
-10 \log_{10} \left( \frac{XPD_{GRX}^{10}}{10} + 10 \right) + \frac{XPD_{GRX}^{10} + XPD_{XPIC}^{10}}{10} + 10 \right) + 2 \text{ with XPIC}
\end{cases}$$
3.7.2 ETSI method (TR 101 016, Annex A)

This algorithm calculates the flat fading (i.e., the probability that a specified fade margin is exceeded due to clear-air XPD only) during a specified period of time (the worst month or the year).

3.7.2.1 Worst month probability

The worst month flat fading probability is calculated according to the following steps:

**Step 1.** Calculate the equivalent XPD fade margin $M_{XPD}$ as:

$$M_{XPD} = XPD_0 + Q + XPIF - SNIR$$

*Where*

- $M_{XPD}$ equivalent XPD fade margin (dB)
- $XPD_0$ antenna boresight XPD (dB), minimum of transmitting and receiving antenna
- $Q$ constant (dB) dependent on the antenna type, typically 5 to 10 dB
- $XPIF$ cross-polarisation improvement factor (dB) due to XPIC, typically 20 dB, set to 0 dB if XPIC not used
- $SNIR$ signal-to-noise ratio (dB) including the interference as additional noise, for a reference BER

**Step 2.** Calculate the worst month flat fading probability $P_{XPD}$ as:

$$P_{XPD} = P_0 \cdot 10^{\left(-\frac{M_{XPD}}{10}\right)}$$

*Where*

- $P_{XPD}$ worst month flat fading probability (1)
- $P_0$ multipath occurrence factor (1), from the worst month flat fading probability calculation
3.8 Calculating link unavailability due to refraction fading

Refraction-diffraction fading, also known as \( k \)-type fading, is characterized by seasonal and daily variations of the earth-radius factor \( k \). As the obstacle attenuation is directly tied to the \( k \) value (due its influence on earth surface curvature), the probability of refraction-diffraction is connected to obstruction attenuation for a given value of \( k \).

3.8.1 Calculating the worst month unavailability using \( K \) distribution method

Since the earth-radius factor is not constant, the probability of refraction-diffraction fading is calculated based on cumulative distributions of the earth-radius factor. The aim of the \( k \) distribution method is to find the \( k \) value for which the related obstacle attenuation results in an unavailability (i.e., an obstacle attenuation corresponding to the fade margin). Then using the \( k \) distribution curve that can be selected in input, the worst month unavailability probability is calculated.

3.8.2 Worst Month to Year conversion methods

The worst month to year conversion method used for unavailability due to refraction fading is given by recommendation ITU-R P841-4.

NOTE: Refer to section 3.9 for calculation details
3.9 Worth Month/Year conversion methods

Methods for calculating unavailability provide an estimate for the worst month or the year depending on the nature of unavailability considered. ITU has proposed the following method for the year/worst month conversion:

- ITU-R P.530
- ITU-R P.841

3.9.1 Recommendation ITU-R P.530

The fading and enhancement distributions for the average worst month obtained in the prediction methods can be converted to distributions for the average year as follows:

Calculating the logarithmic geoclimatic conversion factor $\Delta G$

$$\Delta G = 10.5 - 5.6 \log \left( 1.1 \pm \cos 2\xi \right)^{0.7} - 2.7 \log d + 1.7 \log \left( 1 + |\epsilon_p| \right) \text{ dB}$$

Equation 99

Where

$\Delta G \leq 10.8 \text{ dB}$ and the positive sign in equation is employed for $\xi \leq 45^\circ$ and the negative sign for $\xi > 45^\circ$

$\xi$ is the latitude ($^\circ$N or $^\circ$S)

$D$ is the path length

$|\epsilon_p|$ is the magnitude of path inclination

Calculating the percentage of time $p$ fade depth is $A$ exceeded

$$p = 10^{-\Delta G/10} p_w \%$$

Equation 100

Where

$\Delta G$ is the logarithmic geoclimatic conversion factor

$p_w$ is the percentage of time fade depth is exceeded for the average worst month

3.9.2 Recommendation ITU-R P.841

Recommendation ITU-R P841-4 covers the conversion formulas of annual statistics $p$ to statistics for worst month $p_w$. This conversion relies on two parameters $\beta$ and $Q_1$, which are defined for different environments. The conversion parameters are available in the Project Settings dialog box, on the Microwave Models/Availability/Rain Models/General panel.
3.9.2.1 Year-to-worst month conversion

The year-to-worst month conversion is given by:

\[ p_w(\%) = Q(p(\%))p(\%) \]

Equation 101

Where

\[ Q(p(\%)) = \begin{cases} 12 & p \leq \left( \frac{Q_1}{12} \right)^{\beta} \% \\ Q_1 p^{-\beta} & \left( \frac{Q_1}{12} \right)^{\beta} < p < 3 \% \\ Q_1 3^{-\beta} & 3 \% < p \leq 30 \% \\ Q_1 3^{-\beta} \left( \frac{p}{30} \right)^{\log_{10}(0.3)} & 30 \% < p \end{cases} \]

3.9.2.2 Worst month-to-year conversion

The worst month-to-full year conversion is given by:

\[ p(\%) = \frac{p_w(\%)}{Q(p_w(\%))} \]

Equation 102

Where

\[ Q = Q_1 \left( \frac{p}{p_w} \right)^{\frac{\beta}{1-\beta}} \text{ for } 12p_0 \leq p_w \leq Q_1 3^{(1-\beta)} \left( \frac{p_w}{Q_1} \right)^{\frac{\beta}{1-\beta}} \]

3.9.2.3 Simplified equations

The default values used are \( \beta = 0.13 \) and \( Q_1 = 2.85 \) as recommended in ITU -R P.841 for general planning purposes. These values give, for \( 1.9 \times 10^{-4} < p_w(\%) < 7.8 \):

The worst month-to-full year conversion is given by:

\[ p(\%) = 0.3 p_w(\%)^{1.15} \]

Equation 103

The year-to-worst month conversion is given by:

\[ p_w(\%) = \left( \frac{p(\%)}{0.3} \right)^{0.87} \]

Equation 104
3.10 Unavailability and Error Performance

Interruptions are associated with error performance and unavailability. ITU-T G. recommendations provide quality and availability objectives for digital systems and networks. ITU-R F. recommendations specify and complete the ITU-T G. recommendations for microwave links including those links that encompass several hops.

**NOTE:** SESR stands for Severely Errored Seconds Ratio, BBE stands for Background Block Error Ratio, and ESR stands for Severely Errored Seconds Ratio.

### 3.10.1 Availability

Recommendation F.1703 defines the procedure for calculating availability objectives and average time between interruptions. This recommendation is based on recommendation G.827 for a fictional reference duct 27 500 km in length, and provides equations that use the real length of the link.

Recommendations F.1703/1492/1493 are not required for equipment designed before approval of G.827. For these links, recommendations F.557/695/696/697 should be used.

In practice, availability is evaluated using recommendations P.530 and F.1093.

### 3.10.2 Error performance / quality

Recommendation F.1668 specifies the quality objectives for a fictional reference duct 27 500 km in length for SDH links in accordance with recommendations G.826 and G.828, and provides equations that use real link length. It distinguishes the objectives for intermediate countries and terminals (i.e., international trunks) and access trunks/short distance/long distance (i.e., national trunks).

Recommendation F.1668 is only required for equipment designed before approval of G.826. For all other links, use recommendations F.634/696/697, which are based on G.821.

In practice, error performance is calculated using recommendation F.1605 for SDH links that follow paragraph 3 of appendix 2 of recommendation P530-8, which is not included in later versions of this recommendation.

### 3.10.3 Presentation of availability and performance results

According to the ITU definition, link unavailability is due to long periods of SES. A link becomes unavailable as soon as an SES period greater than 10 seconds occurs and returns to a state of availability after 10 consecutive non-SES seconds. A duct is said to be available only when the availability is verified in both directions. It can be assumed that fading due to rainfall lasts longer than 10 seconds and is then a source of unavailability. Nonetheless recommendation P.530 specifies that clear weather effects may contribute to unavailability in the same way as precipitation may contribute to error performance.

Currently, recommendation F.1605 indicates that, when (X% of the time) loss due to rainfall exceeds the threshold $A_{SES}$, there will be a condition of unavailability; the remainder of the time $100-X\% = Y\%$ is considered as a period of unavailability giving rise to SES seconds. The value of $X$ is being studied and the recommendation indicates that $X = 0\%$ from which $Y = 100\%$.

The calculation of the SESR rate due to rainfall includes evaluating the percentage of time in the year in which the loss margin $A_{SES}$ is exceeded, with the SESR rate being equal to $Y\%$ of this probability.

$$SESR = Y(\%) \cdot p_1(BER_{SES})$$

Equation 105
You can assign any of the following values to Y:
- 100% (default value recommended in F.1605)
- an availability period for a BER of $10^{-3}$
- an availability period for a BER of $10^{-6}$

Availability settings are available in the Project Settings dialog box, on the panels under Microwave Models/Performance/Availability Objectives.

### 3.11 Calculating error performance (ITU-R F.1605)

The calculations described below use several parameters defined for specific equipment types:
- BER<sub>SES</sub> is the reference binary error rate for determining SES
- RBER is the reference binary error rate for residual evaluation of errors
- $N_B$ is the number of bits per block
- $n$ is the number of blocks per second
- $\alpha_1$ is the number of errors per burst for a BER in the range from $10^{-3}$ to and BER<sub>SES</sub> ($10$ to $30$)
- $\alpha_2$ is the number of errors per burst for a BER in the range from BER<sub>SES</sub> and RBER ($1$ and $10$)
- $\alpha_3$ is the number of errors per burst for a BER less than RBER ($1$)

The BER<sub>SES</sub> and RBER are filled in for the equipment types. Typically, the BER<sub>SES</sub> is between $10^{-3}$ and $10^{-6}$, and the value of the RBER falls between $10^{-10}$ and $10^{-13}$.

The SESR, BBER and ESR are probabilities, not percentages.

#### 3.11.1 Calculating SESR

\[
SES = p_{ses} = Y(\%) \cdot p_y(BER_{ses})
\]

Equation 106

#### 3.11.2 Calculating BBER

\[
BBER = SES \cdot \frac{\alpha_1}{2.8 \cdot \alpha_2 \cdot (m-1)} + \frac{N_B \cdot RBER}{\alpha_3}
\]

Equation 107

Where

\[
m = \frac{\log_{10}(RBER) - \log_{10}(BER_{SES})}{\log_{10}(p_y) - \log_{10}(p_{ses})}
\]

\[
p_y = p_y(RBER)
\]

#### 3.11.3 Calculating ESR

\[
ESR = SES + \frac{n \cdot N_B \cdot RBER}{\alpha_3}
\]

Equation 108
Where

\[ m = \log_{10}(RBER) - \log_{10}(BER_{SES}) \]

\[ p_{dR} = p_t(RBER) \]

### 3.11.4 Calculating error performance

Error rates are calculated using the following methods:

1. For multipath, by taking \( p_t \) unavailability due to multipath for the worst month.
2. For rainfall, by taking \( p_t \) unavailability due to rainfall for the worst month.

### 3.12 Calculating unavailability due to equipment types

The probability of unavailability due to the equipment type is calculated using the following formula:

\[ P_e = \frac{MTTR}{MTBF + MTTR} = 1 - \frac{MTBF}{MTBF + MTTR} \]

**Equation 109**

**Where**

- MTTR stands for Mean Time To Repair
- MTBF stands for Mean Time Before Failure

MTBF values are retrieved from radio file settings. Different value can be defined for redundant system (Hot-Standby)

### 3.13 Total Unavailability / Error Performance

#### 3.13.1 Total unavailability in one transmission direction

Total unavailability due to propagation is calculated as the sum of unavailability values due to rainfall and multipath.

\[ P_{\text{propagation}} = P_{\text{rain}} + P_{\text{multipath}} \]

**Equation 110**
3.13.2 Calculating total unavailability due to propagation in both transmission directions

The ITU does not specify how to definitively calculate the total unavailability of a link from unavailability values calculated in each direction of a transmission. Unavailability due to rainfall in both transmission directions can be strongly correlated (when it rains on the path of A toward B, it also rains on the path of B toward A) and the following equation can be used:

$$P_{\text{rain}} = \text{MAX}(P_{\text{RAIN A} \rightarrow B}, P_{\text{RAIN B} \rightarrow A})$$

Equation 111

Unavailability due to multipath cannot be stated nearly as clearly. To deal with this issue, the microwave planning features include a correlation parameter (cor), which has a value that falls between 0 (zero correlation) and 1 (complete correlation).

$$P_{\text{multipath}} = \text{MAX}(P_{\text{MP A} \rightarrow B}, P_{\text{MP B} \rightarrow A}) + (1 - \text{cor}) \cdot \text{MIN}(P_{\text{MP A} \rightarrow B}, P_{\text{MP B} \rightarrow A})$$

Equation 112

If cor = 0, then unavailability due to multipath propagation is the sum of unavailability values in both transmission directions.
If cor = 1, then unavailability due to multipath propagation is the maximum unavailability calculated for one of the two directions of transmission.
The total unavailability is calculated according to Equation 110.

3.13.3 Error performance

The error performance accounting for multipath on the one hand and rainfall on the other hand are added together to define the error performance accounting for both rain and multipath.
In the case of error performance in both directions of transmission, the correlation factor defined above is used for multipath propagation.
4  Calculating interference

4.1  Searching for potential interferers and channel use monitoring

To search for interferers, the following criteria are considered:

- **Distance**—interfering links with extremities that are outside a given range of the studied link extremities are not considered in the calculation.
- **Frequency separation**— interferer links with transmission and reception frequencies that are greater than y MHz from the transmission and reception frequencies of the studied link are not considered in the calculation.

When interferer links are discovered, the following calculations are performed:

- Interference level calculation (described below)
- High/Low conflict analysis. The parity status on the studied link and the interferer sites are verified within the area under study. The radios surrounding the studied link should transmit in the right parity (low when the studied link is high and vice versa)
- Channel reuse analysis. A frequency reuse area is defined. In that area, no other potentially interfering link should use the studied link frequency.

Studied link extremities are noted 1 and 2 and potentially interfering links extremities are noted A and B.

4.2  Calculating interfering Signal Level

Interference analysis of link AB on link 12 (interference received) is as follows:

- \( I_{A1} \): interfering signal level sent by A and received by 1
- \( I_{A2} \): interfering signal level sent by A and received by 2
- \( I_{B1} \): interfering signal level sent by B and received by 1
- \( I_{B2} \): interfering signal level sent by B and received by 2

Interference analysis of link 12 on link AB (interference caused) is as follows:

- \( I_{1A} \): interfering signal level sent by 1 and received by A
- \( I_{1B} \): interfering signal level sent by 1 and received by B
- \( I_{2A} \): interfering signal level sent by 2 and received by A
- \( I_{2B} \): interfering signal level sent by 2 and received by B

Analyzing interference between AB and 12 means analyzing configurations for potential interference.
4.2.1 Calculating interfering field level

Calculation of the field strength of the interfering field I\textsubscript{A1} transmitted by A and received by 1 is given by:

\[ I_{A1} = P_{TX \rightarrow A} - L_{feederTX \rightarrow A} - L_{otherTX \rightarrow A} - L_{channel \rightarrow A} + G_{TX \rightarrow A} - L_{pathloss \rightarrow 1} + G_{RX \leftarrow 1 \rightarrow A} - L_{channel \leftarrow 1} - L_{otherRX \leftarrow 1} - L_{feederRX \leftarrow 1} - IRF(\Delta f) \]

Equation 113

Where

- \( P_{TX \rightarrow A} \) (dBm) is the transmission power in A
- \( L_{feederTX \rightarrow A} + L_{otherTX \rightarrow A} + L_{channel \rightarrow A} \) (dB) is the transmission insertion losses in A
- \( G_{TX \rightarrow A} \) (dBi) is the antenna gain in A in the direction toward 1
- \( L_{pathloss \rightarrow 1} \) (dB) is the propagation attenuation in A and 1
- \( L_{feederRX \leftarrow 1} + L_{otherRX \leftarrow 1} + L_{channel \leftarrow 1} \) (dB) is the reception insertion losses in 1
- \( G_{RX \leftarrow 1 \rightarrow A} \) (dBi) is the antenna gain in 1 towards A accounting for either the co-polar diagram or the cross polar diagram
- \( IRF(\Delta f) \) (dB) is the rejection factor due to equipment including frequency difference (\( \Delta f \)) between the transmission frequency of A and the reception frequency on 1.

4.2.2 Calculating the near-field attenuation value

The distance between a transmitter and a receiver is the projected distance not accounting for antenna height on the tower. When the receiver is located within 10 meters of the tower, the distance accounted for is the oblique distance including antenna heights.

When this oblique distance is less than 1 meter, 1 is considered for calculating attenuation (free space).
4.3 Accounting for antenna diagrams

4.3.1 Calculating antenna discrimination

The antenna diagram to use for the receiver antenna depends on the useful channel polarization used by the interferer and the studied link. When these are the same, the co-polar diagram is used. If they are different, the cross-polar diagram is used.

The different cases are summarized as follows:

<table>
<thead>
<tr>
<th>Interfering channel</th>
<th>Interfering channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Co-polar</td>
</tr>
<tr>
<td>V</td>
<td>Cross-polar</td>
</tr>
</tbody>
</table>

When no cross-polar diagram is defined for the antenna, the co-polar diagram values are considered minus cross-polarisation value you entered in the antenna parameters.

4.4 Accounting for IRF values

4.4.1 Using the equipment IRF curve

The IRF curve, which may be defined in the equipment parameters, gives the protection value contributed by the equipment as a function of the difference between the transmission frequency of the interferer and the receiver frequency.

The 0 value for \( \Delta f = 0 \, \text{MHz} \) is normally used.

The IRF curve is valid for one bandwidth, one modulation type and one capacity. The most appropriate curve is used in the calculations.

4.4.2 Using the equipment T/I curve

The equipment T/I curve, which you can define in the equipment parameters, gives the T/I values as a function of the difference between the transmission frequency of the interferer and the frequency of the receiver. This curve also accounts for channelling and modulation.

This curve is quite similar to the IRF curve except for one parameter: the value of \( \Delta f = 0 \, \text{MHz} \) equals the co-channel T/I value already mentioned.

4.4.3 Using equipment transmit and receive templates

The IRF value of the study link radio may be calculated from the interferer transmission spectra templates and reception spectra templates.
### 4.4.3.1 Calculating power ratios

Calculation of the surface under the curve. It is important to note that A is in dB and the integral calculation must be performed with A as a linear value, also A is noted with a positive value for a loss.

#### Case A

\[
S = (F_2 - F_1) \cdot 10^{\frac{-A}{10}}
\]

#### Case B

\[
S = \int_{F_2}^{F_1} 10^{\frac{-A}{10}} \; dx = 10^{\frac{-A}{10}} \int_{F_2}^{F_1} e^{-\frac{A}{10}F} \; dx = \frac{10^{\frac{-A}{10}}}{\ln 10} \left[ 1 - e^{-\frac{A}{10}F} \right] = \frac{10^{\frac{-b}{10}}}{0.23026a} \left[ 1 - e^{-\frac{b}{10a}} \right]
\]

Equation 114

- The power \( P_i(W) \) in the surface element \( S_i \) is given by the following equation (the second term come from the fact that the curve is symmetrical and we only consider the positive side):

\[
P_i = \frac{S_j}{2 \sum_j S_j} P_{TX}
\]

Equation 115

- The power level \( N_i(dBm) \) of the surface element \( S_i \) is calculated according to:

\[
N_i(dBm) = P_{TX(dBm)} - 10 \log_{10} \left( \frac{2 \sum_j S_j}{S_i} \right)
\]

Equation 116

- If the receiver receives \( N_i \) when the transmitter sends \( P_{TX} \), by definition

\[
NFD = 10 \log_{10} \left( \frac{2 \sum_j S_j}{S_i} \right)
\]

Equation 117
### 4.4.3.2 Determining the NFD

The power level relative to the transmission power resulting from the Tx mask overlay (spectral transmission density) and the Rx mask (receiver selectivity) can be calculated.

We observe $T_{i_{x_i}}$ the positive value of transmission loss for the frequency $F_{1,2,3}$, etc.

We observe $R_{i_{x_i}}$ the positive value of reception loss for the frequency $F_{1,2,3}$, etc.

![NFD Diagram](image)

**Figure 9**  

The objective is to calculate, in the frequency range under the two masks, the power level received by the receiver resulting from the combined effect of transmission and reception masks. The sum of surfaces is calculated, as in the preceding paragraph, using for each point the sum of attenuations due to the transmission mask and the reception mask.

The formula from the previous paragraph (For A if $a=0$, for B if $a\neq0$) is applied.

In the example shown in Figure 6 the following calculation is performed:

<table>
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<tr>
<th>Surface element</th>
<th>$\Delta F$</th>
<th>a. $\Delta F$</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SR_1$</td>
<td>$F_2-F_1$</td>
<td>$(T_{F_i} + R_{F_i}) - (T_{F_i} + R_{F_i})$</td>
<td>$T_{F_i} + R_{F_i}$</td>
</tr>
<tr>
<td>$SR_i$</td>
<td>$F_{i+1}-F_i$</td>
<td>$(T_{F_{i_{x_i}}} + R_{F_{i_{x_i}}}) - (T_{F_{i_{x_i}}} + R_{F_{i_{x_i}}})$</td>
<td>$T_{F_i} + R_{F_i}$</td>
</tr>
</tbody>
</table>

Giving:

$$NFD = 10 \log_{10} \left( \frac{2 \sum S_i}{\sum S_R} \right)$$

Equation 118

### 4.4.3.3 Normalisation

The formula in Equation 128 should be normalized so that NFD = 0 for the same transmission and reception curve and a null frequency deviation.
4.5 Calculating Interference Criteria

4.5.1 Calculating Threshold degradations

Threshold degradation (Equation 52) is calculated both for interference from a single source and total interference from all sources (linear sum of field levels caused by interferers).

For interferences from a single source, the TD is compared with the "TD$_{max \ \ 2 \ \ by \ \ 2}$" defined in the Project Settings dialog box, on the Analysis/Interference panel.

For the total interference from all sources, the TD is compared to the "TD$_{max \ \ aggregated}$" defined in the Project Settings dialog box, on the Analysis/Interferences panel.

4.5.2 Calculating C/I level

C/I ratio is calculated from the field level used for C with either interference from a single source or total interference from all sources (linear sum of field levels caused by interferers).

For interferences from a single source, the C/I is compared to the "C/I 2 by 2" defined in the Project Settings dialog box, on the Analysis/Interferences panel.

For interferences from a single source, the C/I is compared to the "C/I aggregate" defined in the Project Settings dialog box, on the Analysis/Interferences panel.

4.6 Accounting for ATPC

Using the ATPC, calculation of the interfering field is modified according to:

\[
I_{A1} = P_{TX\ A} - ATPC - L_{feederTX\ \ A} - L_{otherTX\ \ A} - L_{channel\ \ A} + G_{TX\ \ A \rightarrow 1} \\
- L_{pathloss\ \ A \rightarrow 1} + G_{RX\ \ 1 \rightarrow A} - L_{channel\ \ 1} - L_{otherRX\ \ 1} - L_{feederRX\ \ 1} - IRF(\Delta f)
\]

Equation 119

The ATPC value can be defined for each channel. The settings are available in the Link Editor, on the Channels tab, by double-clicking the channel to open the Slot Configuration dialog box.
5 Generating profiles

5.1 Extracting the path profile

When extracting geographical data along a path profile, the height is calculated as the sum of the AMSL height (Above Mean Sea Level) and the AGL height (Above Ground Level)

5.1.1 AMSL layers

A raster file is suitable for an AMSL layer if the following conditions are met:

- The file format is MapInfo numerical grid
- The grid contains AMSL height and the internal unit is “Height”
- The grid projection is the same as the project projection

A GIS raster layer is recognized as an AMSL layer if the Height check box is selected and the “AMSL” attribute is defined in the layer settings. The height unit and the height factor applied to the height values are also defined.

The AMSL layers to be used for the profile extraction are selected on the profile sources panel:

You can define several AMSL layers or a single AMSL layer containing grid files at different resolutions in the same folder. If the AMSL height for a profile location is defined in several files, then the AMSL height with the best resolution is used or the highest AMSL height for files at the same resolution.

5.1.2 AGL layers

There are 3 kinds of AGL layers which can be used for the profile extraction:

- AGL vector layers
- AGL raster numerical grid layers
- AGL raster classified grid layers

The AGL layers to be used for the profile extraction are checked in the profile sources panel:
5.1.2.1 AGL vector layers

A vector AGL layer often contains building polygons. It is a very accurate data source to be used if available. A vector file is suitable for a vector AGL layer if the following conditions are satisfied:

- The file format is MapInfo vector or ESRI shape
- The vector file contains only closed polygons
- The AGL height of each polygon is defined by a numeric column in the associated database file

A GIS vector layer is recognized as an AGL vector layer if the Height checkbox is checked and if the “AGL” attribute is defined in the layer settings. The height unit and the column to retrieve the AGL height value are also defined.

If the vector file projection is not the same as the project projection then all the polygons will be re-projected on the fly. As the re-projection is very time consuming, it is recommended to get vector files using the projection of the project.

5.1.2.2 AGL raster numerical layers

A raster file is suitable for a numerical AGL layer if the following conditions are satisfied:

- The file format is MapInfo numerical grid
- The grid contains AGL height and the internal unit is “Height”
- The grid projection is the same as the project projection

A GIS raster layer is recognized as an AGL layer if the Height checkbox is checked and the “AGL” attribute is defined in the layer settings. The height unit and the height factor applied to the height values is also defined.
5.1.2.3 AGL raster classified layers

A raster file is suitable for a classified AGL layer if the following conditions are satisfied:

- The file format is MapInfo classified grid
- The grid projection is the same as the project projection

A GIS raster layer is recognized as an AGL classified layer if the Height checkbox is checked and the “AGL” attribute is defined in the layer settings. The height of each classified item (forest, dense building ...) is defined in the height table. By default, all the heights are set to zero.

5.1.3 Multi-resolution

Several AMSL layers can be defined or a single AMSL layer containing grid files at different resolutions in the same folder.
If the AMSL height for a profile location is defined in several files, then the AMSL height with the best resolution is kept.
If the AMSL height for a profile location is defined in several files at the same resolution then the highest AMSL height is kept.

Several AGL layers can be defined or a single AGL layer containing grid files at different resolutions in the same folder.
If the AGL height for a profile location is defined in several files, then the AGL height with the best resolution is kept.
If the AGL height for a profile location is defined in several files at the same resolution then the highest AGL height is kept.

AGL layers may be ignored if the analyse of the path profile is active. See below.
5.1.4 Vector outline file

An outline file is a MapInfo vector file containing one or several polygons defining the areas in which all the polygons are defined. The union of all the outline files define the 3D area. Outline files are useful if the analyse of the profile areas is active.

In the vector layer setting, a yellow circle indicates an undefined outline file and a green circle indicates a defined outline file.

There are three ways to define an outline file:

- from the bounding rectangle including all the polygons (first icon)
- from the drawing layer (second icon)
- from an existing file (third icon)
Click the first icon to define the outline file from the bounding rectangle including all the polygons. This is a quick but rough way.

Figure 11  Illustration of a bounding rectangle.

Click the second icon to define the outline file from the drawing layer:

1. Set the drawing layer editable
2. Select to create polygon shapes
3. Draw one or several polygons to surround all the buildings
4. Save the drawing layer
5. Open the layer setting and click on the second icon to create the outline file from the drawing layer file
5.1.5 Analyse profile areas

When the analysis of profile areas is active, the checkbox “Analyse profile areas” is set on the profile sources panel:

Profile generation options

- Analyse profile areas

Each AGL vector file must have a defined outline file. The union of all the outline files define the 3D area.

The most appropriate AGL layer is automatically selected by order of priority:

1. For all locations inside the 3D Area building polygons are considered, as well as AGL classified layers with classifications marked as “used in vector area”.

2. For all locations outside the 3D area but within the extent of at least one AGL numerical layer, the AGL numerical layer with the best resolution is considered.

3. For all locations outside the 3D area that are not covered by any AGL numerical layer, the AGL classified layer with the best resolution is considered.

![Diagram of 3D analysis](image)

Figure 12 3D analysis

The clutter scale “Use in vector area” is defined in the clutter settings:

Other scales

- Scales: Used in vector area

Editing this scale, the user select the clutter items which should be considered inside the 3D area. Usually only
the “forest” clutter type is set to “yes”:

5.1.6 Use fixed AMSL height for vector buildings

The use of fixed AMSL height for vector buildings is active if the checkbox “Use fixed AMSL height for vector buildings” is set in the profile sources panel:

If this checkbox is selected, buildings are considered to have flat rooftop:
Before using flat rooftop, the AMSL heights of each building must be calculated once and saved in an internal cache file. If the AMSL heights are not computed then there is a warning icon and the checkbox is disabled:

The user must click on the icon next to the warning icon to compute the AMSL heights for all the buildings and enable the checkbox.

For each polygon building:

- The centre of the polygon is calculated as the mean value of all the polygon points
- The building AMSL height is the AMSL height at the building centre location
- The building AMSL height is extracted from the AMSL layers and saved in an internal cache file
- The fixed flat rooftop height is the sum of the building AMSL height and the building AGL height

If the path profile intersects a polygon building then the effective building AGL height is not a constant value along the path profile. It is the flat rooftop building height minus the AMSL height at the path profile location.

5.1.7 Ignore classified AGL heights near Tx/Rx

Sometimes, a path profile is abnormally obstructed due to a classified AGL heights very close to the transmitter or the receiver especially in urban area.

The checkbox “Ignore classified AGL heights near Tx/Rx” results in any classified AGL that is very close to the transmitter or the receiver being ignored. The distance text field is enabled if checked and can be chosen between 0 and 100 meters.
5.2 User Profile

You can go beyond the cartographic data installed for the work area. You can define a user profile that will be used for profile analyses in the place of the generated profile from cartographic data for the area. This profile can be generated from cartographic data of the area and you can directly modify the profile in the Link Clearance window.

Your profile data is stored in ASCII files, at the highest resolution without adding any correction for curvature. They are determined the same way as for the profile extracted from cartographic data.

5.3 Curvature correction

Once the profile is determined from the cartographic data or from the user profile, the software performs a correction for the curvature of the earth. This correction $\delta h$ (m) is null at the extremities of the profile and maximum in the middle of the link. This is represented by:

$$\delta h = 10^3 \cdot \frac{d \cdot (D - d)}{2 \cdot k \cdot a}$$

Equation 120

Where

- $D$ (km) : length of profile considered.
- $d$ (km) : distance between the point considered in the profile and one of its extremities.
- $k.a$ : radio electric radius of the earth ($k=4/3$ and $a = 6371$ km by default)
### APPENDIX A

#### List of ITU recommendations

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</tr>
<tr>
<td>ITU-R P.526-11</td>
<td>Propagation by diffraction</td>
</tr>
<tr>
<td>ITU-R P.676-8</td>
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<td>Prediction procedure for the evaluation of microwave interference</td>
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<tr>
<td>ITU-R F.1605</td>
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<td>Services Digital Network</td>
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<td>Availability performance parameters and objectives for end-to-end</td>
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<td>Availability objectives for real digital fixed wireless links used</td>
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<td>reference circuit and a hypothetical reference digital path.</td>
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<td>ITU-R F.695</td>
<td>Availability objectives for real digital radio-relay links forming</td>
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<td>reference digital sections forming part or all of the medium grade</td>
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<tr>
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<td>portion of an integrated services digital network connection at bit</td>
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<td>rate below the primary rate utilizing digital radio-relay systems</td>
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<td>connection at a bit rate below the primary rate utilizing digital</td>
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<td>radio relay systems</td>
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### Recommendation

<table>
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<th>Recommendation</th>
<th>Title</th>
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<tbody>
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<td>Error performance objectives for real digital fixed wireless links used in 27 500 km hypothetical reference paths and connections</td>
</tr>
<tr>
<td>ITU-R F.1491-2</td>
<td>Error performance objectives for real digital radio links used in the national portion of a 27 500 km hypothetical reference path at or above the primary rate</td>
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<td>ITU-R F.1397-2</td>
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<td>ITU-R F.634-4</td>
<td>Error performance objectives for real digital radio-relay links forming part of the high-grade portion of international digital connections at a bit rate below the primary rate within an integrated services digital network.</td>
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<td>Propagation prediction techniques and data required for the design of trans-horizon radio-relay systems</td>
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### List of other references

<table>
<thead>
<tr>
<th>Reference</th>
<th>Title</th>
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<tbody>
<tr>
<td>ETSI: TR 101 016, V1.1.1, 1997-02</td>
<td>Transmission and Multiplexing (TM); Digital Radio Relay Systems (DRRS); Comparison and verification of performance prediction models</td>
</tr>
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</table>
APPENDIX B

Regression coefficients of ITU-R P.838-1

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>$k_H$</th>
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Frequency-dependent coefficients for estimating specific rain attenuation for horizontal (H) and vertical (V) polarizations.
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## Appendix C
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## APPENDIX D
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