RADIO PROPAGATION
IN ATDI TOOLS

Release number v4.0

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1. Introduction

1.1. Generic deterministic propagation model valid from 30MHz to 350GHz

Unlike standard radio planning software, ATDI tools calculate coverage and interference at any point of the map used. If 5 m resolution maps are used, then all pixels at 5 m will be calculated for the coverage/interference, and also the frequency assignment is based on these calculations at 5m.

ATDI tools include a deterministic model, valid from 30MHz to 350 GHz, and tested since 1994 by hundreds of thousands of measured points.

This model was created by Jacques Deygout in 1994, and is a map-based deterministic propagation model to fulfil all V/U/S/EHF requirements at the same time.

- Diffraction component = non-line of sight path (NLoS)
  Deygout 1966 is limited to 3 obstacles (ITU-R 526-11), Deygout 94 has no limitation and supports all terrain resolutions.
  Delta Bullington is referenced in ITU-R 526, 452, 2001-and 1812

- Subpath component applied in LoS and NLoS conditions.
  Computes the subpath diffraction loss for a LoS subsection of a diffraction path. The method is also used for a LoS with subpath diffraction, in which case it is applied to the entire path.
  Fresnel integrals (former Standard-RM subpath model)
  Standard = ITU-R P-526 Ap 2 to Annex 1
  Coarse integration: includes phase change effect

  The concept of the separation of the attenuations due to the "Subpath" with respect to the NLOS attenuations (diffraction) is a concept defined by Jacques Deygout and integrated in conjunction with ATDI in our software in 1994, following the diffraction model developed the same year (mixed between Bullington and Deygout 66, not limited in number of obstacles and independent from the resolution).

  This concept is reflected in recommendation 526: Attachment 2 to Annex 1 - Sub-path diffraction losses.

  The different "Subpath" models are closely linked to the quality of the terrain model used.

  The reference is Fresnel integrals. This and other methods available are detailed in the points below.

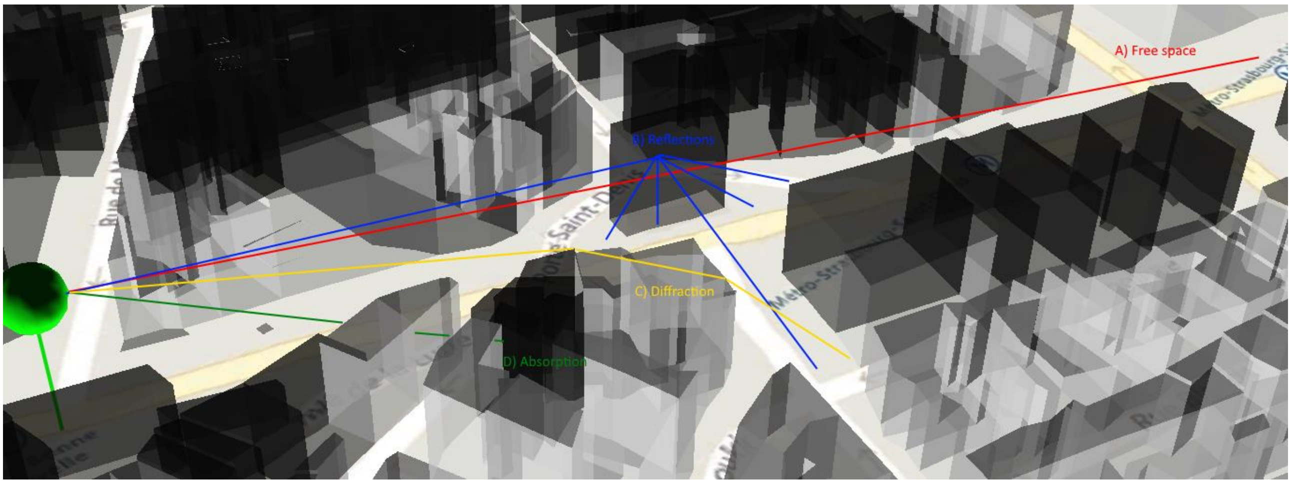
  Recommended models (if associated with Deygout 94):
    - Standard or Fine enhanced in HR (terrain in high resolution <= 5m).
    - Coarse or Fine or Fine enhanced in MR (land in average resolution> = 10 m).

  Please refer to ***3.2.3 Subpath attenuation methods*** for detailed information.

- Troposcattering: if used, min(tropospheric attenuation, diffraction attenuation) is applied

- 2D reflections are not compatible with Coarse, Standard-RM and Standard Subpath methods.

- Other attenuations (option) are not recommended by default.



http://www.atdi.com/wp-content/uploads/2012/05/PropaPath3.png

1.2. Standard models for frequencies lower than 30MHz

ATDI tools also cover frequencies lower than 30MHz with the use of other standard models, such as Groundwave (*3.3.1.9 ITU-R 368-9 (10 kHz – 30 MHz) (Groundwaves)*) and Skywave (*3.3.1.8 ITU-R 1147-4 (150-1700 kHz) (Sky-wave for LF/MF at night time)*), detailed within this document.

1.3. HF Module

ATDI tools also include a dedicated *HF module*, specially developed for this range of frequencies.

HF calculations are performed through a specific module, so that the user does not have to create a project and load cartographic layers to work on HF analysis.

With this module, the user is able to:

- Create and manage HF antennas
- Save HF stations
- Perform calculation all over the World
- Display S/N maps
- Perform communication statistics calculation
- Define the Maximum Usable Frequency (MUF) as well as the Frequency of Optimal Transmission (FOT)

The calculations are based on the ITU-R P.533-13 and ITU-R P.1240-1 recommendations.

For further information about this module, please refer to the document ***HF Module in ATDI tools.pdf***, available in the online library.

1.4. Correlation results

ATDI tools can compare different propagation models for a given service based on measurements.

1.4.1. FM

Model-Episode 1

Model	Standard deviation	Average error	Correlation factor	Differences < 6 dB
ITU-R 525 Deygout 94 Fine integration	3.42 dB	0.84 dB	0.97	91.17%
ITU-R 1546-5 (Broadcast analog) 50% time 50% locations	7.43 dB	-5.56 dB	0.89	60.28%
ITU-R 1812-3 50% time 50% locations	3.62 dB	1.57 dB	0.97	88.55%
Okumura-Hata / original	5.10 dB	1.38 dB	0.94	83.46%
ITM / NTIA – 50% time 50% locations	6.26 dB	2.12 dB	0.92	78.75%

Parameters influencing the correlation:

The configuration of the propagation model: reference (dBd, dBi, dBv), percentage of time and percentage of locations (if applicable), options like Tropo, Climate, Reflections…,

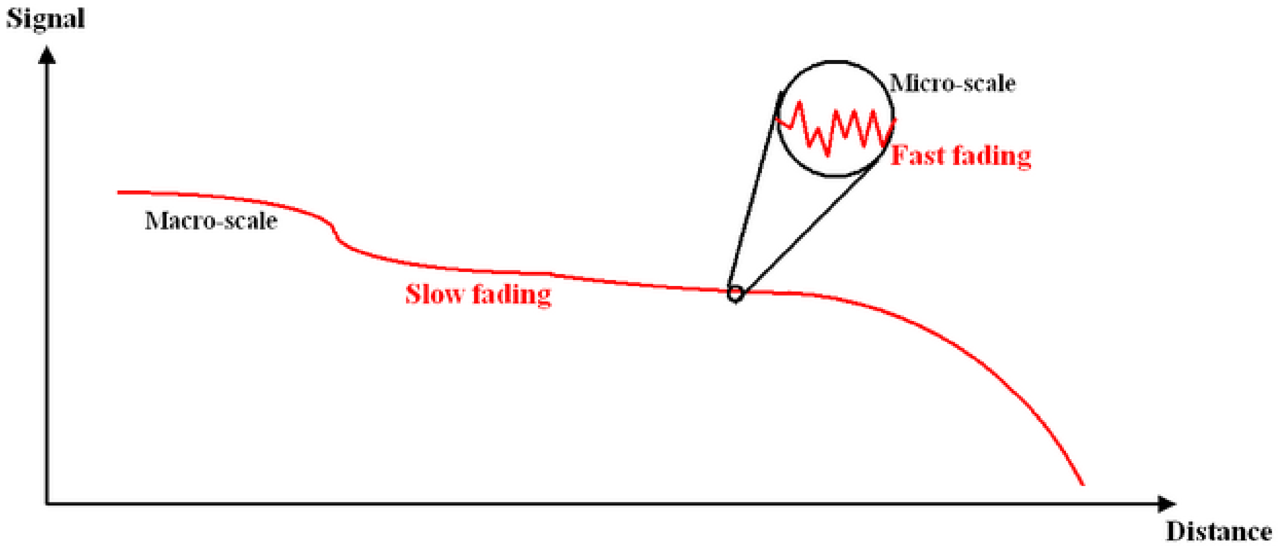
The quality of the cartography used by the planning tool: the resolution of the DTM, and the quality of the clutter file need to be adapted to the technology simulated. Applying the Lee criteria (see below) is for instance a good way to check the sampling resolution to use depending on the frequency of the technology simulated.

The quality of the GPS coordinates needs to take into account: GPS have today an absolute planimetric accuracy of 7.8 meters at a 95% confidence level, and this quality decreases in obstructed environment (decrease of the GDOP).

The fast fading effect and RF prediction: the LEE criteria

One of the main aspects to take also into consideration for the correlation with measurement is the fast fading effect. Lee’s goal was to find a valid method of estimating the local average power of a signal in the mobile radio environment. His conclusion, that the proper technique is to average 50 samples taken over a distance of 40λ (wavelengths), has become a standard technique, widely used within the industry. This basis has become so widely accepted that it can sometimes be used in situations where Lee sampling is not strictly applicable. Even though it may not be optimum in all situations, it does provide a base-line that allows measurements to be compared.

Background to signal level variations: the envelope of a received mobile radio signal is composed of a slow fading signal with a fast fading signal superimposed on it. In many applications, it is necessary to measure the local average power of the slow fading signal by smoothing out (or averaging) the fast fading part.



The fading experienced by a moving receiver has two major causes:

- The multi-path phenomenon: the signal transmitted from the base station is usually blocked by these surrounding structures and many reflected waves are generated. Summing ail of the multi-path waves at the mobile unit results in fast variations in the received signal which is called multi-path fading. It is also called short-term fading or fast fading referring to the short time period during which signals change.

- The variation of the average signal power as the mobile moves. This is due to different propagation paths between the base station and the mobile unit moving over different terrain configurations at different times. Since the propagation path is always changing as the mobile moves, the path loss values and hence local average power of the received signal vary. Because it is affected by the location of the mobile moving in real time and it varies slowly, it is called the local mean of the long-term fading.

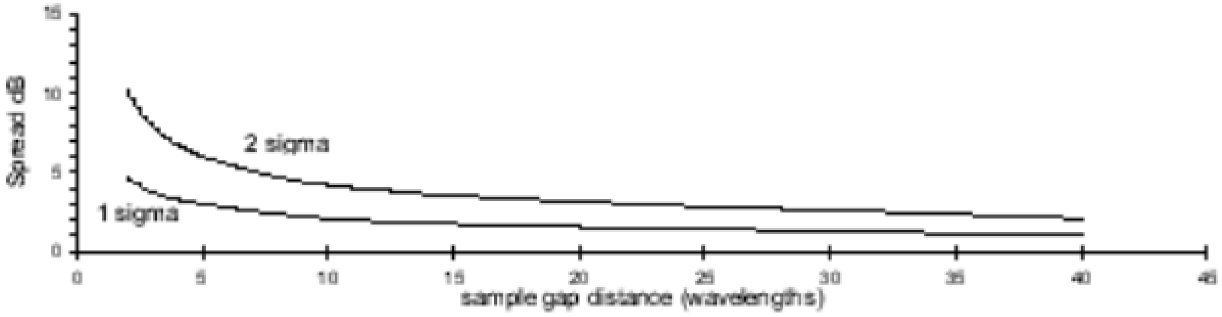
Since the received mobile radio signal contains both short term and long-term fading, to estimate the local mean of long-term fading that predictable using a planning tool, the fast fading effect has to eliminated from the measured signal, otherwise the true average power and the measured average power will not be the same.

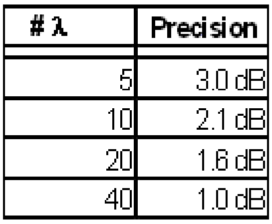
Obtaining a Local Average Signal Power (Local Mean): how to measure the local mean of the signal when the signal is received by a moving receiver, Lee addressed two major questions. His approach to both was aimed at reducing the errors in the measurements:

- The first question is how to choose a proper length of signal data for averaging.

- The second question, after determining the length, is how many independent sample points are needed for averaging over that length.

Choosing the Proper Length of a Local Mean: as we know, the length of a local signal has to be chosen properly. If it is chosen too short, the short-term fading is still present after the averaging process. If it is chosen too long, information about the long-term fading which we want to preserve, will be smoothed out. To find the proper length, Lee calculated the variance of the estimated local mean as a function of the length. It is important to note that he assumed that the fast fading followed Rayleigh statistics. The variance of a set of samples is the square of the standard deviation of the samples from their mean and is a measure of the spread of the sample values. Lee presents a graph of the variance in dB against the length.





# λ	Precision
5	3.0 dB
10	2.1 dB
20	1.6 dB
40	1.0 dB

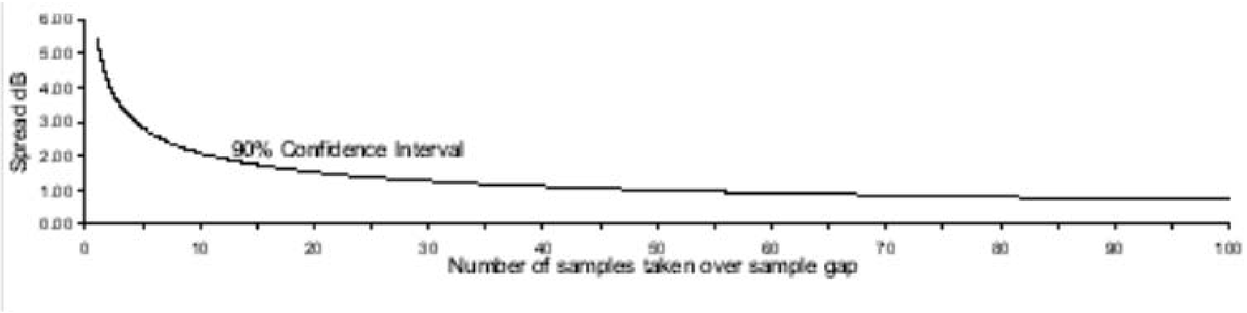
This graph guides the choice of the length by showing how much variance we can expect when using different lengths. This choice a matter of judgment rather than hard fact. Lee suggested the choice of:

- Length = 20λ, if we are willing to accept a 1σ m spread in a range of 1.6 dB

- Length = 40 λ if we are willing to accept a 1σ m spread in a range of 1.0 dB.

If we try to choose less than 20 wavelengths, the 1σ m spread increases quickly. If we try to choose the length 2L greater than 40λ, the 1σ m spread decreases very slowly, but, averaging over longer than 40 wavelengths risks smoothing out of long-term fading information. Lee concluded that a length of between 20 wavelengths and 40 wavelengths is the proper length for averaging the signal. It is proper in the sense that a length significantly shorter or longer is likely to result in a reduced accuracy of measurement.

Sampling Average: when using an analogue filter as an averaging process, it is difficult to control the bandwidth and Lee chose to use arithmetic averaging of samples instead of analogue averaging. This led him to address the question of how many samples should be taken across the length. Lee aimed to minimize the number of samples and calculated how many points were needed. The calculation is based upon taking the average of two variables with different statistical distributions. Lee calculates how many samples must be used for the resulting average to be within +/- 1 dB of the true mean.



The resulting figure of 50 samples does not guarantee that the average is within +/- 1 dB of the true mean, though it gives a 90% confidence that it will be.

Effects of different fading environments: Lee concluded that the measured length of a signal necessary to obtain the local average power is in the range of 20 to 40 wavelengths (λ), based on the Rayleigh distribution. The sufficient number of samples for estimating this local average power values is 50, based on a 90 percent confidence interval and less than 1 dB in error in the estimate. The processed average data retain the long-term fading information which is the local average power of the signal and predictable by a planning tool, while the short-term fading can be considered as filtered.

References:

- Estimate of Local Average Power of a Mobile Radio Signal, William c.y. Lee, IEEE Trans. Veh.Tech. Vol VT-34, No. l, Feb 1985.
- The Mobile Radio Propagation Channel, David Parsons, John Wiley 8: Sons 1992,
- Valid RF Field Measurements using Lee Sampling criteria, Willteck White paper (http://www.willtek.com/english/service/literature/white_papers)
- TETRA field measurement protocol, Emmanuel Grenier, ATDI, Feb 2004

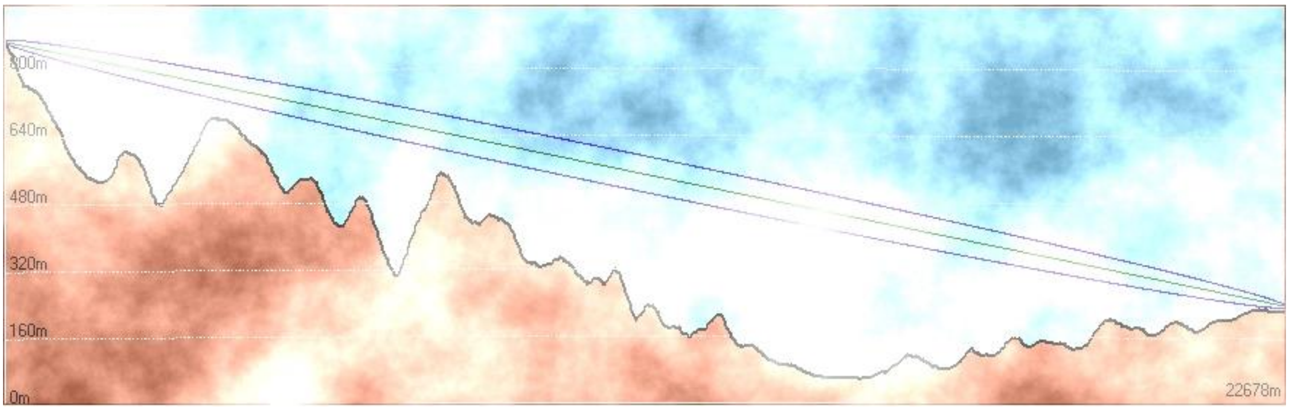
1.4.2. Wimax

Model-Episode2

Propagation model versus Artistic vision

Rule #1: a propagation model must be reversible (A->B = B->A)

Test LOS:



Parameters:

. Tx/Rx antenna height (A): 10 m (AGL) 863 m (ASL)
. Rx/Tx antenna height (B): 10 m (AGL) 228 m (ASL)
. Tx power 10 W (EIRP)
. Distance: 22.678 km
. Type of path: LOS (line of sight) – Subpath free – Clutter class: Open
. Frequency: 900 MHz

Model	A->B (dBµV/m)	B->A (dBµV/m)	Status
ITU-R 525	57.7	57.7	OK
ITU-R 370	49.2	14	NOK
ITU-R 1546	49.4	21.1	NOK
ITU-R 1812	57.6	57.6	OK
ITU-R 452	57.5	57.5	OK
Durkin	42	42	OK
Okumura-Hata	52.8	36.6	NOK
ITM-122	48.9	48.7	?
FCC98	57.7	57.7	OK

1.4.3. VHF / UHF Band: TV transmitters

This paragraph presents the results of coverage predictions and measurements for operational television transmitters located in Botswana.
Coverage predictions have been carried out by using a 100m Digital Terrain Models (DTM), known transmitter parameters (transmitter power, frequency (band III, IV and V), transmitter location, antenna height, antenna pattern, antenna peak gain, transmission system losses…), antenna height for receivers and specified coverage thresholds.

The following table presents correlation results between coverage predictions based on the tuned ITU-R P.525/Deygout 1994 propagation model and measurements for television.

100 measured values have been taken into account to carry out the following correlations:

TV Transmitter	Average Error (dB)	Standard Deviation (dB)	% of errors < 7 dB
Franscistown TV	0.2	1.3	100%
Gabane VHF TV	3.3	2.8	83.3%
Palapye TV	-6.6	6.8	43.9%
Sekakangwe TV	-5.2	2.9	80.0%
Gabane UHF TV	1.8	1.9	100%
Jwaneng TV	1.3	1.9	100%
Kanye TV	-5.5	5.1	75%
Lobatse TV	-1.0	1.0	100%
Mahalapye TV	-0.3	0.4	100%
Maun TV	5.5	5.0	50.0%
Serowe TV	0.0	1.4	100%

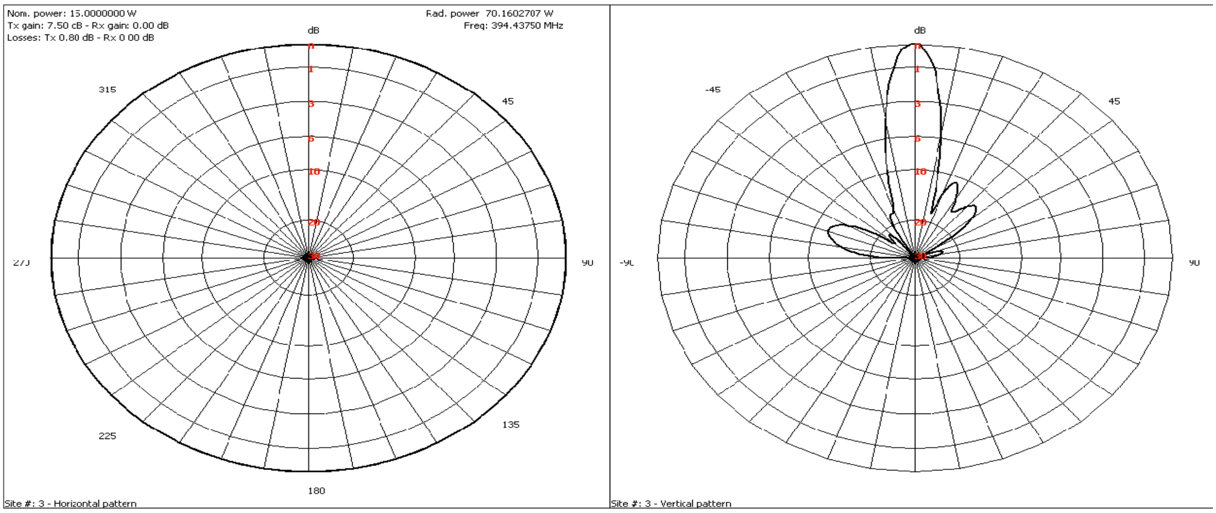
1.4.4. TETRA band

This paragraph presents the results of coverage predictions and measurements for three operational TETRA transmitters located in Belgium.

1.4.4.1. Transmitter 1: 394.4375 MHz

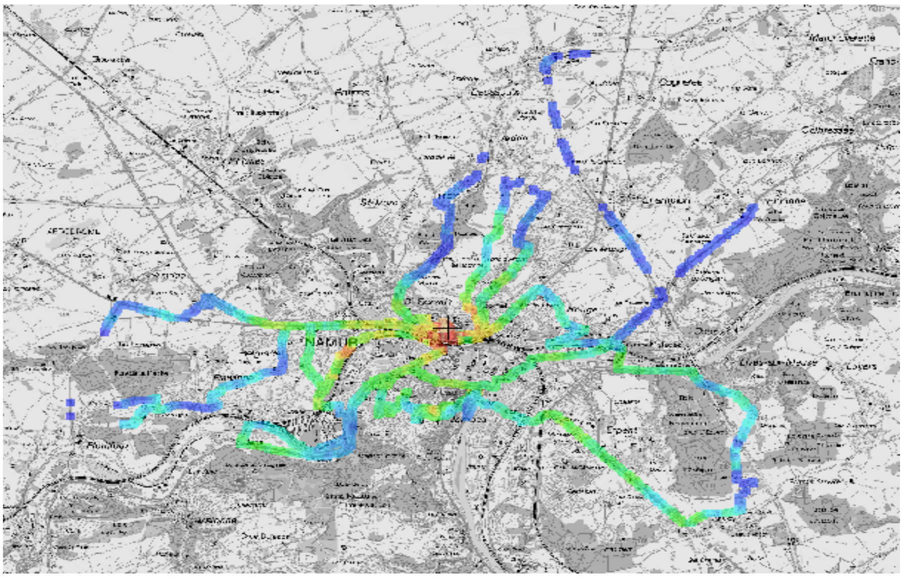
- **Cartographic data:** Coverage predictions have been carried out by using a 30m Digital Terrain Models (DTM)) with a clutter associated.

- **Transmitter parameters:**
  - Radiated Power: 70.16 W
  - Frequency: 394.4375 MHz
  - Antenna height: 31.20m
  - Antenna patterns:



- **Coverage parameters**
  - Propagation model: tuned ITU-R P.525 propagation model associated with Deygout 1994 diffraction model, Fine subpath attenuations, user defined attenuations per clutter and other attenuations (dB/km) have been considered.
  - Height of receiver antennas: 1.80m

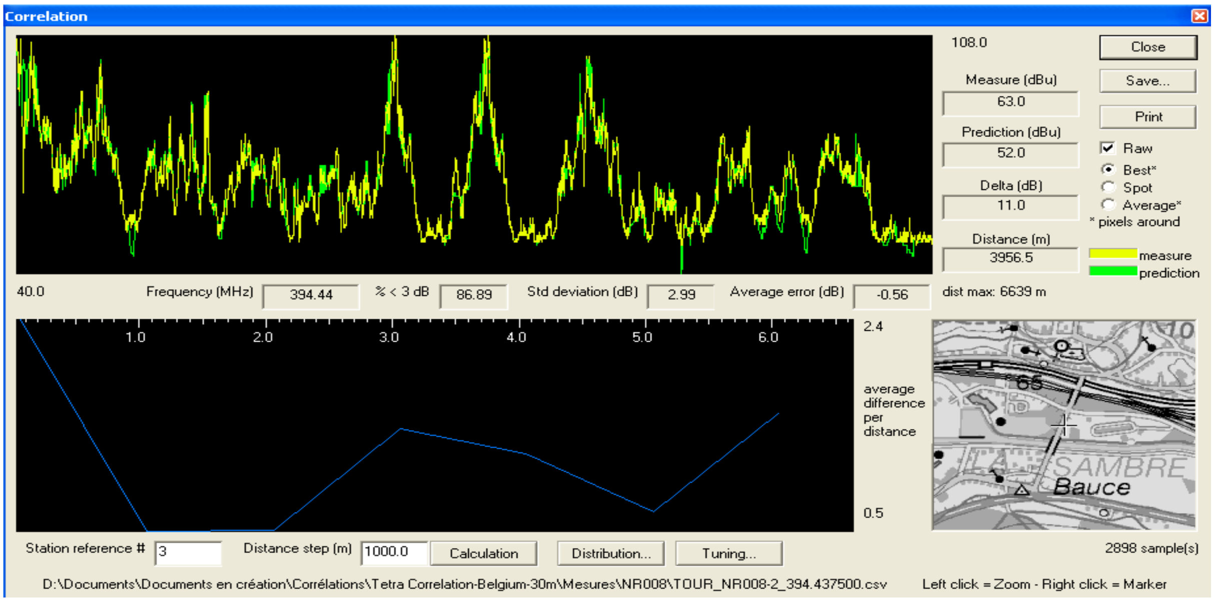
- **Correlation parameters**
  - Measurements: 2898 measured values have been taken into account to carry out the following correlations



Imported measured values

- Interval: +/- 3 dB
- Surface: 2 pixels
- Method: the correlations have been carried out by using Best mode with the Raw mode checked.

- **Correlation results**
  - Average error: -0.56 dB
  - Standard deviation: 2.99 dB
  - Correlation percentage: 86.89%



Measure (dBu) 63.0

Prediction (dBu) 52.0

Delta (dB) 11.0

Distance (m) 3956.5

☑ Raw

● Best*

○ Spot

○ Average*

* pixels around

Frequency (MHz) 394.44

% < 3 dB 86.89

Std deviation (dB) 2.99

Average error (dB) -0.56

dist max: 6639 m

Station reference # 3

Distance step (m) 1000.0

2898 sample(s)

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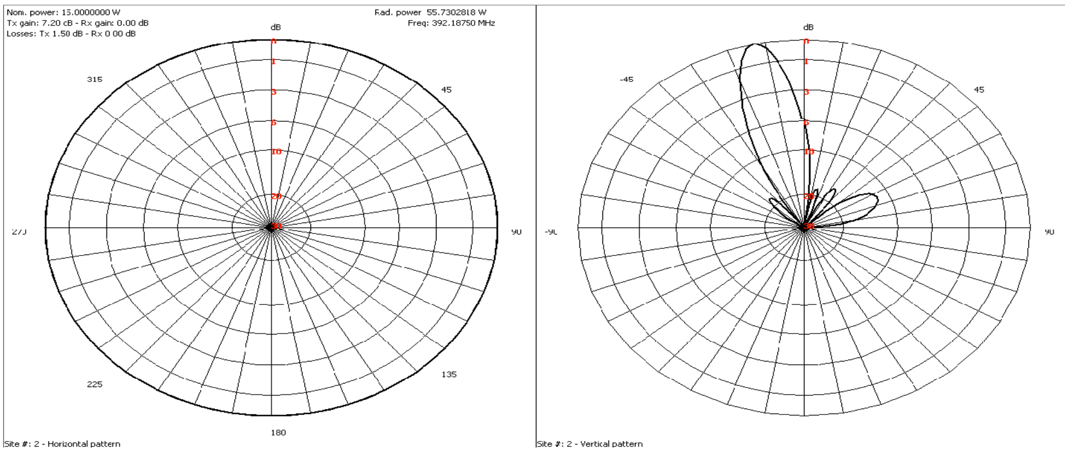
Coverage prediction versus measurements for TETRA transmitter – 394.4375 MHz

1.4.4.2. Transmitter 2: 392.1875 MHz

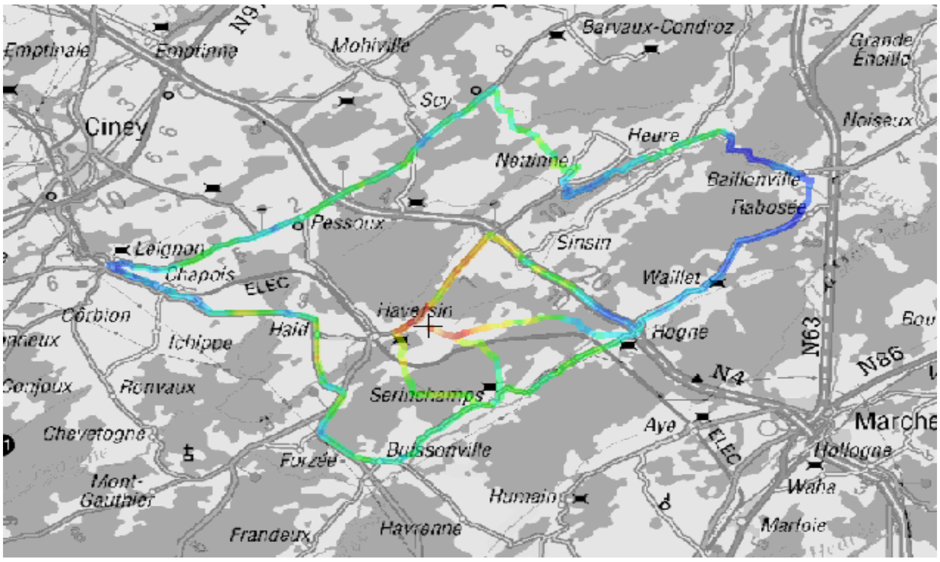
- **Cartographic data:** Coverage predictions have been carried out by using a 30m Digital Terrain Models (DTM)) with a clutter associated.

- **Transmitter parameters:**
  - Radiated Power: 55.73 W
  - Frequency: 392.1875 MHz
  - Antenna height: 55.92m
  - Antenna patterns:



- **Coverage parameters**
  - Propagation model: tuned ITU-R P.525 propagation model associated with Deygout 1994 diffraction model, Fine subpath attenuations, user defined attenuations per clutter and other attenuations (dB/km) have been considered.
  - Height of receiver antennas: 1.80m

- **Correlation parameters**
  - Measurements: 2342 measured values have been taken into account to carry out the following correlations

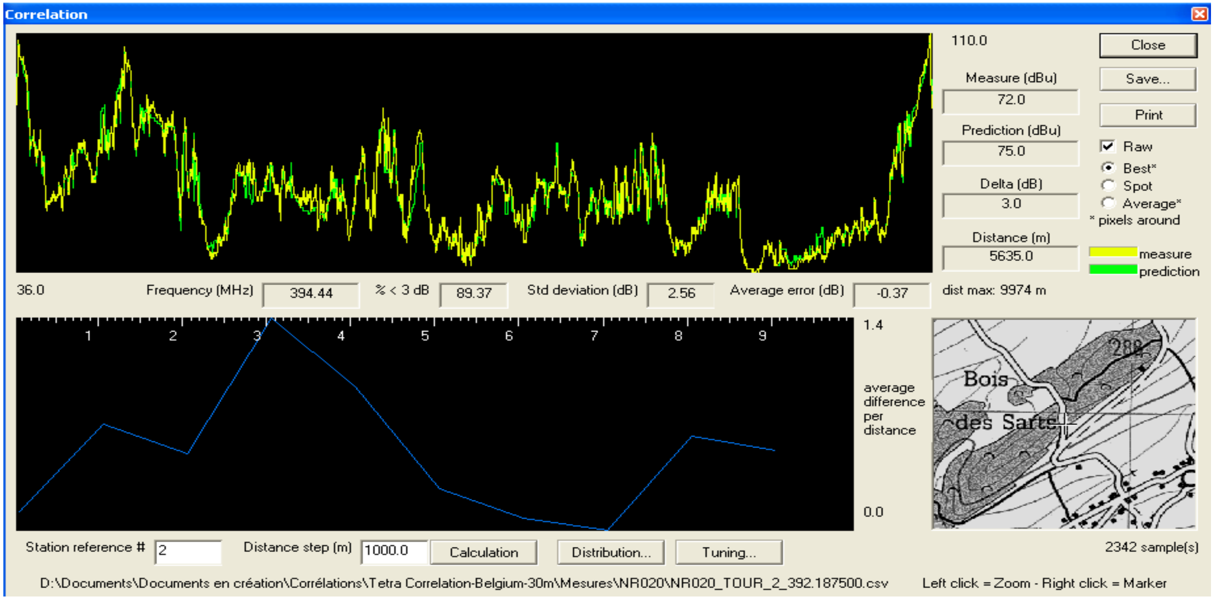


Imported measured values

  - Interval: +/- 3 dB
  - Surface: 2 pixels
  - Method: the correlations have been carried out by using Best mode with the Raw mode checked.

- **Correlation results**

  - Average error: -0.37 dB
  - Standard deviation: 2.56 dB
  - Correlation percentage: 89.37%


Correlation

Measure (dBu) 72.0
Prediction (dBu) 75.0
Delta (dB) 3.0
Distance (m) 5635.0

☑ Raw
● Best*
○ Spot
○ Average*
* pixels around

Frequency (MHz) 394.44
% < 3 dB 89.37
Std deviation (dB) 2.56
Average error (dB) -0.37
dist max: 9974 m

Station reference # 2
Distance step (m) 1000.0
2342 sample(s)

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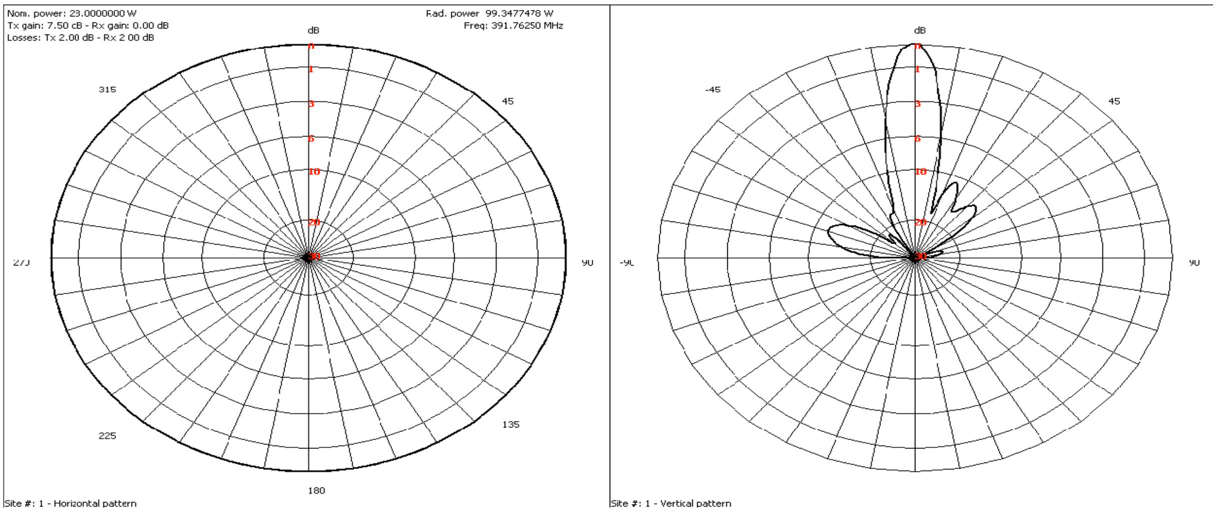
Coverage prediction versus measurements for TETRA transmitter – 392.1875 MHz

1.4.4.3. Transmitter 3: 391.7625 MHz

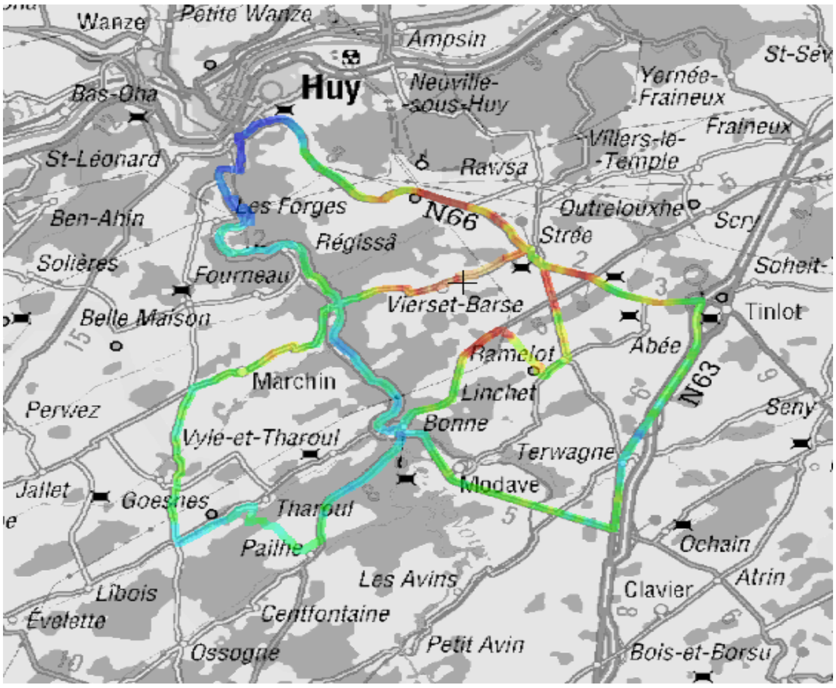
- **Cartographic data:** Coverage predictions have been carried out by using a 30m Digital Terrain Models (DTM)) with a clutter associated.

- **Transmitter parameters:**
  - Radiated Power: 99.35 W
  - Frequency: 391.7625 MHz
  - Antenna height: 71.05m
  - Antenna patterns:



- **Coverage parameters**
  - Propagation model: tuned ITU-R P.525 propagation model associated with Deygout 1994 diffraction model, Fine subpath attenuations, user defined attenuations per clutter and other attenuations (dB/km) have been considered.
  - Height of receiver antennas: 1.80m

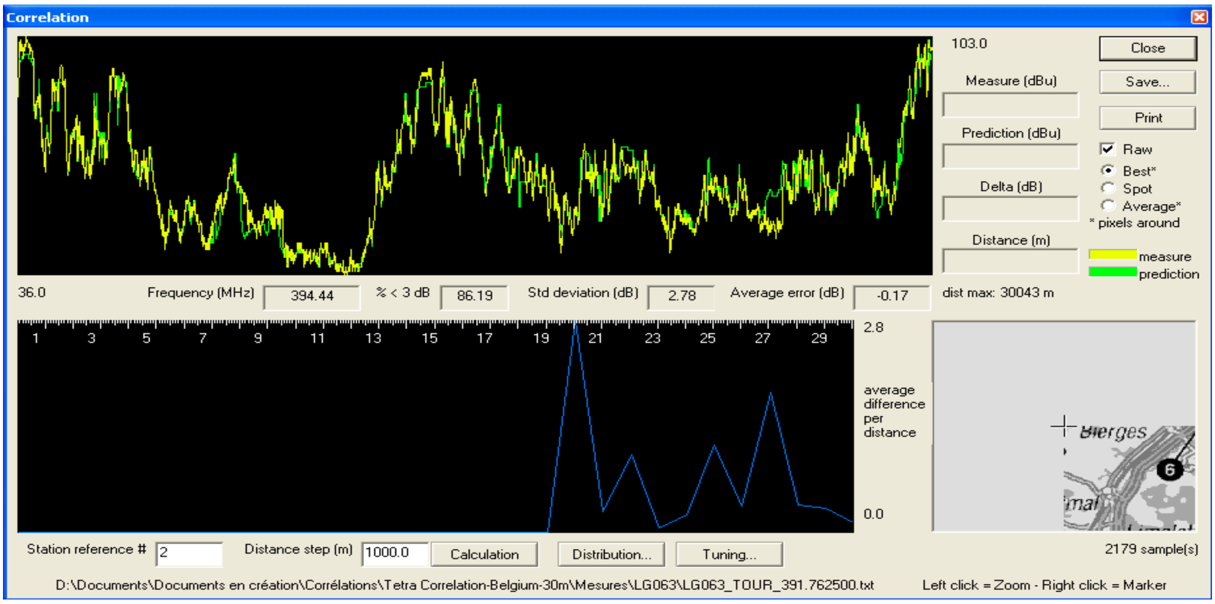
- **Correlation parameters**
  - Measurements: 2179 measured values have been taken into account to carry out the following correlations



Imported measured values

  - Interval: +/- 3 dB
  - Surface: 2 pixels
  - Method: the correlations have been carried out by using Best mode with the Raw mode checked.

- **Correlation results**
    - Average error: -0.17 dB
    - Standard deviation: 2.78 dB
    - Correlation percentage: 86.19%



Frequency (MHz) 394.44 % < 3 dB 86.19 Std deviation (dB) 2.78 Average error (dB) -0.17 dist max: 30043 m

☑ Raw
● Best*
○ Spot
○ Average*
* pixels around

Station reference # 2 Distance step (m) 1000.0 2179 sample(s)

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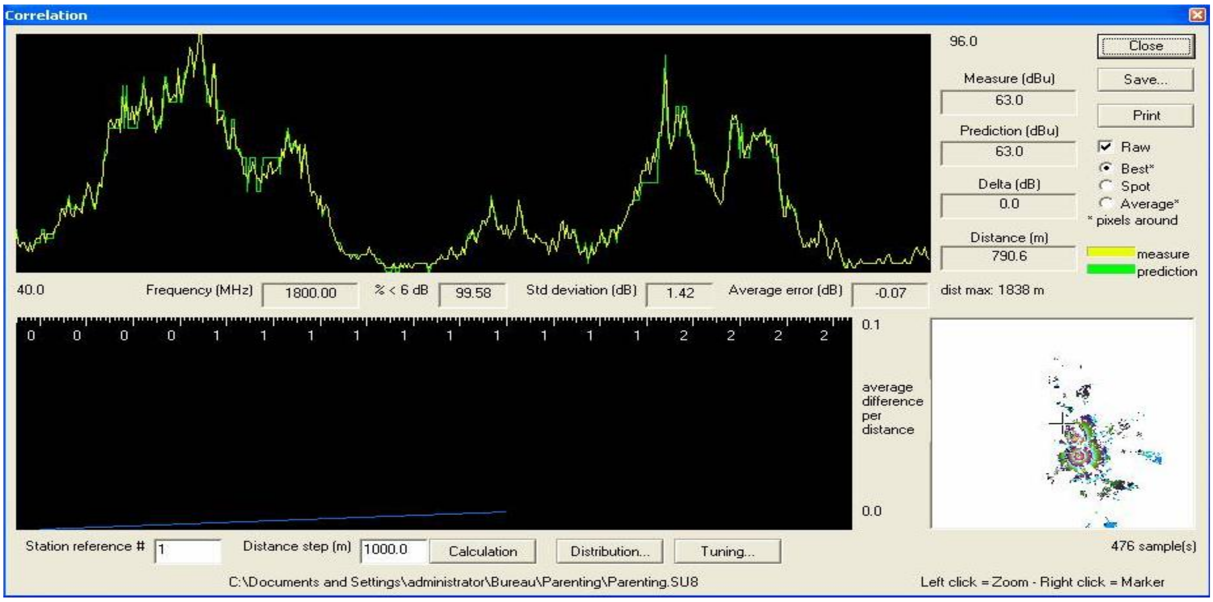
Coverage prediction versus measurements for TETRA transmitter – 391.7625 MHz

1.4.5. Others frequency bands

This paragraph presents the results of coverage predictions and measurements for others different frequencies.

1.4.5.1. 1800 MHz

- **Correlation parameters**
    - Measurements: 476 measured values have been taken into account to carry out the following correlations
    - Interval: +/- 6 dB
    - Surface: 1 pixels
    - Method: the correlations have been carried out by using Best mode with the Raw mode checked.
- **Correlation results**
    - Average error: -0.07 dB
    - Standard deviation: 1.42 dB
    - Correlation percentage: 99.58%



Measure (dBu): 63.0
Prediction (dBu): 63.0
Delta (dB): 0.0
Distance (m): 790.6
☑ Raw
● Best*
○ Spot
○ Average*
* pixels around
Frequency (MHz): 1800.00
% < 6 dB: 99.58
Std deviation (dB): 1.42
Average error (dB): -0.07
dist max: 1838 m
Station reference #: 1
Distance step (m): 1000.0
476 sample(s)
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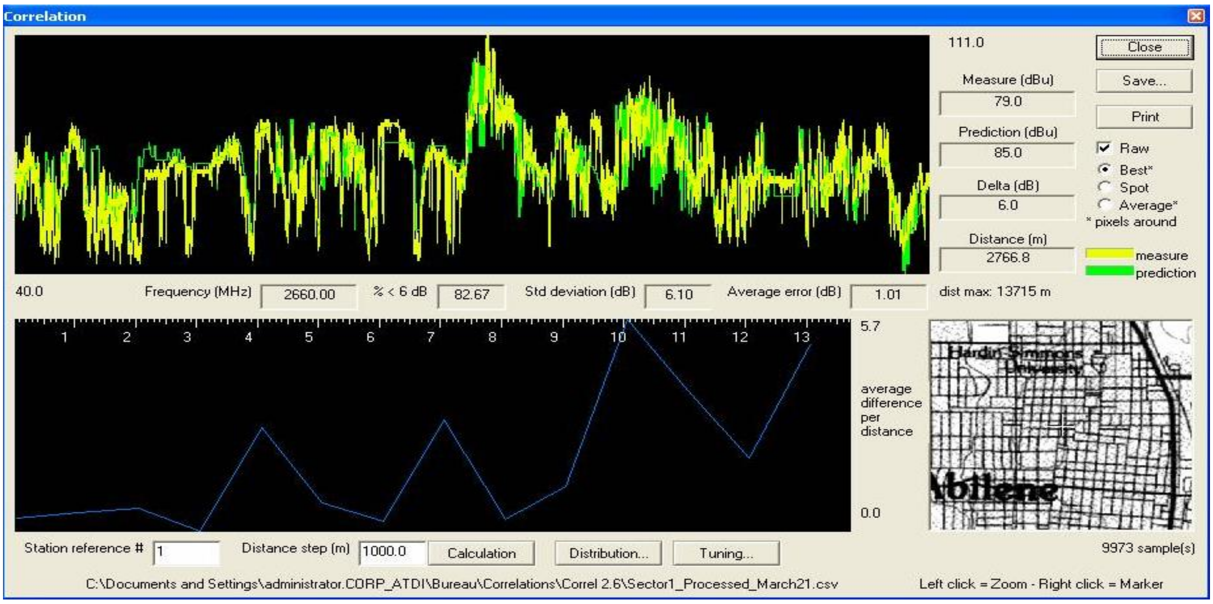
Coverage prediction versus measurements for 1800 MHz transmitter

1.4.5.2. 2660 MHz

- **Correlation parameters**
  - Measurements: 9973 measured values have been taken into account to carry out the following correlations
  - Interval: +/- 6 dB
  - Surface: 1 pixel
  - Method: the correlations have been carried out by using Best mode with the Raw mode checked.
- **Correlation results**
  - Average error: 1.01 dB
  - Standard deviation: 6.10 dB
  - Correlation percentage: 82.67%



Correlation

Measure (dBu): 79.0

Prediction (dBu): 85.0

Delta (dB): 6.0

Distance (m): 2766.8

Frequency (MHz): 2660.00

% < 6 dB: 82.67

Std deviation (dB): 6.10

Average error (dB): 1.01

dist max: 13715 m

☑ Raw

● Best*

○ Spot

○ Average*

* pixels around

Station reference #: 1

Distance step (m): 1000.0

9973 sample(s)

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Coverage prediction versus measurements for 2660 MHz transmitter

2. Technical conventions used in ATDI tools

In this section, we give a short presentation of conventions used in ATDI tools, in order to introduce the propagation models:

- Calculation modes for the propagation;
- Antenna gain modelling;
- Different types of spatial propagation computations.

2.1. Calculation modes for the propagation

There are two different modes of calculating propagation in ATDI tools:

- the *Path Radio* mode, aimed at taking into account every modelling step which contribute to field strength / power received calculation;
- the *Path budget* mode, that is a simplified way of calculation for specific use.

Unless mentioned, every field strength/power variable is expressed in dB.

2.1.1. Path Radio Mode

In the path radio mode, it is possible to compute either the field strength at the receiving antenna location or the power received. In this mode, ATDI tools directly uses the propagation model selected in the dialog box Tools/Propagation model.

2.1.1.1. Field strength calculation

The field strength is computed from the following equation:

$$\boxed{Frec = Prad + R - Lprop}$$ [basic field strength propagation equation]

With:

- Frec: received field at the antenna Rx location,
- Prad: radiated power by the transmitter Tx,
- R: field strength offset due to the electromagnetic impedance of vacuum (=120π Ω),
- R=10log(120π/4π)=10log(30)=14.8dB.
- The quantity R’=R+60=74.8dB is more frequently used in order to express distances in km and field in dBμV/m (in Lprop).
- Lprop: propagation loss.

The radiated power can be expressed as :

$$Prad = PTx + GTxma – DTxoa – LTx$$

Where:

- PTx: Tx nominal power,
- GTxma: Tx main axis antenna gain,
- DTxoa: Tx off-axis pattern loss,
- LTx: Tx internal losses.

The propagation loss is given by:

$$Lprop = Lfsd + Ld + Lsp + Lgas + Lrain + Lclut + Lmodel$$

With:

- Lfsd: free space distance loss,
- Ld: diffraction loss,
- Lsp: subpath loss,
- Lgas: attenuation caused by atmospheric gas,
- Lrain: attenuation caused by hydrometeor scatter,
- Lclut: clutter attenuation,
- Lmodel: specific unclassified attenuation deriving from model selection in the model dialog box.

The role of these components is explained in more details in the point *Propagation models implemented in ATDI tools* of this document. Actually, the value Lprop is the one yielded by the model selected in the dialog box. In addition, some of the standard attenuation terms Lfp, Ld, Lsp, Lgas and Lrain are computed and the displayed value of Lmodel is evaluated from the remaining difference:

$$Lmodel= Lprop–(Lfsd+Ld+Lsp+Lgas+Lrain+Lclut)$$

2.1.1.2. Received power calculation

For the calculation of the power received, the above-mentioned field strength offset R must be replaced by the power received offset C minus the free space frequency loss term Φ defined by:

$$C = -20\log(4\pi/c) = +147.6 \text{ dB} \qquad \Phi = 20*\log f$$

where :

- c is the propagation speed of electromagnetic energy
- f is the frequency

In order to introduce distances in km and frequencies in MHz, the offset C is often replaced by C’ = C-180 = -32.4 dB. Besides, the Rx antenna gain must be added so that the basic power propagation equation reads:

$$\boxed{\mathrm{Prec} = \mathrm{Prad} + C - \Phi - \mathrm{Lprop} + \mathrm{GRx}}$$

which amounts to use :

$$\boxed{\mathrm{Prec} = \mathrm{Frec} + C - R - \Phi + \mathrm{GRx}}$$

as a conversion filter from field strength to power received.

Like the Tx antenna gain, the Rx antenna gain can be subdivided into :

$$\boxed{\mathrm{GRx} = \mathrm{GRxma} - \mathrm{DRxoa} - \mathrm{LRx}}$$

With:

- GRxma: Rx main axis antenna gain
- DRxoa: Rx off-axis pattern loss
- LRx: Rx internal losses

2.1.1.3. Basic transmission loss: conversion formulas

Many propagation formulas in the literature (e.g. ITU recommendations) are expressed through the basic transmission loss Lb. Since Lb is different from Lprop, a specific care must be paid for integration and interpretation. Actually, this quantity that is used to calculate the received power Prec is the sum of every loss component except Prad and GRx. It is thus defined such that:

$$\boxed{\mathrm{Prec} = \mathrm{Prad} - \mathrm{Lb} + \mathrm{GRx}}$$

So, we have :

- $\mathrm{Lb} = -C + \mathrm{Lprop} + \Phi$

and if Frec is desired :

- $\mathrm{Frec} = \mathrm{Prad} + R - \mathrm{Lb} - C + \Phi$

2.1.2. Path Budget mode

In the path budget mode, **only the computation of the received power is available**. However, this mode has been specifically dedicated to microwave links (MW) so that some simplifying assumptions are made. The general formula becomes:

$$\boxed{\mathrm{Prec} = \mathrm{Frec} + \mathrm{GRx} - (\mathrm{DRxoa} + \mathrm{DTxoa} + \mathrm{Lmodel})}$$

i.e. the terms DRxoa, DTxoa and Lmodel are not in the budget. Indeed, for microwave link, no off-axis angle has to be taken into account because antennas are supposed to be pointed toward one to another. Besides, since no peculiar attenuation problem is expected (MW links are supposed to be established with visibility between Tx and Rx), no additional model loss Lmodel is required. As a result, the model to be used is the classical basic power propagation equation with free-space loss plus other standard losses. One may notice somehow that this formula is sensitive to the diffraction geometry selected in the dialog box.

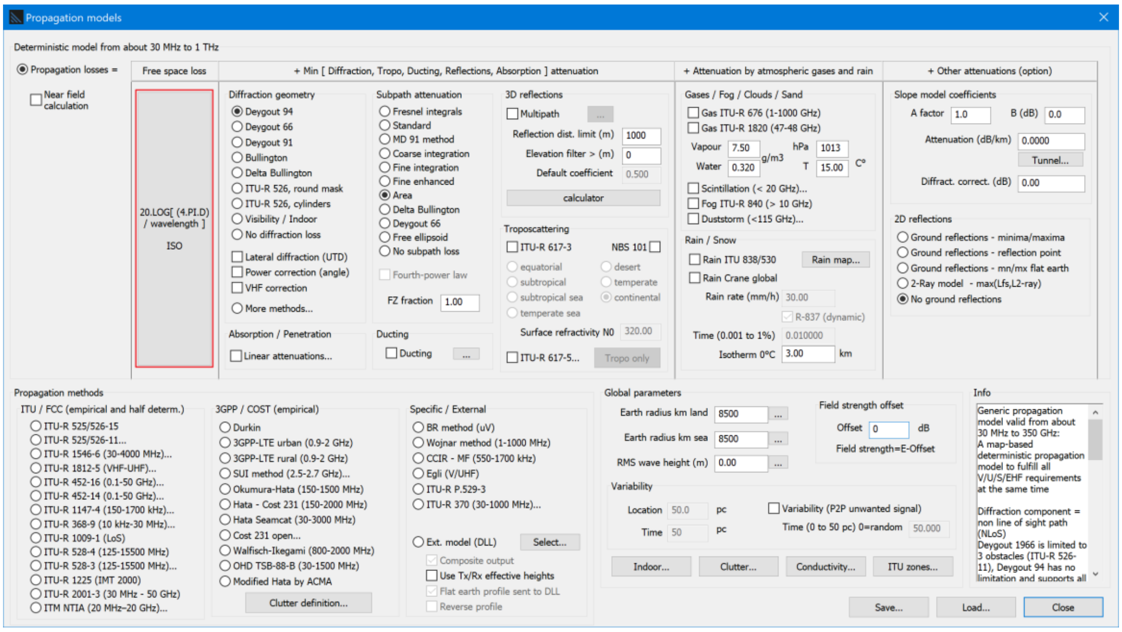
2.2. Antenna Modelling

As previously stated, the gain of an antenna (either Tx or Rx) can be expressed as G = Gma – Doa – L. The stage of modeling G is always delicate. Indeed, there are different antenna gain references for the main-axis gain Gma as well as different ways to calculate the off-axis pattern loss Doa.

2.2.1. Main-axis antenna gain conventions

There have traditionally been several conventions to express antenna gains in the main axis. Those conventions actually refer to the gain G_{xref} of the field strength in the main axis of the chosen ideal reference antenna w.r.t. the ideal isotropic antenna. In ATDI tools, four conventions can be used, that are available in the *Propagation models* dialog box:

- *Isotropic* antenna (ISO) convention (unit dBi): G_{xref} = 0dB, fully available in ATDI tools;
- *Half-wave dipole* (1/2d) convention (unit dBd): G_{xref} = 2.15dB, fully available in ATDI tools;
- *Short vertical antenna* convention (unit dBv): G_{xref} = 4.8 dB, fully available in ATDI tools;
- *Quarter-wave dipole* (1/4d) convention: G_{xref} = 5.2dB, available in the *Field Strength Converter* only;
- *Hertz dipole* (hertz) convention: G_{xref} = 1.75dB, available in the *Field Strength Converter* only.


Propagation models

Deterministic model from about 30 MHz to 1 THz

● Propagation losses = Free space loss + Min [Diffraction, Tropo, Ducting, Reflections, Absorption] attenuation + Attenuation by atmospheric gases and rain + Other attenuations (option)

Free space loss: 20.LOG[(4.PI.D) / wavelength] ISO

Diffraction geometry: ● Deygout 94

Subpath attenuation: ● Area

FZ fraction: 1.00

Reflection dist. limit (m): 1000

Elevation filter > (m): 0

Default coefficient: 0.500

Surface refractivity N0: 320.00

Vapour: 7.50 g/m3

Water: 0.320 g/m3

hPa: 1013

T: 15.00 C°

Rain rate (mm/h): 30.00

☑ R-837 (dynamic)

Time (0.001 to 1%): 0.010000

Isotherm 0°C: 3.00 km

A factor: 1.0

B (dB): 0.0

Attenuation (dB/km): 0.0000

Diffract. correct. (dB): 0.00

2D reflections: ● No ground reflections

Earth radius km land: 8500

Earth radius km sea: 8500

RMS wave height (m): 0.00

Offset: 0 dB

Field strength=E-Offset

Location: 50.0 pc

Time: 50 pc

Time (0 to 50 pc) 0=random: 50.000

☑ Composite output

☑ Flat earth profile sent to DLL

Info:
Generic propagation model valid from about 30 MHz to 350 GHz:
A map-based deterministic propagation model to fulfill all V/U/S/EHF requirements at the same time

Diffraction component = non line of sight path (NLoS)
Deygout 1966 is limited to 3 obstacles (ITU-R 526-11), Deygout 94 has no limitation and supports all

Propagation models dialog box

The conversion between these conventions is ruled by the following formula for the main axis antenna gain G_{ma}:

$$\boxed{Gma(conv) = Gma(iso) + Gxref(conv)}$$

The reference (either ISO or 1/2d) can be selected in the *Propagation models* dialog box. According to the selection, the dialog boxes asking for the radiated power require ERP (effective radiated power) if 1/2d or EIRP (equivalent isotropic radiated power) if ISO.

NOTE: the antenna reference can be selected also within the *Threshold* (only ISO, 1/2d and short vertical) and *Field strength converter* dialog boxes.

2.2.2. Calculation of the antenna off-axis pattern loss

There are two kinds of antenna models in ATDI tools: 2D models and 3D models. These models can be chosen in every parameters dialog box related to an object (station, MW link…).

In 2D models, antenna loss is computed from the associated "horizontal" pattern D_h and "vertical" pattern D_v,

$$\boxed{DRxoa = Dh(\alpha h) + Dv(\theta v)}$$

where α_h is the angle between the considered direction and the main axis in the plane of the "horizontal" diagram and θ_v is the angle between the considered direction and the main axis in the plane of the "vertical" pattern (α_h and θ_v can be viewed as locally referenced azimuth and elevation w.r.t. the hypothetical 3D pattern). Generally speaking, the main axis is referenced with 0° and 0dB losses in the patterns. Somehow, there are antennas, such as those brought in airplanes, where 0dB losses are only ±90° apart from the forward direction 0° of the aircraft. This is the reason why, in ATDI tools, there are some antenna patterns such that $D_h(0°)$ and $D_v(0°)$ are not equal to 0dB.

3D pattern models also exist: models defined from recommendations ITU-R 465, ITU-R F.699-4, ITU-R F.1245, ... and RPE models. These attenuation patterns happen to be rotationally symmetric around the main axis. The attenuation pattern is defined by:

$$\boxed{DRxoa = D(\varphi)}$$

where φ, the 3D off-axis angle, is given from by α_h and θ_v by :

$$\boxed{\varphi = acos(cos\alpha h\ cos\theta v)}$$

2.3. Various types of spatial computation

Spatial computations are performed on Digital Elevation Model (DEM): matrix containing horizontally regularly spaced altitude points. ATDI tools can perform three kinds of spatial computations on a DEM:

- point-to-point (P2P) calculation:

From the knowledge at one point (Tx) and the altimetric profile Tx-Rx being given, computation of the field strength (or power) at Rx location;

- profile calculation:

From the knowledge at one point (Tx) and the altimetric profile Tx-Rx being given, computation of the field strength (or power) profile along the path;

- coverage calculation:

From the knowledge at one point (Tx) and an altimetric area around Tx being given, computation of the field strength (or power) within this area.

In ATDI tools, the computation of profiles is done with a succession of point-to-point calculations, and coverage is computed itself through successive profiles that fill the coverage area. This way of doing is not mandatory. Somehow, most electromagnetic propagation models resort to 2D models taking into account the elevation profile located on the vertical plane from Tx to Rx (which is called path profile too). Thus, using straight line succession of point-to-point or neighbouring profiles calculations enables an algorithmic to reduce the computational charge.

Some of the propagation models available in ATDI tools are computed through external dynamic files (dynamic link library -DLL- files). Somehow, the models that require a heavy computational charge are internally included in ATDI tools, so that P2P calculation times on a large number of stations are not increased. See point *Propagation models implemented in ATDI tools* of this document for more details on propagation models.

2.4. ATDI tools behaviour associated with elements

We straightforward use the following symbols for elements:

🟩 : station. Spatial calculations available: P2P, profiles, coverage.

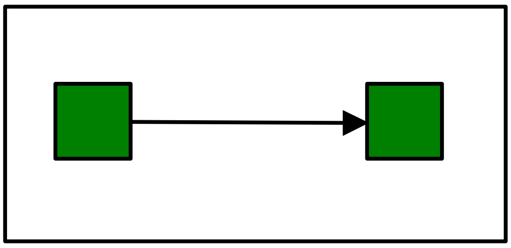
▼ : particular case of station, head of microwave link. Spatial calculations available: P2P, profiles, coverage.

⊗ : empty point, standing for start point or end point of a profile chosen with the mouse with no pre-defined elements. Spatial calculations available: profiles.

↔ : subscriber terminal. Spatial calculation available: P2P.

Either P2P, profile or coverage calculation require the knowledge of a path profile. Thus, regarding the calculation mode (path radio/path budget), each kind of calculation uses a default mode.

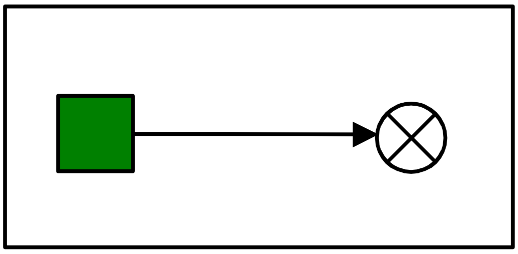
2.4.1. P2P or profile from station to station



Default mode: path radio.

Received power calculation hypothesis:
$G_{Rx}= G_{Rxma}-D_{Rxoa}-L_{Rx}=0.$

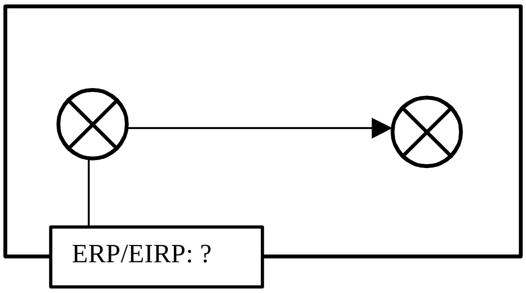
2.4.2. Profile from station to empty point



Default mode: path radio.

Received power calculation hypothesis:
$G_{Rx}= G_{Rxma}-D_{Rxoa}-L_{Rx}=0.$

2.4.3. Profile from empty point to empty point

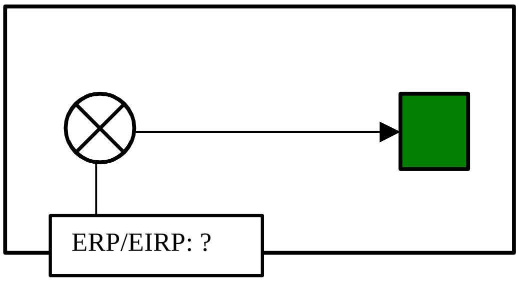


Default mode: path radio.

Received power calculation hypothesis:
$G_{Rx}= G_{Rxma}-D_{Rxoa}-L_{Rx}=0$.

Radiated power $P_{rad}=P_{Tx}+G_{Txma}-D_{Txoa}-L_{Tx}$:
defined in the dialog box

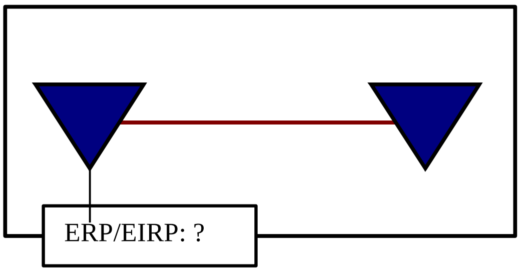
2.4.4. Profile from empty point to station



Default mode: path radio.

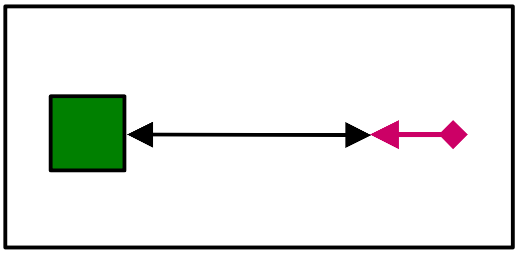
Radiated power $P_{rad}=P_{Tx}+G_{Txma}-D_{Txoa}-L_{Tx}$:
defined in the opened dialog box.

2.4.5. Microwave link P2P or profile



Default mode: path budget.

2.4.6. Station to subscriber or subscriber to station



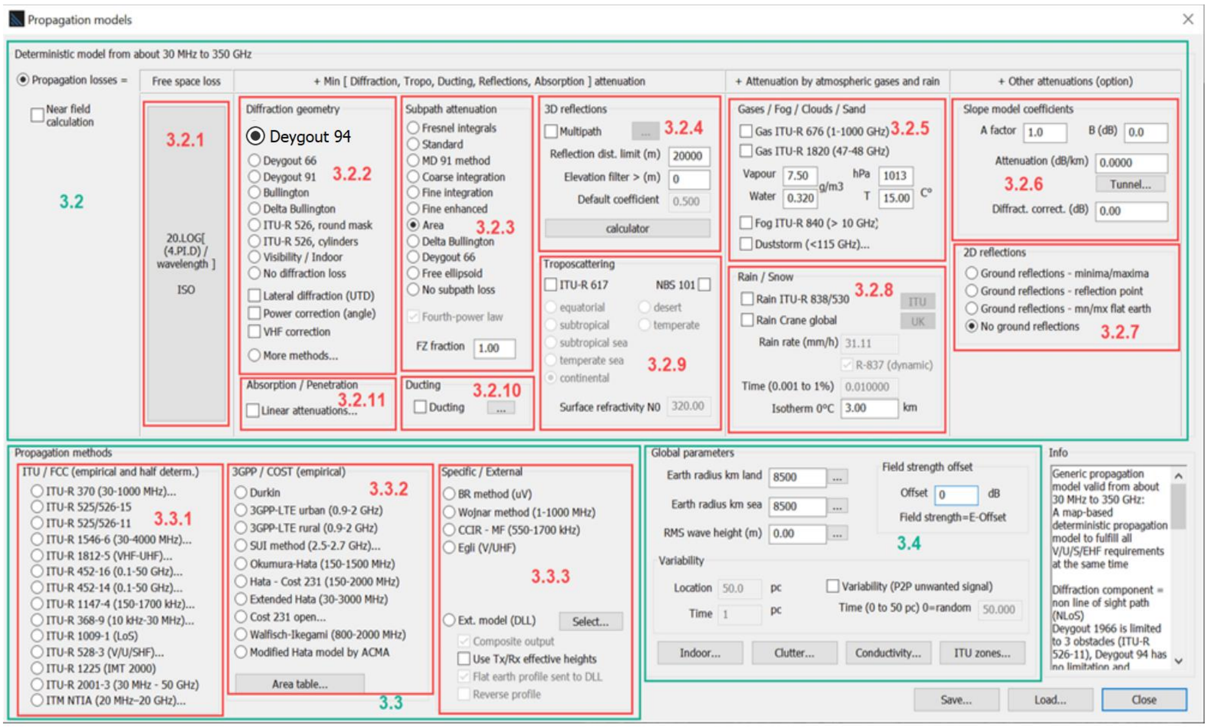
Default mode: path radio.

2.4.7. Coverage

Path mode: path radio.

3. Propagation models implemented in ATDI tools

This paragraph gives a short description of propagation models available in ATDI tools.



Propagation models

Deterministic model from about 30 MHz to 350 GHz

● Propagation losses = | Free space loss | + Min [Diffraction, Tropo, Ducting, Reflections, Absorption] attenuation | + Attenuation by atmospheric gases and rain | + Other attenuations (option)

☐ Near field calculation

20.LOG[(4.PI.D) / wavelength]
ISO

Diffraction geometry
● Deygout 94
○ Deygout 66
○ Deygout 91
○ Bullington
○ Delta Bullington
○ ITU-R 526, round mask
○ ITU-R 526, cylinders
○ Visibility / Indoor
○ No diffraction loss
☐ Lateral diffraction (UTD)
☐ Power correction (angle)
☐ VHF correction
○ More methods...

Subpath attenuation
○ Fresnel integrals
○ Standard
○ MD 91 method
○ Coarse integration
○ Fine integration
○ Fine enhanced
● Area
○ Delta Bullington
○ Deygout 66
○ Free ellipsoid
○ No subpath loss
☑ Fourth-power law
FZ fraction 1.00

3D reflections
☐ Multipath
Reflection dist. limit (m) 20000
Elevation filter > (m) 0
Default coefficient 0.500

Troposcattering
☐ ITU-R 617 NBS 101 ☐
○ equatorial ○ desert
○ subtropical ○ temperate
○ subtropical sea
○ temperate sea
● continental
Surface refractivity N0 320.00

Absorption / Penetration
☐ Linear attenuations...

Ducting
☐ Ducting

Gases / Fog / Clouds / Sand
☐ Gas ITU-R 676 (1-1000 GHz)
☐ Gas ITU-R 1820 (47-48 GHz)
Vapour 7.50 g/m3 hPa 1013
Water 0.320 T 15.00 C°
☐ Fog ITU-R 840 (> 10 GHz)
☐ Duststorm (<115 GHz)...

Rain / Snow
☐ Rain ITU-R 838/530
☐ Rain Crane global
Rain rate (mm/h) 31.11
☑ R-837 (dynamic)
Time (0.001 to 1%) 0.010000
Isotherm 0°C 3.00 km

Slope model coefficients
A factor 1.0 B (dB) 0.0
Attenuation (dB/km) 0.0000
Diffract. correct. (dB) 0.00

2D reflections
○ Ground reflections - minima/maxima
○ Ground reflections - reflection point
○ Ground reflections - mn/mx flat earth
● No ground reflections

Propagation methods

ITU / FCC (empirical and half determ.)
○ ITU-R 370 (30-1000 MHz)...
○ ITU-R 525/526-15
○ ITU-R 525/526-11
○ ITU-R 1546-6 (30-4000 MHz)...
○ ITU-R 1812-5 (VHF-UHF)...
○ ITU-R 452-16 (0.1-50 GHz)...
○ ITU-R 452-14 (0.1-50 GHz)...
○ ITU-R 1147-4 (150-1700 kHz)...
○ ITU-R 368-9 (10 kHz-30 MHz)...
○ ITU-R 1009-1 (LoS)
○ ITU-R 528-3 (V/U/SHF)...
○ ITU-R 1225 (IMT 2000)
○ ITU-R 2001-3 (30 MHz - 50 GHz)
○ ITM NTIA (20 MHz–20 GHz)...

3GPP / COST (empirical)
○ Durkin
○ 3GPP-LTE urban (0.9-2 GHz)
○ 3GPP-LTE rural (0.9-2 GHz)
○ SUI method (2.5-2.7 GHz)...
○ Okumura-Hata (150-1500 MHz)
○ Hata - Cost 231 (150-2000 MHz)
○ Extended Hata (30-3000 MHz)
○ Cost 231 open...
○ Walfisch-Ikegami (800-2000 MHz)
○ Modified Hata model by ACMA

Specific / External
○ BR method (uV)
○ Wojnar method (1-1000 MHz)
○ CCIR - MF (550-1700 kHz)
○ Egli (V/UHF)
○ Ext. model (DLL)
☑ Composite output
☐ Use Tx/Rx effective heights
☑ Flat earth profile sent to DLL
☐ Reverse profile

Global parameters
Earth radius km land 8500
Earth radius km sea 8500
RMS wave height (m) 0.00
Field strength offset
Offset 0 dB
Field strength=E-Offset
Variability
Location 50.0 pc
Time 1 pc
☐ Variability (P2P unwanted signal)
Time (0 to 50 pc) 0=random 50.000

Info
Generic propagation model valid from about 30 MHz to 350 GHz:
A map-based deterministic propagation model to fulfill all V/U/S/EHF requirements at the same time

Diffraction component = non line of sight path (NLoS)
Deygout 1966 is limited to 3 obstacles (ITU-R 526-11), Deygout 94 has no limitation and

Please refer to the corresponding point of this document according the green/red boxes above for detailed information.

3.1. Introduction

The implementation of these models implies many kinds of constraints: algorithmic complexity, memory requirement, author's creativity and choices but also the evolution of customer demand. As a result, it is not always possible to exactly have a "nominally implemented model" as far as this expression makes sense. Apart from robustness to ill-programming, another reason is that, due to discretization, there is always an implicit uncertainty between the theoretical definition of models and their implementation on computers (this is the question of well-posedness and numerical stability of models). Thus, in this paragraph, we briefly mention models that are implemented, emphasizing the differences or the necessary additions that are made with respect to their original definition.

Special interest has the Deterministic Generic propagation model, valid from 30 MHz to 350 GHz, about which we give further information in the point

Generic deterministic propagation model valid from 30MHz to 350GHz.

3.1.1. Geometrical/statistical/mixed models

Propagation models available in ATDI tools can be divided into:

- **Geometrical (or deterministic) models:** (BR method; Wojnar; ITU-R P.525/526)

These models provide an estimation directly derived from the path profile. In many cases, this estimation uses the properties of Fresnel geometry. In ATDI tools, the decomposition of the propagation loss $L_{prop}=L_{fsd}+L_d+L_{sp}+L_{gas}+L_{rain}+L_{clut}+L_{model}$ was done for this purpose. Indeed, apart from the free space attenuation term L_{fsd}, the two major terms L_d and L_{sp} stand for geometrical attenuation terms. L_d is a diffraction correction term that can be selected in the diffraction geometry box of the *Tools/Propagation model* dialog box. To use no diffraction correction, select the no diffraction loss button. Second, a subpath attenuation term that can be selected in the subpath attenuation box (click no subpath loss to deactivate). The additional corrective terms L_{gas}, L_{rain}, L_{clut} and L_{model} are defined in the previous chapter. Geometrical model take the Earth curvature into account (i.e. the require altimetric correction due to the rotundity of the Earth).

- **Statistical (or empirical) models:** (ITU-R P.370-7; ITU-R P.452)

They are based on measurement, depend on the geometry only in a more restrictive sense. They were originally designed to provide estimations without DEM, but they require a few synthetic geometrical parameters. Basic parameters are the effective antenna height, the time and/or site variability, the kind of ground. Additional geometrical corrective terms such as clearance angle can be used but, in the propagation loss formula, we always have $L_d=L_{sp}=L_{gas}=L_{rain}=L_{clut}=0$ and the term L_{model} recapitulates all the possible attenuation terms except the free space loss. (No specific division into attenuation components was looked forward because relevant parameters vary from one statistical model to another).

- **Mixed models:** (Okumura-Hata/Davidson; ITU-R P-1546)

These try to take advantage from both geometrical and statistical modeling techniques.

3.1.2. Fully referenced/partially referenced/user models

Besides, there is also another 3-class subdivision of propagation methods available in ATDI tools, dealing with the scientific and public “fame” of the model:

- **Fully referenced models**

It means implementation of methods that were published (either in books, scientific review or technical recommendation such as ITU’s, CEPT’s…). In this category, we can find:

  - Okumura-Hata/Davidson method;
  - ITU-R P.370-7 model;
  - ITU-R P.525/P.526 model;
  - ITU-R P.452 model,
  - ITU-R P.1546 model.

- **Partially referenced models**

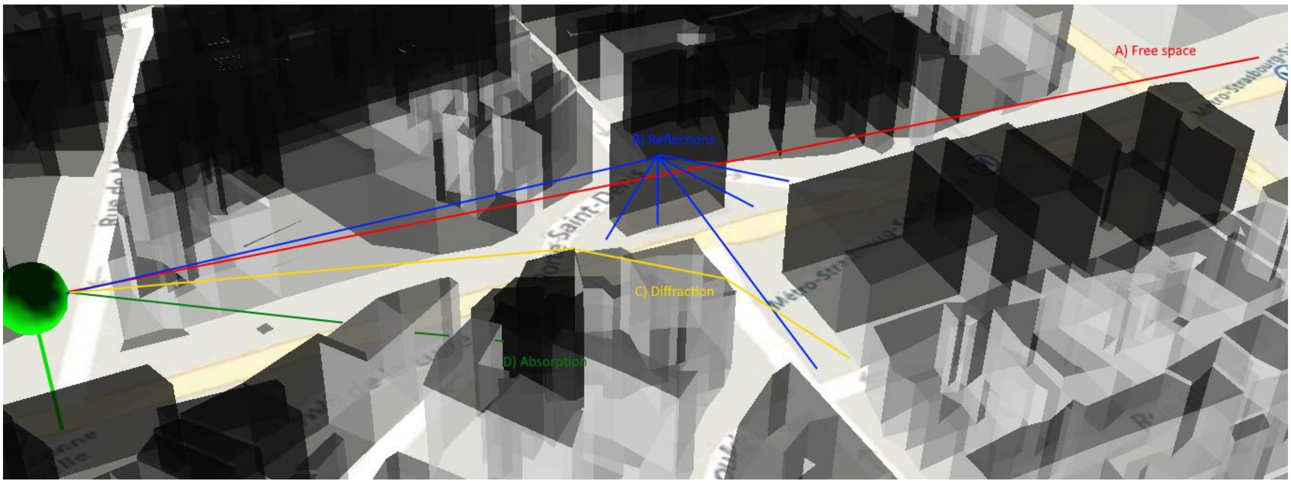
It means implementation of methods that were published but that have still been under study and may be modified by their authors, or models that were completed by ATDI to provide better estimates or models whose reference were not complete:

  - Wojnar method;
  - BR method.

- **Specific Models**

At last, the third class of model corresponds to another important functionality offered by ATDI tools: specific models that can be defined and implemented by the user and called as user models. The model can then be selected by browsing from the user model field in the models frame of the dialog box.

3.2. Generic deterministic propagation model valid from 30MHz to 350GHz



http://www.atdi.com/wp-content/uploads/2012/05/PropaPath3.png

3.2.1. Free space attenuation

The free space attenuation term is always given by:

$$\boxed{Lfsd = 20\log(4\pi d/\lambda)}$$

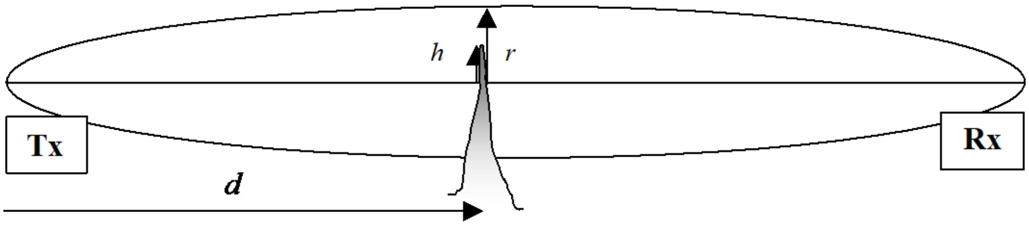
Free space attenuation only depends on the distance from Tx to Rx, but is defined on the use of an isotropic receiving antenna: choose reference antenna accordingly.

3.2.2. Diffraction attenuation models

When one selects a geometrical model, there is the possibility to compensate for diffraction, i.e. attenuation yielded when the direct transmitter/receiver ray encounters one or several obstacles. In Fresnel theory, the attenuation brought by one single knife-edge located in free space can be derived using Fresnel Integrals. Since those integrals have no explicit solution, a good approximation to this knife-edge diffraction loss is used:

$$\boxed{Ld = 6.9 + 20\log[(\nu-0.1) + \mathrm{sqrt}(1 + (\nu-0.1)2)]}$$

where ν=sqrt(2)h/r. The fraction h/r, called the *clearance ratio*, is the ratio of the algebraic height (positive upward) of the edge above the line of sight over the radius of Fresnel ellipsoid at distance *d* from the Tx (cf. figure).



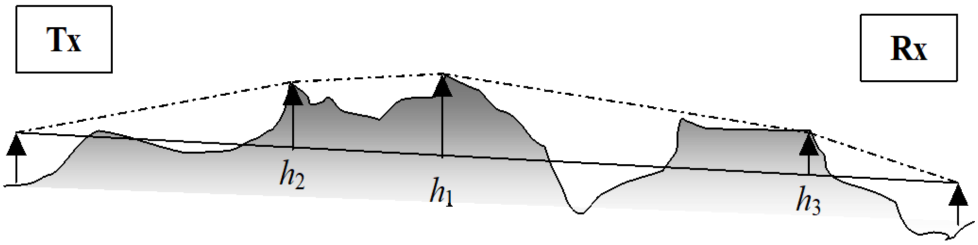
The different diffraction methods actually offer specific ways to identify one ⍰ (single obstacle diffraction) or several ν (multiple obstacle diffraction) according to a path profile. Here are the different diffraction methods available in ATDI tools.

3.2.2.1. Deygout Methods

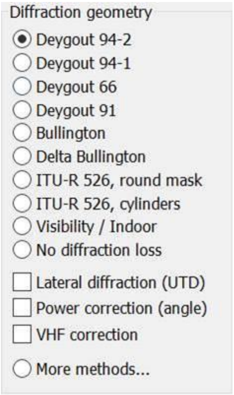
In 1966, Deygout proposed a diffraction method that takes 2 obstacles into account: a primary obstacle (obtained from the maximum clearance ratio ν_1 w.r.t. the line of sight between Tx and Rx) and, if this primary obstacle exists ($\nu_1>0$), a secondary obstacle (obtained from the maximum clearance ratio ν_2 w.r.t. the line of sight between Tx and the primary obstacle and between the primary obstacle and Rx). The global diffraction loss is then given by $L_d'=L_d(\nu_1)+L_d(\nu_2)$ (cf. Jacques Deygout, Multiple knife-edge diffraction of microwaves, IEEE Transaction on Antennas and Propagation, July 1966). This method provided better estimations than Bullington's, but still slightly optimistic.

Deygout 91, limited to 3 obstacles, is an enhanced/alternative version of Deygout 66. This method is not referenced by ITU.

Deygout-94 for multiple knife-edge diffraction: In 1994, Deygout presented a generalized improvement of this method using a potentially infinite number of edges (Jacques Deygout, Données fondamentales de la propagation radioélectrique, juillet 1994, Editions Eyrolles). The search for the edges is sequential: if the primary obstacle exists, one searches for two secondary obstacles (one between Tx and the obstacle and the other between the obstacle and Rx). Then, this search is performed again on each side of the secondary obstacles possibly looking for ternary obstacles. This process is reiterated recursively ($n+1^{ary}$ obstacles depend particularly on n^{ary} obstacles) until no new obstacle is found. Then, the global diffraction loss is $L_d'=\Sigma_i L_d(\nu_i)$.



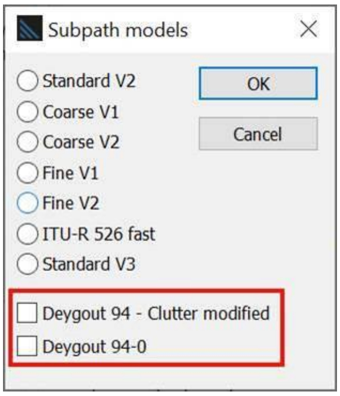
The different Deygout models that have evolved over time remain accessible (from the original "Deygout 94-0" model). Either directly from the propagation model selection box:


Diffraction geometry
● Deygout 94-2
○ Deygout 94-1
○ Deygout 66
○ Deygout 91
○ Bullington
○ Delta Bullington
○ ITU-R 526, round mask
○ ITU-R 526, cylinders
○ Visibility / Indoor
○ No diffraction loss

☐ Lateral diffraction (UTD)
☐ Power correction (angle)
☐ VHF correction

○ More methods...

Or from "More methods…" :



Subpath models

○ Standard V2
○ Coarse V1
○ Coarse V2
○ Fine V1
○ Fine V2
○ ITU-R 526 fast
○ Standard V3

☐ Deygout 94 - Clutter modified
☐ Deygout 94-0

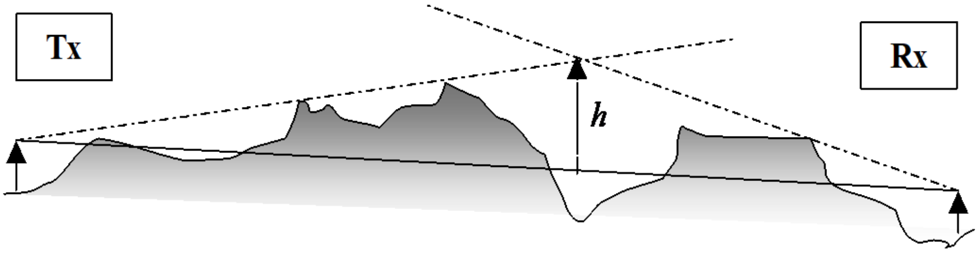
Notes:

- A new propagation engine has been introduced in V23.2.9 (faster and more accurate), but the "Deygout-1" diffraction model had to be removed, since it was not compatible with that new propagation engine. The "Deygout-2" diffraction model has then been renamed "Deygout 94".

- The "Deygout 94-2" was formerly simply called "Deygout 94" when there was only one Deygout model in the main box is now the . It has been renamed "Deygout 94-2" to distinguish it from the previous model ("Deygout 94-1") which has been moved from the "More method" box to the main box (modification of 07/03/2020 from V22 .4.8).
  The V2 model has been improved compared to the V1 model with a new clutter attenuations "Clutter entry loss" (modification of 01/28/2020 since V22.4.5). This model is considered with the options "Rx over ground" and "Rx over ground relaxed" and for receivers located under the ground. This model calculates the Fresnel-Kirchhoff losses just behind the obstacle if the receiver is below the ground height and if the point is seen by the transmitter. The "Rx over ground relaxed" option moves the obstacle to extend the distance between the receiver and the ground obstacle. The accuracy is 1/4 pixel.
  Since the original model, various improvements have been made in terms of precision and calculation speeds.
  Between the V1 and the V2, the modifications remained minor however.

3.2.2.2. Bullington Method

In this method, the height *h* is determined by the intersection of the two straight lines used to define the Tx and Rx clearance angles. An equivalent virtual obstacle is then obtained from the height of this intersection w.r.t. the line of sight. This method has obviously, a tendency to provide optimistic estimations.

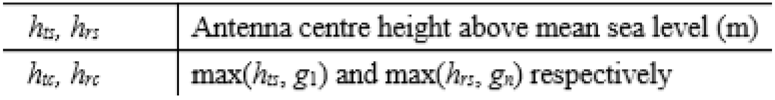


3.2.2.3. Delta Bullington Method

Delta Bullington is referenced in ITU-R 526-15, 452-16, 2001-3 and 1812-5.

Implementation note about Clutter:

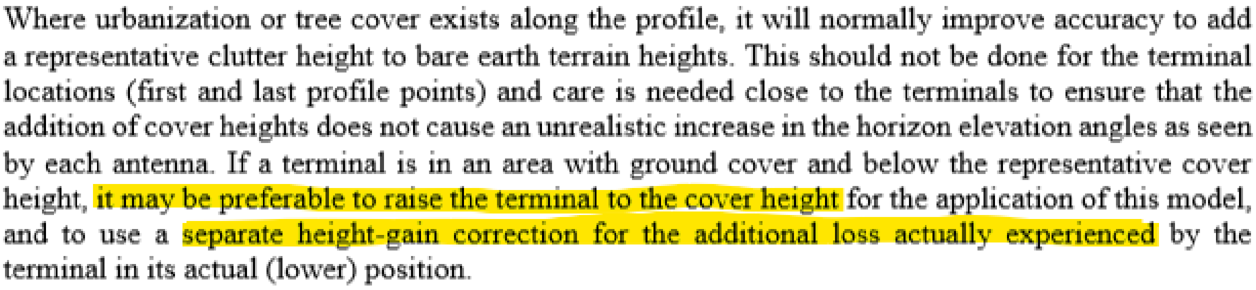
- 1812-5: Profile takes into account clutter heights along the path and terminal clutter heights as defined in the ITU R.1812 clutter options dialog box (2 -> n-1). For transmitter and terminal locations (1 and n), the following considerations are applied (Table 5):



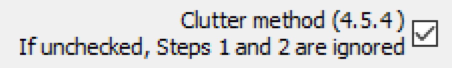
h_{ts}, h_{rs}	Antenna centre height above mean sea level (m)
h_{tc}, h_{rc}	max(h_{ts}, g_1) and max(h_{rs}, g_n) respectively

- **526-15**:
- Profile considers clutter heights along the path. Terminal clutter heights as defined in the General Clutter dialog box. For transmitter and terminal locations (1 and n), the following considerations are applied:

The transmitter and terminal heights are not raised to the clutter height, if antenna heights are lower than clutter height since the recommendation does not provide separate height gain correction method.

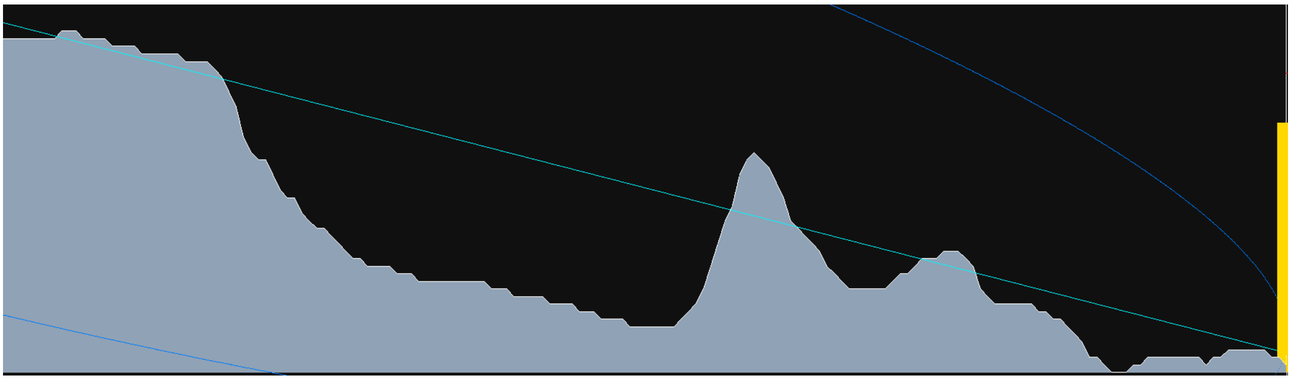


Where urbanization or tree cover exists along the profile, it will normally improve accuracy to add a representative clutter height to bare earth terrain heights. This should not be done for the terminal locations (first and last profile points) and care is needed close to the terminals to ensure that the addition of cover heights does not cause an unrealistic increase in the horizon elevation angles as seen by each antenna. If a terminal is in an area with ground cover and below the representative cover height, it may be preferable to raise the terminal to the cover height for the application of this model, and to use a separate height-gain correction for the additional loss actually experienced by the terminal in its actual (lower) position.

- **452-16**:
- Profile does not consider clutter heights along the path. Terminal clutter heights as defined in the ITU R.452 clutter options dialog box (Nominal height). For transmitter and terminal locations (1 and n), the formulas described in 4.5 Additional clutter losses section are applied.
- Clutter method (452):
- 

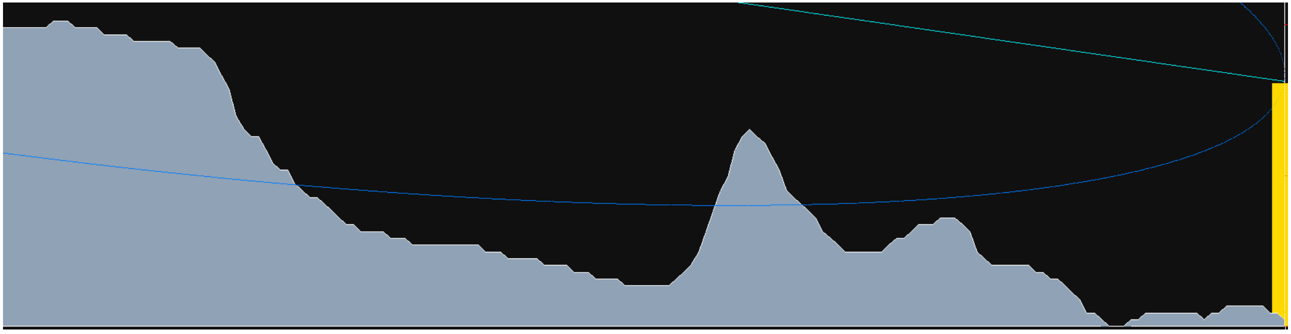
  Clutter method (4.5.4) ☑
  If unchecked, Steps 1 and 2 are ignored

  This option allows to ignore the steps 1 and 2 from ITU-R P.452 (4.5.4 Method of application)
  “Step 1: Where the clutter type is known or can be safely assumed, the main procedure is used to calculate the basic transmission loss to the nominal height, ha, for the appropriate clutter type, as selected from Table 4. The path length to be used is d – dk (km). However where d >> dk this minor correction for dk can safely be ignored. Step 2: Where there is a “site-shielding” obstacle that will provide protection to the terminal this should still be included in the basic calculation, but the shielding loss (Ast or Asr (dB)) should be calculated to the height ha at distance ds, rather than to h at dL as would otherwise be the case.”
  Example (Rx antenna = 1.5m, Clutter height at Rx location = 35m):
  If Clutter method (4.5.4) is OFF, and if the clutter height is greater than Rx antenna height, the Rx is not raised to clutter height and diffraction is computed accordingly:



In that case, the Rx is masked by terrain obstacles, and the FS computed includes the attenuation by diffraction. The equation 57 (height gain model correction) adds attenuation due to the presence of clutter closed to the terminal.

If Clutter method (4.5.4) is ON, and if the clutter height is greater than Rx antenna height, the Rx is raised to clutter height and diffraction is computed accordingly:



In that case, the Rx is no longer masked by terrain obstacles, and the FS computed will be higher. The equation 57 (height gain model correction) does not compensate the lake of diffraction.

- **2001-3**:
- Profile considers clutter heights along the path. Terminal clutter heights as defined in the General Clutter dialog box. For transmitter and terminal locations (1 and n), the following considerations are applied:

The transmitter and terminal heights are not raised to the clutter height, if antenna heights are lower than clutter height since the recommendation does not provide separate height gain correction method.

From recommendation:

“The model is believed to be most accurate from about 3 km to 1 000 km. At shorter distances, the effect of clutter (buildings, trees, etc.) will tend to dominate unless the antenna heights are high enough to give an unobstructed path. “

3.2.2.4. ITU-R 526 round mask method

Knife edge diffraction method have a global tendency to provide optimistic estimations of the field strength, by lack of involving attenuation by obstacles. The round mask method try to compensate this drawback using a model based on one single volumic circular approximation of the top of the main obstacle. It is defined in recommendation ITU-R P.526-5, § 4.3.

3.2.2.5. ITU-R 526 cylinders method

This method is a generalization of the round mask method to multiple obstacles. It is defined in the previous version (-4) of the recommendation ITU-R.526.

3.2.2.6. Visibility / Indoor method

In case of diffraction, the returned field strength is 0.

3.2.2.7. No diffraction loss

The attenuation by diffraction is 0; only the attenuation due to the Fresnel ellipsoid is taken into account.

3.2.2.8. Options

Lateral diffraction (UTD): The minimum attenuation between the vertical diffraction and the lateral diffraction is returned.

- Principle: The lateral diffraction is calculated around the main obstacle (last point seen) by analyzing the width of that one and by calculation 2 attenuations on both sides of the direct ray. Then the 3 paths are combined (vertical, lateral left, lateral right) by summing the received powers.
- Application: The lateral diffraction is calculated only if no other obstacle is found between the main obstacle and the receiver. Otherwise, the diffraction attenuation computed is the one of the vertical diffraction only.
- Note: it is considered only if a "BLG" layer is present in the project.

Power correction (angle): This option can take account of the diffracted power on the first obstacle and compensate the diffraction attenuation due to the antenna pattern. The correction factor is the following:

Correction = 10.Log(Radiated power towards the receiver / Radiated power towards the 1st obstacle)

This option cannot be used in the following point-to-point features:

- path budget with passive reflectors;
- microwave links path budget;
- point-to-point interference in "spurious" and "non spurious" mode (mainly because of interference with passive reflectors).

Spherical wave: For lower frequencies, a spherical wave correction term can be selected. The results of attenuation calculations due to interference (Deygout or Bullington) are related to the approximation of a plane wave. In order to take into account the limited distance between extremities of links to the object, the portion of the obstacle causing interference may be evaluated.

3.2.3. Subpath attenuation methods

ATDI's experience in using practically geometrical models with classical diffraction corrections, comparisons with measurements and customer remarks and queries have brought to the following statement: these models provide too optimistic field strength values. Obviously, the other available corrections (clutter, gaseous, rain, …) were not sufficient to provide relevant correction terms. This means that an additional geometrical correction was desirable. In his book [Deygout94], J. Deygout proposed an additional correction term:

$$\boxed{Lgr = 20\log(75000d) - 20\log(\pi h1h2f)}$$

where d is the distance to Tx (in km), h_1 and h_2 are respectively the Tx and Rx antenna height (in m) and f the frequency (in MHz). This correction term is directly derived from surface reflection modelling (for low incident angles). This correction (called L_{gr} for ground reflection attenuation) works, but only in specific conditions (limited bandwidth, antenna heights).

Actually, ATDI tools' author had the idea that a major part of the missing attenuation could be obtained by some "measurement" of the proportion of the profile that is located within Fresnel ellipsoid below the line of sight (which justifies the denomination of subpath loss).

The concept of the separation of the attenuations due to the "Subpath" with respect to the NLOS attenuations (diffraction) is a concept defined by Jacques Deygout and integrated in conjunction with ATDI in our software in 1994, following the diffraction model developed in same year (mixed between Bullington and Deygout 66, not limited in number of obstacles and independent of the resolution).

This concept is reflected in the recommendation 526: Attachment 2 to Annex 1 - Sub-path diffraction losses

The different "Subpath" models are closely linked to the quality of the terrain model used.

The reference is ***Fresnel integrals***. This and other methods available are detailed in the points below.

Recommended models (if associated with Deygout 94):

- Standard or Fine enhanced in HR (terrain in high resolution <= 5m)
- Coarse or Fine or Fine enhanced in MR (land in average resolution> = 10 m)

3.2.3.1. Fresnel integrals

This method is solving the Fresnel integrals for subpath attenuation.

It is extremely dependent on the least obstacle that obscures all or part of the first Fresnel ellipsoid, but investing very long computation time.
If the altimetric variations (altimetric and planimetric accuracy of the obstacles) do not significantly change the diffraction attenuation (NLOS), the attenuation due to the occultation of the Fresnel ellipsoid is not the same.
In ATDI software, diffraction (NLOS) and subpath are decorrelated, although the same calculation is performed in LOS and NLOS cases for 526/1812/452 recommendations.

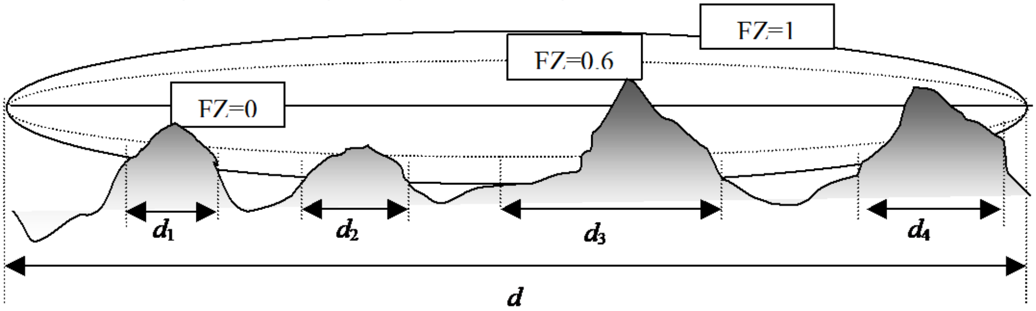
2D reflections are not compatible with this method.

3.2.3.2. Standard subpath attenuation

This option corresponds to Annex 1 of rec. 526. It calculates the attenuation due to the obstruction of the first 1/2 ellipse of Fresnel. This attenuation is based on L_{gr} value, but with a correction coefficient:

$$\boxed{Lsp = FZ * \rho * Lgr}$$

where ρ is the proportion of the total path that is located above the first Fresnel virtual ellipsoid (on the figure $\rho=(d_1+d_2+d_3+d_4)/d$) and FZ (for Fresnel Zone) is a coefficient of reduction of this virtual ellipsoid: FZ=1 means that the whole ellipsoid is considered, FZ=0 means that the virtual ellipsoid reduces to the straight line of sight segment (see figure).



The obstacle height accuracy low is less than 0.1m

3.2.3.3. MD 91 method

MD 91 corresponds to the model Deygout 66 modified by the Brazilians in 91.

This model is included in Recommendation ITU-R P.526-12 and takes into account the opposite phase of direct and reflected waves when the ground enters the first Fresnel zone, weighted by the hidden area.

The diffraction model is based on the construction of Deygout with unlimited number of obstacles.

Warning: do not use the subpath MD91 model with ground reflections option.

This model will be improved based on the results of measurements and correlations and feedback.

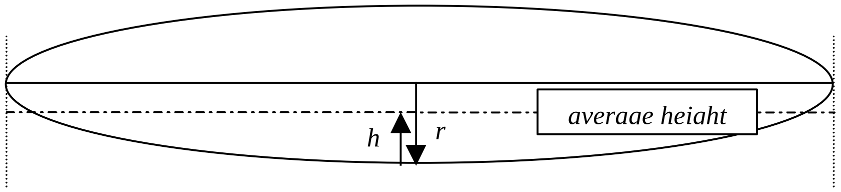
3.2.3.4. Coarse integration subpath attenuation

This option calculates the altimetric average of the path profile correlated with the Fresnel ellipsoid (mean of the altitudes for the intersection calculation).

The idea is to consider diffraction type subpath attenuation term using a value of h above the virtual Fresnel Ellipsoid lower limit instead of the line of sight. The value of h is defined as the average value of the profile elevation above the lower elevation of the central section of this ellipsoid. If r is the value of the largest radius of the ellipsoid, the subpath attenuation is given by:

$$\boxed{Lsp = 6.4 + 20\log[\nu + sqrt(1+\nu 2)]}$$

where ν=sqrt(2)h/r.



This method is particularly recommended for accelerated calculation times. It has a natural tendency to predict pessimistic results, or in the case of widely changing trajectories, to predict optimistic results.

3.2.3.5. Fine integration subpath attenuation

Fine integration is derived from Standard and is calculated between the last point seen from the transmitter and the receiver (non-reciprocal).

This option correlates all the points of the terrain with the Fresnel ellipsoid. In this method, the attenuation is also a diffraction type and the subpath attenuation term is given by:

$$\boxed{Lsp = 6.4 + 20\log[\nu + \mathrm{sqrt}(1+\nu 2)]}$$

with ν=sqrt(2)max$_i$(h_i/r_i), where the max$_i$ extends on every clearance ratio along the profile. This method takes much longer time. It is recommended for transmission sites that are located relatively higher above the surrounding terrain (such as peaks or cliffs).

The obstacle height accuracy low is less than 0.1m

3.2.3.6. Fine enhanced subpath attenuation

Fine enhanced is derived from Standard (reciprocal).

The obstacle height accuracy low is less than 0.1m.

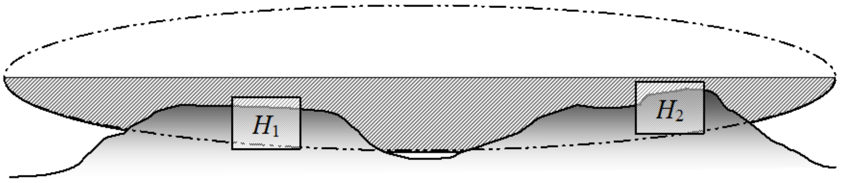
3.2.3.7. Area subpath attenuation

Area calculates the difference between the occulted and non-occulted areas (experimental).

This option calculates the total area of the Fresnel ellipsoid, compares this area to the area that is engaged by the terrain, and applies the corresponding attenuation. In this method, the attenuation is also a diffraction type and the subpath attenuation term is given by:

$$\boxed{Lsp = 6.4 + 20\log[\nu + \mathrm{sqrt}(1+\nu 2)]}$$

with ν=sqrt(2)H/R, where H/R is the ratio of the elevation surface located above the ellipsoid by the half-area of the ellipsoid (on the figure below, $H=H_1+H_2$).



3.2.3.8. Delta Bullington subpath attenuation

Delta Bullington is referenced in ITU-R 526-13, 2001, 452-16, and 1812-4.

3.2.3.9. Deygout 66 subpath attenuation

Deygout 66: relating to recital 526-11 / 452-14.

3.2.3.10. Free Ellipsoid subpath attenuation

Free ellipsoid: sets the field to NULL if the first Fresnel ellipsoid * FZ fraction intersects the field.

This function actually computes no subpath attenuation but returns 0 if the virtual ellipsoid is not free, i.e. it considers that the ellipsoid must be cleared.

It can be used to search for sites to locate MW links.

3.2.3.11. No subpath loss

No attenuation due to subpath is considered.

3.2.3.12. More methods

It allows to retrieve the former subpath models (standard V2, coarse V1, coarse V2…).

3.2.3.13. Options

Fourth-power law: This option (when available) will add to the subpath attenuations the calculation of the fourth-power law (Wojnar principle of dual ray).

> Note: it is mainly intended to be used with the "Fresnel integral" subpath model.
> It can also be used with "Fine" and "Area" subpath models, but not always relevant depending on the frequency range and resolution of the cartographic dataset. Don't use it by default with these models.

FZ fraction: Factor for the clearing of the ellipsoid. Enter in this field the factor to be applied. The factor will be applied to Coarse integration, Fine integration, Standard and Free ellipsoid options.

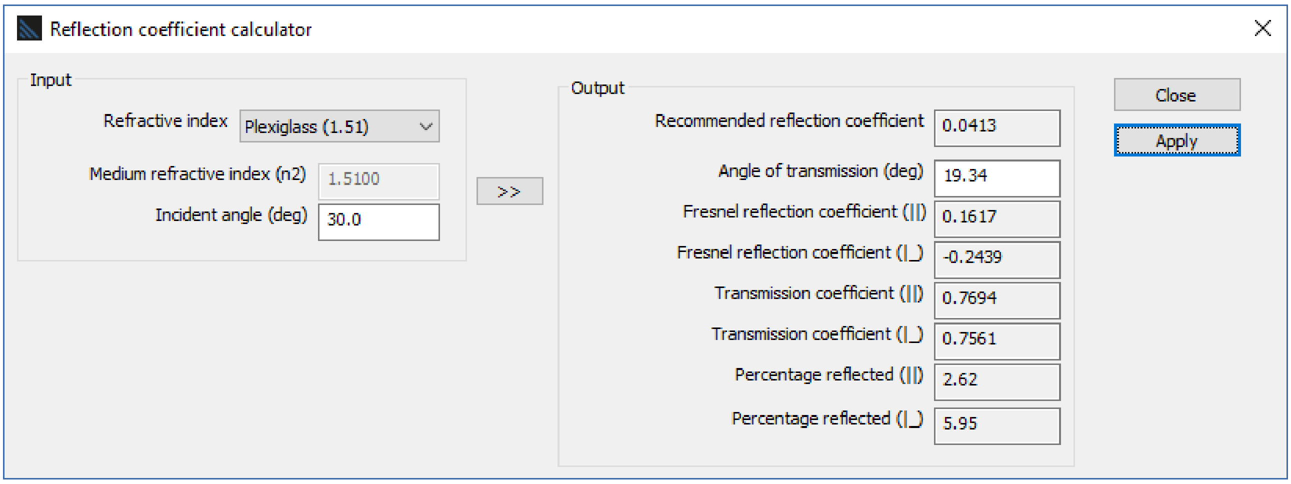
3.2.4. 3D reflections

Multipath: if checked, the multipath contributions to the field strength received will be considered. For further information, please refer to the document *3D reflection model parameter setting.pdf* (www.data.atdi-group.com/doc/619.pdf)

Reflection dist. limit (m): The tool will look for potential reflection points up to this distance from the transmitter. Looking for reflection points far away from the transmitter might not be relevant and will increase the computing time.

Elevation filter > (m): The tool will look for potential reflection points where the altitude is greater than this value. Looking for reflection points that are below a minimum elevation might not be relevant and will increase the computing time.

Default coefficient: reflection coefficient depends on the type of material. Please use the "Calculator" to define it:



Refractive index: Plexiglass (1.51)
Medium refractive index (n2): 1.5100
Incident angle (deg): 30.0

Recommended reflection coefficient: 0.0413
Angle of transmission (deg): 19.34
Fresnel reflection coefficient (||): 0.1617
Fresnel reflection coefficient (|_): -0.2439
Transmission coefficient (||): 0.7694
Transmission coefficient (|_): 0.7561
Percentage reflected (||): 2.62
Percentage reflected (|_): 5.95

3.2.5. Gases / Fog / Clouds attenuation term

The attenuation term is given by:

$$\boxed{L_{gas} = \gamma(f,T,\rho,p)d}$$

where *d* is the distance from Tx, therefore linear w.r.t. this distance. The coefficient γ depends on the water vapour density ρ, the temperature T, the atmospheric pressure p and the frequency f.
In ATDI tools, the implementation for the computation of γ includes both attenuation due to dry air and vapour. Since the main dependency for γ is upon frequency, T is fixed to 15°C, ρ is fixed to 7.5g/m^3 and p is set equal to 1013hPa. In the recommendation, the specific attenuation coefficient is given from 1 to 350GHz. Below 1GHz, γ is set equal to 0 since, at these frequencies, the attenuation by gases is negligible.

When a geometrical model (or a user model) is selected, the term Lgas is automatically included in Lprop.

There are two methods implemented in ATDI tools to take into account attenuation due to atmospheric gases:

- Recommendation ITU-R 676 (1-1000 GHz)
- Recommendation ITU-R 1820 (47-48GHz)

Besides, recommendation ITU-R 840 (>10GHz) is implemented to take into account attenuation due to fog and clouds.

Options:
- Vapour: vapour density in g/m3
- Water: water density in g/m3
- hPa: pressure in hectopascals (equal to millibars)
- T°: temperature in Celsius degrees

3.2.6. Slope model coefficient

The user may modify any of the models using the following formula:

$$\boxed{E = A \times Model + B}$$

where

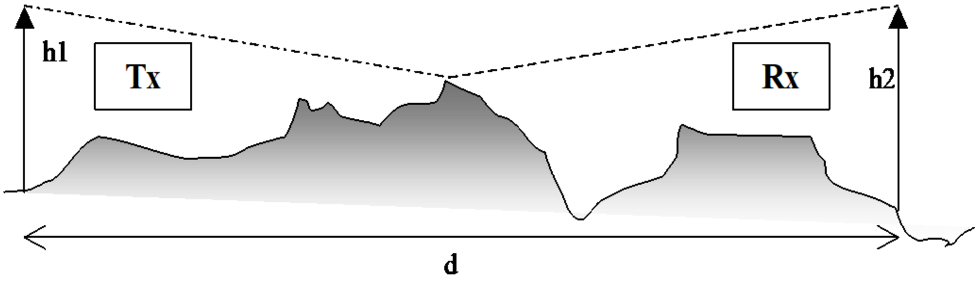
Model: field-strength as calculated by one of the standard models
A: coefficient
B: attenuation in dB

Factor A and attenuation B are variable parameters
- A factor: Enter in this field the correction coefficient A applicable to standard models
- B (dB): Enter in this field the attenuation factor B applicable to standard models
- Attenuation (dB/km): Enter in this field the attenuation value in dB/km
- Diffraction correct. (dB): This value in dB is added to the diffraction attenuation within a range between -50 to +50dB.

3.2.7. 2D reflections

There are three models available for 2D reflections:

- **Ground reflections (minima/maxima)**



The attenuation or the gain is given by : **$1+\rho^2+2\rho*\cos(\sigma+(4\pi h1h2/\lambda d))$**,
where:

ρ : Reflection factor,

σ : Phase shift between direct ray and reflected rays,
h1,h2 : Antenna heights,
λ : Wavelength,
d : Distance between Tx and Rx.

The attenuation is limited to 25dB (minima) and the gain to 6dB (maxima).

Note : This model can be used only if the distance D between the transmitter and the receiver follows the following rule : d > 10*max(h1,h2).

- **Ground reflections (minima/maxima flat earth)**: Same model as Ground reflections (minima/maxima), but the Earth curvature is not taken into account (flat Earth) in antenna heights calculations.

- **Ground reflections (reflection point)**: This model is the one described in the ITU-R P.530-10 recommendation. It is identical to the Reflections model used in the profile window, calculates first the reflection point before running the calculation of the attenuation/gain value between +6 and -20.

- **2-Ray model – max(Lfs,L-2ray)**: A description of that model can be found in https://en.wikipedia.org/wiki/Two-ray_ground-reflection_model. The maximum attenuation between free space losses and the 2-Ray losses is considered.

3.2.8. Rain / Snow attenuation term

The attenuation is linear w.r.t. to distance too:

$$L_{rain} = \gamma(f,R)d$$

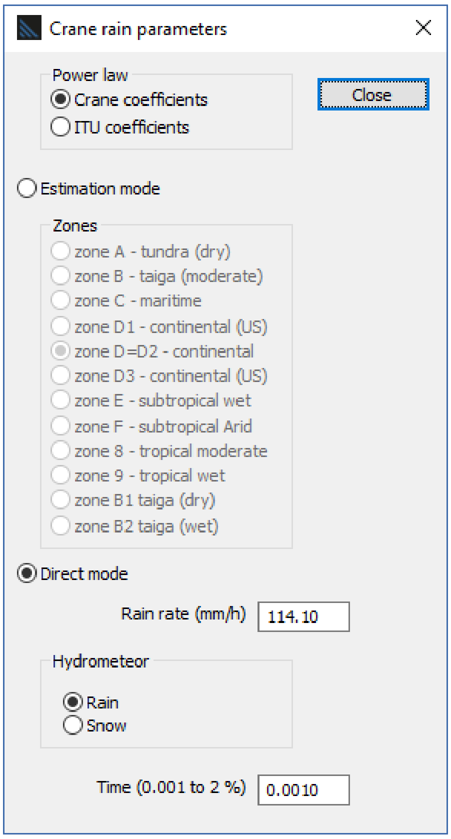
where γ depends on the frequency between 1 and 400GHz (rec. 838) and on a rainfall intensity R depending on the location on Earth (rec. 837) and on time variability (in percentage, between 0.001 and 1%). For the implementation, the table 1 in rec. 838 was linearly interpolated between successive frequencies in the table. Rec. 837 is fully implemented using the ITU Earth RAINZONE map whose resolution in latitude and in longitude is ½ degree. Below 1GHz, the specific attenuation term γ is set to 0.

L_{rain} is included in L_{prop} only if the rain atten option is activated in the propagation models box and only for geometrical and user models.

There are two methods implemented in ATDI tools to take into account attenuation due to the rain:

- ITU-R 838/530: the rain attenuation according to the ITU-R 838 and 530-8 (for reliability calculation) is taken into account in calculation. Click on the *ITU* button to access the Rain zone box displaying the rain zones on the planisphere and allowing to view the rain zone that will be taken into account with the ITU model.

- Crane Global model: the rain attenuation according to the Crane model (1985). Click on the *ITU* button to open the *Crane rain parameters* box:



Crane rain parameters

Power law

● Crane coefficients

○ ITU coefficients

○ Estimation mode

Zones

- ○ zone A - tundra (dry)
- ○ zone B - taiga (moderate)
- ○ zone C - maritime
- ○ zone D1 - continental (US)
- ● zone D=D2 - continental
- ○ zone D3 - continental (US)
- ○ zone E - subtropical wet
- ○ zone F - subtropical Arid
- ○ zone 8 - tropical moderate
- ○ zone 9 - tropical wet
- ○ zone B1 taiga (dry)
- ○ zone B2 taiga (wet)

● Direct mode

Rain rate (mm/h): 114.10

Hydrometeor

● Rain

○ Snow

Time (0.001 to 2 %): 0.0010

For further information, please refer to the document *Crane rain parameters box.pdf* (www.data.atdi-group.com/doc/35.pdf)

The selection of one of these methods gives access to the following fields:

- Rain rate (mm/h): precipitation in mm/h
- R-837 (dynamic): check to use the ITU-R 837 rain model
- Time (0.001 to 1%): percentage of time during which one will have a precipitation of n mm/h

Isotherm 0°C: define the mean 0° C isotherm height.

3.2.9. Troposcattering

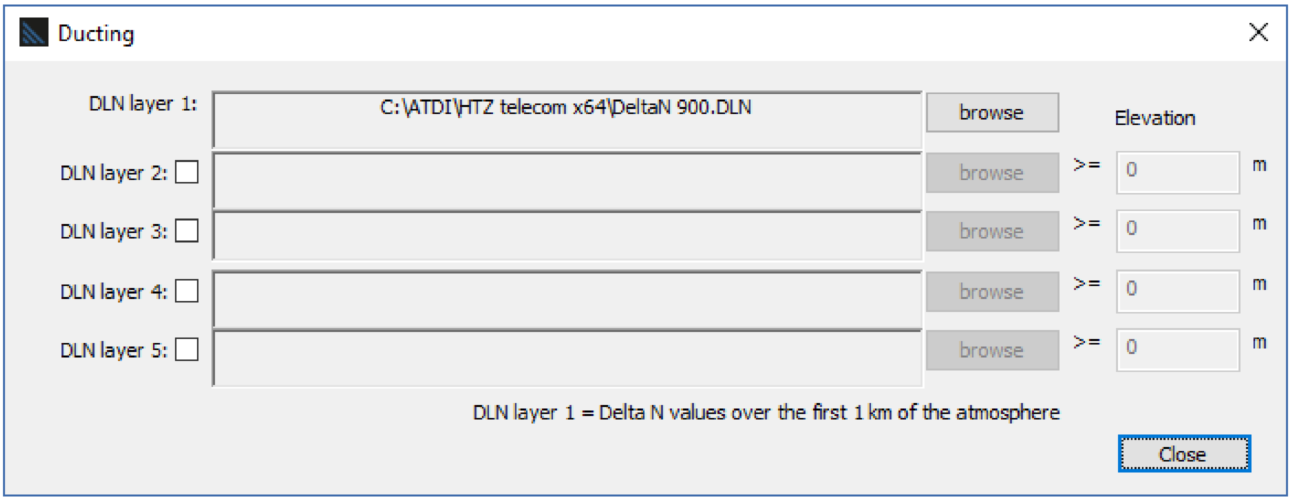
Attenuation due to tropospheric scatter according climate is referenced in ITU-R P.617-3.

3.2.10. Ducting

It is possible to add the ducting effect to any of the models available in ATDI tools. This model corresponds to section 4.5 of the ITU-R P.452-10 recommendation, except for the Ad(p) value (eq. 16) in order to avoid time variability and takes into account local refractivity gradients.

It is able to calculate automatically the refractivity gradient applied along the path, based upon maps that are integrated into ATDI tools (DLN layer).

If a DN map has been imported, and if the path analysis goes over it, the DN values of the imported maps are used. Otherwise, the default values of the equivalent Earth radius specified in the propagation model box are used. Theoretically, a default value of 6370 km for the equivalent Earth radius should be used. A default refractivity map corresponding to the "DeltaN 900.DLN" file (ic1 geocoded in 4SEC grid and containing DN values from 0 to 255) is provided with the tool. In order to load a DLN file, the user can whether check the "Ducting" option or browse with "..." to select the predefined .DLN file. The name of the DLN file associated to the ducting model is saved in the .PRM file.



DLN layer 1: C:\ATDI\HTZ telecom x64\DeltaN 900.DLN

DLN layer 2: ☐ >= 0 m

DLN layer 3: ☐ >= 0 m

DLN layer 4: ☐ >= 0 m

DLN layer 5: ☐ >= 0 m

DLN layer 1 = Delta N values over the first 1 km of the atmosphere

Owing to the multiple DLN files that can be loaded, the ducting trap depends not only on the Rx location, but also on its height. Up to 5 different DLN files can be loaded. The reference of the elevation specified depends on the selected mode:

- AGL: above ground level;
- R/S : above sea level.

Note: the type of refractivity maps handled by ATDI tools are N refractivity maps and not M refractivity curves because the tool calculates the Earth curvature along the path.

The result given by the ducting effect will be considered as a gain that will be applied on the propagation:

When the model is selected: $\boxed{FS_{model} = FS + Gain_{duct}}$

where:
$\mathbf{FS_{model}}$ = Field Strength calculated using the selected model, diffraction, subpath model and other component (gaz, rain, and the duct…)
FS = Field Strength calculated using the selected model, diffraction, subpath model and other component (gaz, rain…)
$\mathbf{Gain_{duct}}$ = 0 dB when no ducting effect is found
= … > 0 dB when ducting effect is found

The evaluation of ducting affect requires a larger computation time. Thus, the user will care about activating this component only when necessary. Since the ducting/layer reflection implies very favourable propagation conditions, the output field strength of this component can be higher the free space’s, especially for small time percentage.

For further information about Ducting effect, please refer to the corresponding documents available on the online library.

3.2.11. Ground Occupancy influence

In ATDI tools, it is possible to involve the additional “clutter layer” sometimes included in the DTM file. Properties of this clutter or ground occupancy layer can be defined in the *Tools/Clutter options…* (or the *Tools/Propagation model/Clutter…*) box.

The first influence of the clutter is a modification of local altitude of the DTM, according to the following rules for the first ten predefined codes:

Clutter code	Altimetric modification
0 – open	none
1 – village	+ 6 m
2 – suburban	+ 10 m
3 – urban	+ 15 m
4 – dense urban	+ 20 m
5 – forest	+ 12 m
6 – hydro	none
7 – high urban	+ 35 m
8 – park/wood	+ 4 m
9 – roof - building	none

The ten following terms are optionally defined by the user.

There are three options that allow to consider the altitude of the Tx/Rx in different ways:

- T/R over clutter, in this case, the value set for the receiver’s height is defined over the clutter’s height.
- T/R over ground *spot*, the value set for the receiver’s height is defined over the ground.
- Rx over ground relaxed, the value set for the receiver’s height is defined over the ground, and when the receiver is located inside a clutter, the clutter is cut around the receiver (the receiver is encircled by the clutter, but not inside).

Regarding the attenuation term L_{clut}, there are several possibilities offered to the user:

- ITU clutter attenuation (CCIR);
- UER clutter attenuation;
- User attenuation;
- Tuning
- None (i.e., no attenuation due to the ground occupancy code will be considered)
- TSB-88
- dB/km
- Flat+diffraction

While ***ITU (CCIR) attenuation*** terms subdivides into 4 bands:

ITU attenuation terms L_{clut} (dB)				
Clutter code	$f \leq$ 40MHz	40 < $f \leq$ 160MHz	160 < $f \leq$ 450MHz	$f >$ 450MHz
0	3	5	7	9
1	9	12	15	18
2	19	22	25	28
3	22	25	28	31
4	25	28	31	34
5	27	27	27	27
6	0	0	0	0
7	29	32	35	38
8	3	5	7	9
9	0	0	0	0

UER attenuation terms subdivide into two bands (VHF or UHF):

UER attenuation terms L_{clut} (dB)		
Clutter code	$f <$ 300MHz	$f \geq$ 300MHz
0	2	4
1	6	8
2	8	12
3	8	12
4	8	12
5	4	8
6	0	0
7	8	12
8	4	8
9	0	0

These two classes of attenuation and also ***user attenuation***, are *locally* constant w.r.t. the distance from Tx and are given in dB.

The option ***dB/km** attenuations* is also a user defined attenuation coefficient γ, but the whole attenuation depends *locally linearly* upon the distance:

$$\boxed{L_{clut} = \Sigma_i \gamma_i d_i}$$

where γ_i is the *user* attenuation coefficient along the i^{th} clutter portion of the path and d_i is the distance encountered on this portion.

For geometrical and *user* models, L_{clut} is automatically added to L_{prop}.

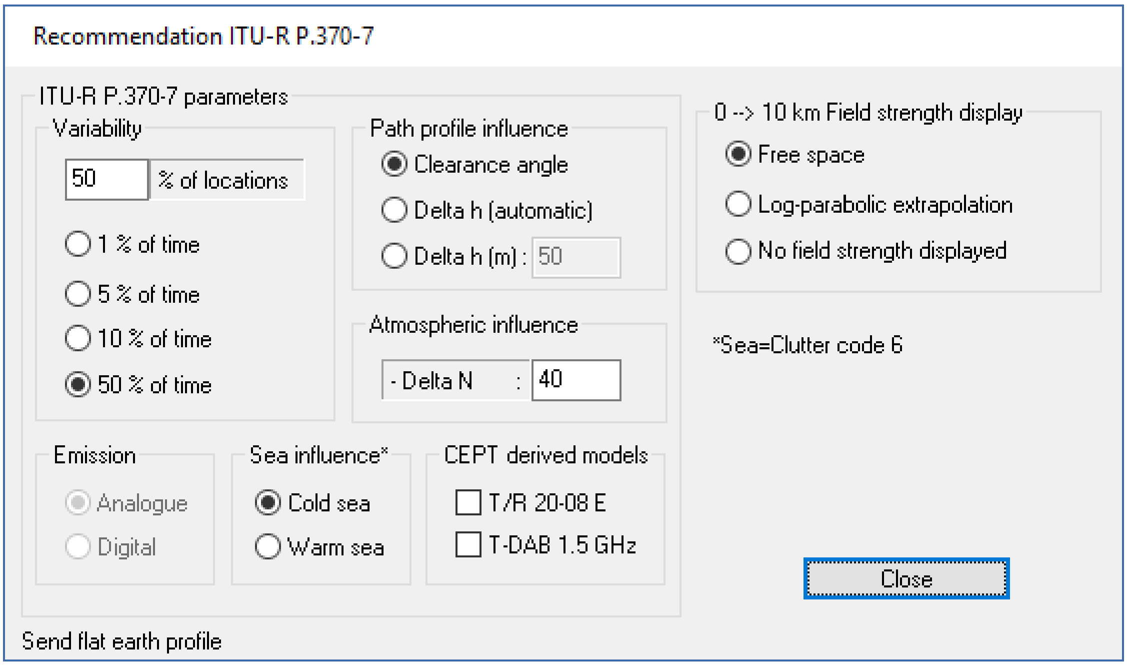
For further information about clutter attenuations, please refer to the document ***Clutter attenuations in ATDI tools.pdf*** (http://www.data.atdi-group.com/doc/118.pdf).

3.3. Other propagation methods

3.3.1. ITU / FCC (empirical and half deterministic)

3.3.1.1. ITU-R 370 (30-1000 MHz)

The recommendation ITU-R P.370-7 is a VHF and UHF band prediction method to be used in the planning of broadcast services. In its most basic mode, it requires few ground altitude knowledge. It is mainly based on a synthesis of field-strength measurement obtained from different situations: location and time variability, transmitting and receiving antenna heights, atmospheric refractive index gradient, frequency band type (VHF or UHF), propagation path type (land, cold sea, warm sea). In addition to this, it is possible to optionally include geometrical ground irregularity corrections, requiring then the whole knowledge of the digital elevation model (DEM) values along the path. Somehow, this model is mainly statistical, and its implementation in ATDI tools is rather fast and easy to use.



Recommendation ITU-R P.370-7

ITU-R P.370-7 parameters

Variability

50 % of locations

○ 1 % of time
○ 5 % of time
○ 10 % of time
● 50 % of time

Path profile influence

● Clearance angle
○ Delta h (automatic)
○ Delta h (m) : 50

Atmospheric influence

- Delta N : 40

Emission

● Analogue
○ Digital

Sea influence*

● Cold sea
○ Warm sea

CEPT derived models

☐ T/R 20-08 E
☐ T-DAB 1.5 GHz

0 --> 10 km Field strength display

● Free space
○ Log-parabolic extrapolation
○ No field strength displayed

*Sea=Clutter code 6

Send flat earth profile

3.3.1.1.1. User level

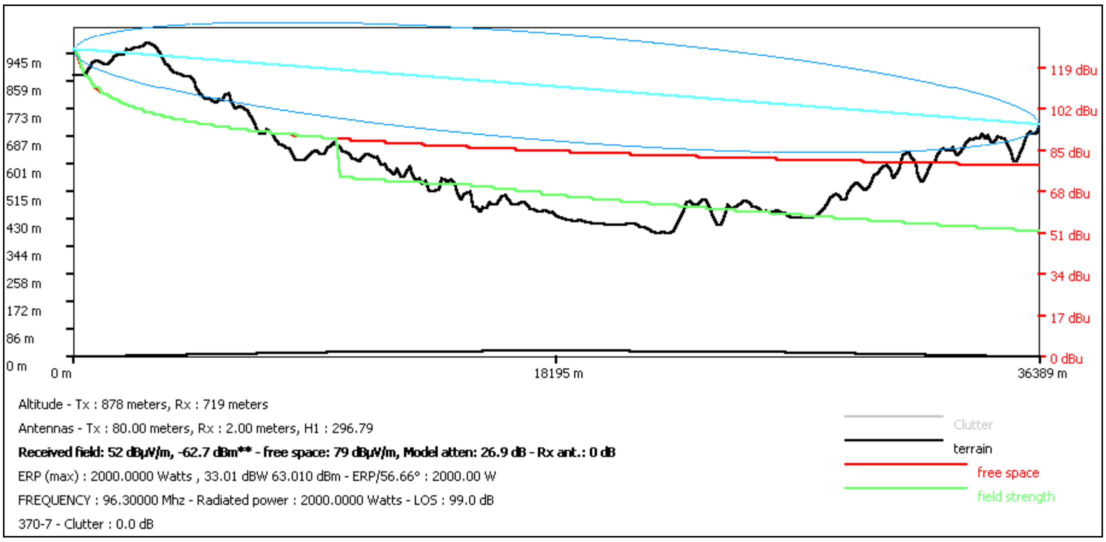
- Propagation curves accuracy: The digitization of curves has a general precision of ±1dB for more than 95% of the distances from 10 to 1000km. Below 10km, either free space field-strength or continuous extrapolation is displayed. Above 1000km, curves might diverge since they are strictly based on interpolation in the interval [10;1000] km. Some curves in the recommendation are not defined as far as 1000km. These curves were extrapolated out to 1000 km.

- Path profile roughness influence: 3 options are available to take the irregularity of the profile into account (each method excludes the others):
    - clearance angle: the correction is computed through two clearance angles: one from the transmitter Tx (limited to negative angles) and one from the receiver Rx. Thanks to the latter, altitude profile is taken into account in the field-strength profile computation, which increase the computational cost of the method with this option;
    - Δh automatic: Along each profile, Δh is computed between 10 and 50km, or between 10 and d km if the profile length d is in [10;50] km. Below 10 km, the value of Δh displayed is 50 m (the corresponding correction Δh is 0dB);
    - Δh manual: Internal computation of Δh is not performed but left to the user so as not to slow down coverage computations (the value of Δh is thus uniform on every profile for a given coverage).
- clearance angle and effective antenna height accuracy: If the whole profile is less than 15km long (total length d), the effective antenna height computation is not performed from profile altitudes located between 3 and 15km but between 3 and d km. However, the computation remains exact if d ⍰ 15km, even for points located below 15km of the Tx since this computation is done once for all before ATDI tools calls the 370-7 model (the model is called at every point along the path). On the contrary, clearance angle computations that are performed at every point along the profile, are a priori exact only if the current point is at least 16km away from the Tx;
- clearance angle variability: If the computation of the clearance angle θ (either from Tx and from Rx) yields values outside [-40;1,5] degrees, then θ is forced to the nearest boundary value (-40 or 1,5);
- Atmospheric influence (Refractive air index gradient): It is actually an average gradient and not a dN/dh. It is defined in recommendation 370-7 as N(0m)-N(1000m), which corresponds to the opposite of usual ΔN, whose mean value is –40 or –39.
- First ten kilometres field strength display: A new functionality is now available for the part of the model that is undefined, i.e. between 0 and 10km. Previously, free space attenuation was displayed on this section of the path (free space option, cf. Fig. 1). Now, a possibility is offered to display a fully continuous field strength profile from the Tx using the log-parabolic extrapolation option (cf. Fig. 2). This option provides, from a logarithmic distance scale, a parabolic interpolation between 3 points: the free space field strength value at 3km and the 370-7 curve values at 10 and 11km. Somehow, this interpolation may not look “parabolic” mainly for two reasons:
    - Interpolation: The value of the interpolation at distance x between 3 and 10km actually depends on the values of the field at 10 and 11km, depending themselves on the

altitude values at these points (through the computation of the effective antenna height). Since these values are not known (cf. remark above on the computation of the effective antenna height), these field strength values (at 10 and 11km) are computed with the current effective antenna height at distance x;

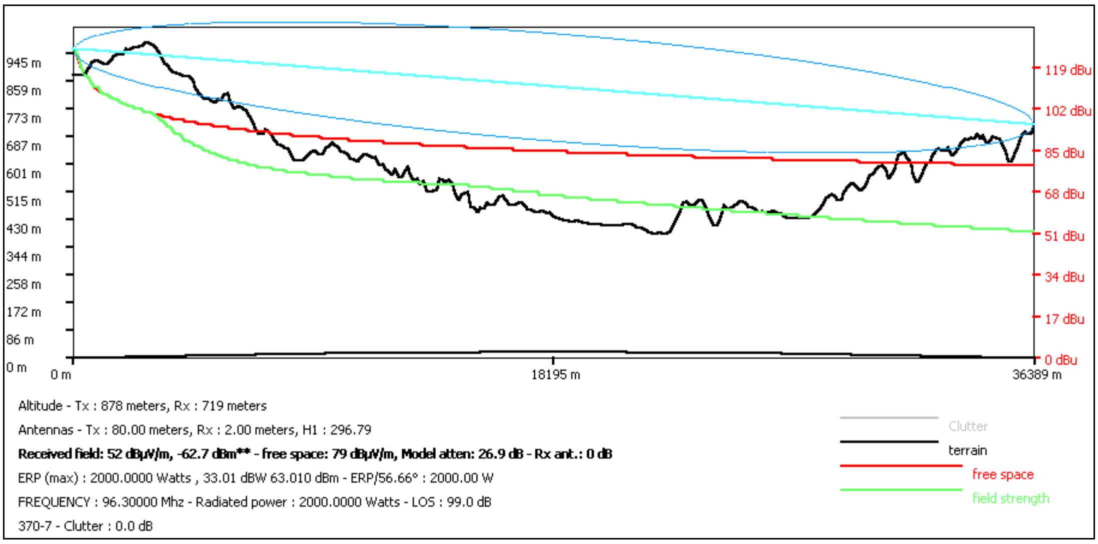
- Clearance angle: If the option clearance angle is on, the clearance angles (and especially the Rx clearance angle computed from distance x) are also taken into account in the field strength computation (cf. Fig. 3).

Note that, for the sake of continuity, the section from 0 to 3km is maintained with standard free space attenuation values.



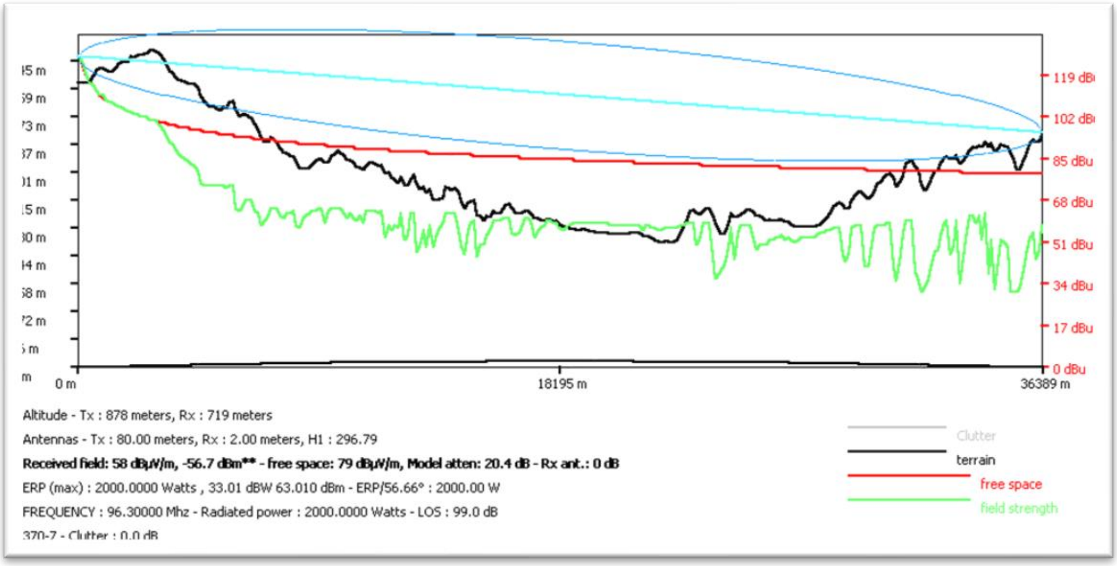
Altitude - Tx : 878 meters, Rx : 719 meters
Antennas - Tx : 80.00 meters, Rx : 2.00 meters, H1 : 296.79
Received field: 52 dBµV/m, -62.7 dBm - free space: 79 dBµV/m, Model atten: 26.9 dB - Rx ant.: 0 dB**
ERP (max) : 2000.0000 Watts , 33.01 dBW 63.010 dBm - ERP/56.66° : 2000.00 W
FREQUENCY : 96.30000 Mhz - Radiated power : 2000.0000 Watts - LOS : 99.0 dB
370-7 - Clutter : 0.0 dB

Figure 1: example of field strength profile (green) when the option free space is on and the option clearance angle is off. Along the ten first kilometers, the green curve is the same as the red curve (free space attenuation).



Altitude - Tx : 878 meters, Rx : 719 meters
Antennas - Tx : 80.00 meters, Rx : 2.00 meters, H1 : 296.79
Received field: 52 dBµV/m, -62.7 dBm - free space: 79 dBµV/m, Model atten: 26.9 dB - Rx ant.: 0 dB**
ERP (max) : 2000.0000 Watts , 33.01 dBW 63.010 dBm - ERP/56.66° : 2000.00 W
FREQUENCY : 96.30000 Mhz - Radiated power : 2000.0000 Watts - LOS : 99.0 dB
370-7 - Clutter : 0.0 dB

Figure 2: field strength profile on the same path as Figure 1's, when the option log-parabolic extrapolation is on and the option clearance angle is off. The field strength displayed is continuous.



Altitude - Tx : 878 meters, Rx : 719 meters

Antennas - Tx : 80.00 meters, Rx : 2.00 meters, H1 : 296.79

Received field: 58 dBµV/m, -56.7 dBm - free space: 79 dBµV/m, Model atten: 20.4 dB - Rx ant.: 0 dB**

ERP (max) : 2000.0000 Watts , 33.01 dBW 63.010 dBm - ERP/56.66° : 2000.00 W

FREQUENCY : 96.30000 Mhz - Radiated power : 2000.0000 Watts - LOS : 99.0 dB

370-7 - Clutter : 0.0 dB

Figure 3: field strength profile on the same path as Figure 1's, when the option log-parabolic extrapolation is on and the option clearance angle is on. In addition to continuity, the section between 3 and 10km also integrates clearance angle correction.

3.3.1.1.2. Practice level

The Rec. CEPT 20-08 (UK-Ireland) coordination agreements are mainly based on the rec. 370-7. Some of the modifications or additions are implemented in ATDI tools and the following features can be found:

- additional curves for effective antenna heights: h1=9 m and h1=18 m, (from the rec. CEPT 20-08) have been added to the implementation of curves of rec. 370-7 figure 10. The interpolation method between the different values h1 remains the same as in rec. 370-7;
- Ground irregularity: It is no longer taken into account: (i.e. no clearance angle is computed and Δh is forced to 50 m), whatever the user selects in the corresponding boxes;
- Oversea path: A proportion of more than 80% of sea path is regarded as a "fully oversea path". In that case, the following correction is negatively adopted: 20*3,64118*log(h2/10)/6dBµV/m, so that the correction is 10dB if the Rx antenna height is 1.5 m (this formula is similar to correction methods in rec. 370-7 for h2, the coefficient c being set to 3,64118);
- Other cases: They are considered as land paths, an additional correction loss is inserted: 10dB out to 50km, 3dB beyond 100km and linear interpolation by [10;3]dB through [50;100]km ;
- UHF band: It is automatically selected, for any transmitter frequencies.

- Other features are 370-7's: Since the rec. 370-7's methodology is based on a statistical standpoint, the method is implicitly written for altitudes that integrate no earth-curvature correction. Now, ATDI tools includes at starting an earth-curvature correction since standard model developed so far is based on a geometrical standpoint. In the ATDI tools implementation of rec. 370-7, altitude profile influence appears within effective antenna height computation and clearance angle computation (not more since Δh is introduced by the user). The following choices are made:
- Effective antenna height: It is computed without earth-curvature correction (it is actually pre-computed and brought to the DLL function computing the field-strength). It is defined as the antenna height above the average value of altitude between 3 and 15km. Doing that way is important since, using an altitude correction might bring a bias of 7.3 m for RT=6378km and 5.5 m for RT=8500km, which cannot be disregarded for low height transmitters;
- Δh: It is also computed without earth-curvature correction (when the option Δh automatic is selected);
- Clearance angle computation: The altitudes are kept with their earth-curvature correction, so as to alleviate the computational charge within the function. The resulting bias can be regarded as negligible (maximum 17.6 m for the 16thkm) since it yields at worst a 0.25dB field-strength decrease (recall the ±1dB uncertainty due to curve digitization).

Note: the gain for a given Rx antenna height h2 is (20/6)* c*log(h2/10) where coefficient c depends on the clutter type. Rec. 370-7 offers 3 clutter types: rural, suburban and urban. This has been automatically included within ATDI tools according to the following rule:

- ATDI tools clutter codes 2, 3, 4, 7 (respectively corresponding to urban 8 m, 15 m, 30 m and 50 m), activate 370-7 urban c values;
- ATDI tools suburban clutter code 1 activate 370-7 suburban c values;
- The rest of ATDI tools clutter codes activate 370-7 rural c values.

3.3.1.2. ITU-R 525/526 method

Contrary to the Fresnel model, there is no offset w.r.t. standard free space attenuation when ITU-R 525/526 is selected. This denomination actually stands for standard free space attenuation described in the ITU-R P.525-2 recommendation. 526 means that the diffraction term described in the recommendation ITU-R P.526 (-5 with round mask and -4 with cylinders) can be selected in the diffraction geometry frame to get a full ITU model (without any subpath attenuation term).

Versions 11 and 13 are implemented in ATDI tools.

3.3.1.3. ITU-R 1225 (IMT 2000) (Indoor)

Principle:
1) The free space is calculated according to the ITU-R P.525 formula.
2) The ITU-R M.1225 formula is carried out only in case of NLOS (the direct ray is crossing obstacles).
3) If a building layer is loaded and if the receiver is located inside the building (the receiving antenna height is lower than the building height) then the attenuation calculated will be:

40log10(dkm)+30log10(frequency)+49 (equation 1.2.1.2)

4) In all other cases, the dhb factor is calculated (transmitting antenna height above the average height without clutter). By default dhb=HTx-HRx (with Rx over clutter or not).
5) If the receiver is over ground with a height clutter h>HRx then dhb=HTx-(hclutter-HRx).
6) Then the attenuation calculated becomes:

40*(1.-4.*0.001*dhb)*log10(dkm)-18log10(dhb)+21log10(frequency)+80 (equation 1.1.1.3)

Note: if dhb<=0 then dhb=1, if dhb>50 then dhb=50 and if attenuation>free space then attenuation=free space - 1.

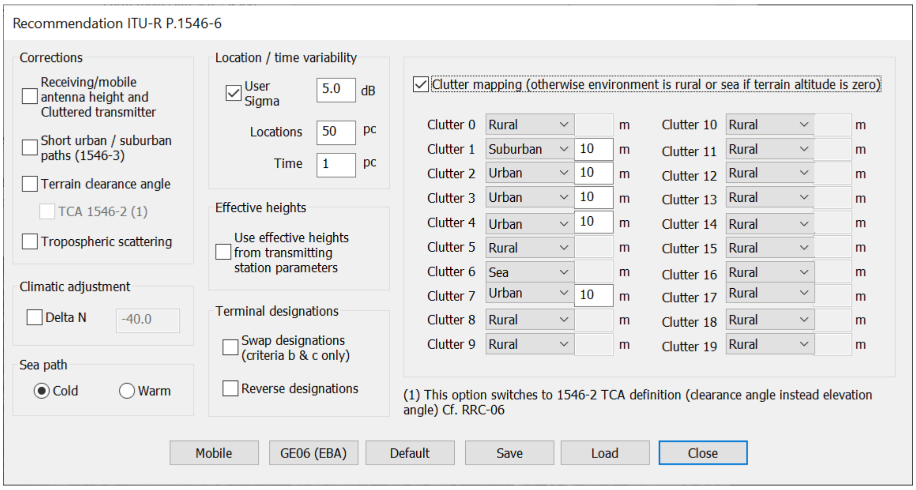
Attenuation= number of penetrated walls of type w * attenuation (dB), according to ITU R M-1225

Palette: use STD.PAL (available in the SW installation folder)

Each IDR code refers to the lockup table (Tools/Indoor parameters). For further information about Indoor parameters, please refer to the document ***Indoor calculations.pdf*** (http://www.data.atdi-group.com/doc/130.pdf).

3.3.1.4. ITU-R 1546-6 (30-3000 MHz)

The recommendation ITU-R P.1546 is a point to area VHF/UHF (30MHz to 3000MHz) prediction method for use in the planning and coordination of broadcast and land mobile services. The method is destined to supersede a number of ITU recommendations including ITU-R P.370. The model is based on a core set of curves ultimately derived from measurements. These curves are then corrected for various factors including: location and time variability, transmitting and receiving antenna heights, clutter environments, atmospheric refractive index gradient, frequency band and propagation path type (land, cold sea, warm sea & mixed). In addition to this, the method includes corrections for ground obstructions derived from a digital elevation model (DEM) along the path profile. This model is also called BLM, for Broadcast Land Mobile.



☐ Receiving/mobile antenna height and Cluttered transmitter
☐ Short urban / suburban paths (1546-3)
☐ Terrain clearance angle
☐ TCA 1546-2 (1)
☐ Tropospheric scattering

☑ User Sigma 5.0 dB
Locations 50 pc
Time 1 pc

☐ Use effective heights from transmitting station parameters

☐ Delta N -40.0

☐ Swap designations (criteria b & c only)
☐ Reverse designations

● Cold ○ Warm

☑ Clutter mapping (otherwise environment is rural or sea if terrain altitude is zero)

Clutter 0	Rural		m	Clutter 10	Rural		m
Clutter 1	Suburban	10	m	Clutter 11	Rural		m
Clutter 2	Urban	10	m	Clutter 12	Rural		m
Clutter 3	Urban	10	m	Clutter 13	Rural		m
Clutter 4	Urban	10	m	Clutter 14	Rural		m
Clutter 5	Rural		m	Clutter 15	Rural		m
Clutter 6	Sea		m	Clutter 16	Rural		m
Clutter 7	Urban	10	m	Clutter 17	Rural		m
Clutter 8	Rural		m	Clutter 18	Rural		m
Clutter 9	Rural		m	Clutter 19	Rural		m

(1) This option switches to 1546-2 TCA definition (clearance angle instead elevation angle) Cf. RRC-06

3.3.1.4.1. User level

The statement of the parameters selected in the dialog box is saved, for the next call, in a file named Prop1546.cfg located on the root of the active disk.

- Propagation curves accuracy: The digitization of curves has a general precision of ±1dB for more than 95% of the distances from 1 to 1000km. Below 1km, either free space field-strength or continuous extrapolation is displayed.
- clearance angle: The correction is computed through two clearance angles: one from the transmitter Tx and one from the receiver Rx. Altitude profile is then taken into account in the field-strength profile computation, that increases the computational cost of the method;
  - **TCA 1546-2**: This option fixes error in 1546-3/4/5/6 (clearance angle replaced by elevation angle adds attenuation by diffraction even in case of LOS / free Fresnel zone). It computes clearance angle according 1546-2 release. Please refer to Appendix 1 for detailed information.
- refractive air index gradient: it is actually an average gradient and not a dN/dh. It is defined as N(0m)-N(1000m), which corresponds to the opposite of usual ΔN, whose mean value is –40 or –39.
- environment: four types of environment clutter are defined in P.1546 (Urban, Suburban, Rural and Sea) with different corrections for each.
- type of emission: Three types of emission are considered in P.1546 (Broadcast Analogue, Broadcast Digital and Mobile), with different corrections for each type.

3.3.1.4.2. Practice level

- **Earth curvature**: Since the rec. P.1546's methodology is based on a statistical standpoint, the method in implicitly written for altitudes that integrate no earth-curvature correction. Now, ATDI tools includes at starting an earth-curvature correction since standard model developed so far are based on a geometrical standpoint. In the ATDI tools implementation of P.1546's, altitude profile influence appears within effective antenna height computation and clearance angle computation. The following choices are made:
  - the equivalent antenna height (h) between 3 and 15km is computed without earth-curvature correction. It is defined as the antenna height above the average value of altitude averaged between 0.2d and d km. Doing that way is important since, using an

altitude correction might bring a bias of 7.3 m for RT=6378km and 5.5 m for RT=8500km, which cannot be disregarded for low height transmitters;

- the effective antenna height is computed without earth-curvature correction. It is defined as the antenna height above the average value of altitude between 3 and 15km. Doing that way is important since, using an altitude correction might bring a bias of 7.3 m for RT=6378km and 5.5 m for RT=8500km, which cannot be disregarded for low height transmitters;
- the clearance angles (Tx and Rx) are computed without earth-curvature correction, so as to alleviate the computational charge within the function. The resulting bias can be regarded as negligible (maximum 17.6 m for the 16thkm) since it yields at worst a 0.25dB field-strength decrease (recall the ±1dB uncertainty due to curve digitization).

NOTE: For ITU-R 1546-4, that is accessible from External model selection, the user should check “**Flat earth profile sent to DLL**” in the propagation model main dialog box of ATDI tools.

- **Environment and clutter**: The user shall define the correspondence between the different clutter values in ATDI tools (from 0 to 20) and the environment defined in P.1546 (Urban, Suburban, Rural and Sea). A default correspondence is proposed:
    - clutter codes 2, 3, 4, 7 (respectively corresponding to urban 8 m, 15 m, 30 m and 50 m) activate Urban;
    - clutter code 1 activates Suburban;
    - clutter code 6 activates Sea;
    - the rest of clutter codes activate Rural.

  If there is a clutter file in the project, the clutter value is sent to the dll for each point, converted into an environment thanks to the table of correspondence and an adequate correction is then applied. If there is no clutter file, the value sent to the dll is always 0 and then the same correction is applied for all points.

  The user has also the capability to force the environment to “Sea” if the altitude is equal to 0, independently of the clutter value. Thanks to this option, it is possible to take into account the Land/Sea ratio and the sea influence even without any clutter.

  Different heights above ground are defined in ATDI tools for each clutter (Tools/Clutter options). This height is sent to the dll for each point of calculation and used in the calculation of:
    - Equivalent height of the antenna (h1) between 1 and 15km
    - Correction at the Rx level

It is not used for the calculation of the clearance angles and for the calculation of the effective heights.

3.3.1.5. ITU-R 1812-5 (30-3000 MHz)

1) Calculations of diffraction are applied exclusively on the altitude layer (neither building nor clutter is considered).
2) The height of the building (BLG layer) is sent to the DLL according to the following principle: we keep the maximum value between the Building height and the Clutter height, and the BLG layer is considered as clutter.
3) If a correction of the receiving height has to be applied (depending on the model) and if there is a BLG layer, then the correction is made according to the height of the building if Building height> Clutter height.

The DN50 and N050 maps are considered in the ITU-R P.1812 and ITU-R P.452 propagation models. In these models, the ducting is calculated if there is a part of the path over the sea and the tropospheric component is calculated if the path is diffraction and the percentage of time is less than 50%.

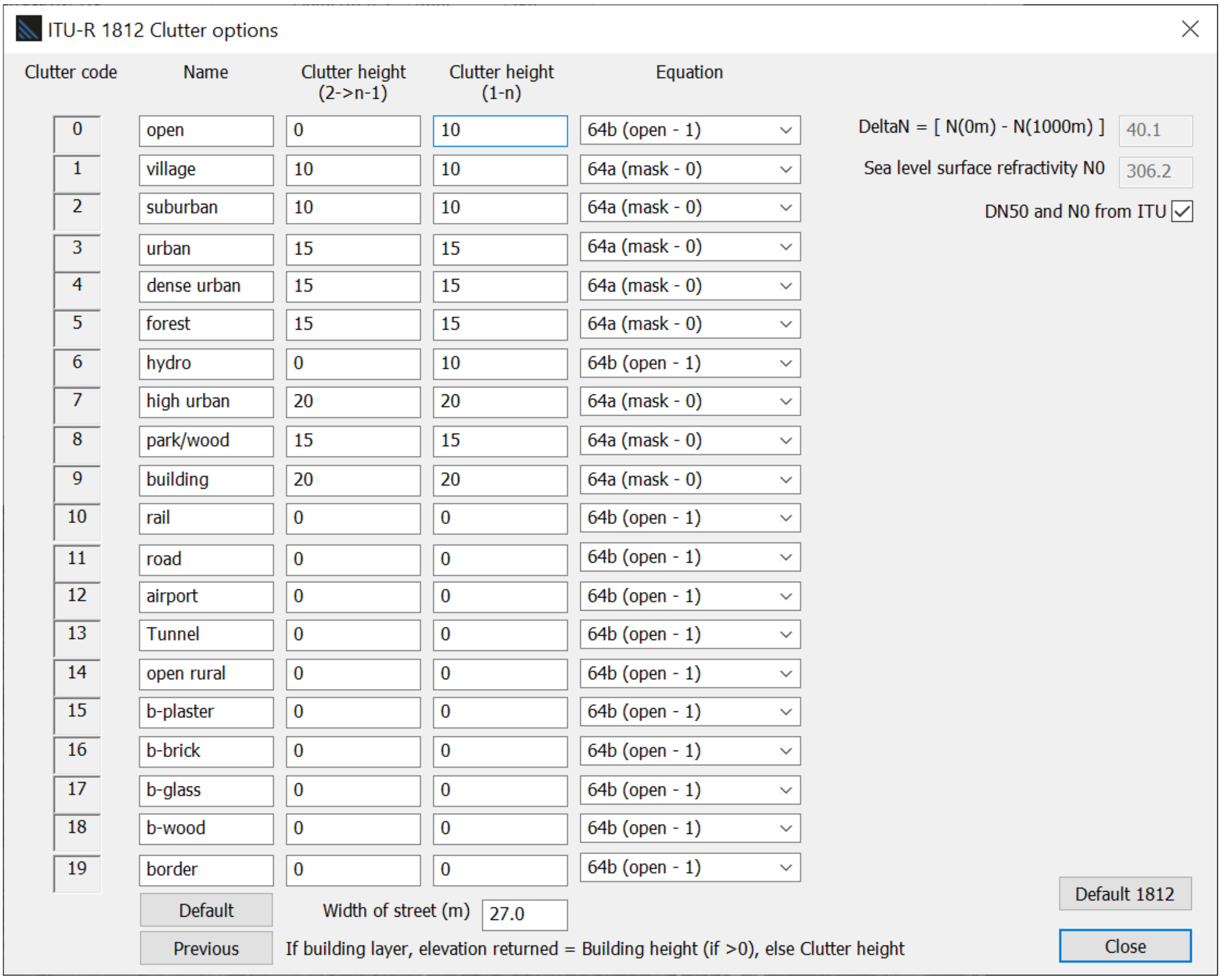
The DN50.BIN and N050.BIN files are included in the SW installation packages (also, the function *FILE/CONVERT/Import DN50 and N050 txt files…* imports the ITU DN50.TXT and N050.TXT files (http://www.itu.int/rec/R-REC-P.1812-5-201309-I/en) and creates the DN50.BIN and N050.BIN files in the root folder of the program).

New report in the profile window with the 1812-5 and 452-16 models:
The diffraction losses, tropospheric losses, ducting losses, Lb parameter (equation 54), Beta0 parameter and DN50 parameter have been added.
Diffraction, tropospheric and ducting components are provided before to the calculation of total attenuation. By default, the ducting is calculated automatically. It is computed if the path is mixed land/sea or sea only. When the ducting option is checked in the propagation model parameters, the calculation is constant in case of diffraction. The 452-16 line shows the different components of the model (for example with 50% of the time): Diffraction: Delta Bullington Tropo: n.a. if the percentage of time is greater than or equal to 50%. Ducting Clutter: unlike the 452-14, the clutter attenuation is computed only if the transmitting or receiving height is lower than ha (clutter height defined in the clutter settings). Lb = Total losses. Beta = Beta0
DN = DN50 calculated from the DN50.bin file located in the main installation folder. Same for 1812-4. If other models than the 452-16 or 1812-4 are selected, the ducting option requires loading one or more .DLN files.
The Deltan 900.DLN file is located in the main installation folder.
If the option is checked, the ducting is always computed in case of diffraction. If the option is unchecked, the ducting is computed in case of diffraction and if the path is mixed or sea. The percentage of time is configured in the propagation models settings.

When selecting the 452-14 model, there is no change of the clutter heights. In the Deygout 526-11 (RR) and 452-14 diffraction models, the clutter heights considered are the values defined in the clutter parameters. But for 452-16 and 1812-4 models, the clutter heights are modified when selecting the model. The calculation of the clutter attenuation is based only on the clutter height defined in the "Clutter parameters" box. Because of the low variation of the attenuation due to distance dk, the value chosen for dk for a given height is the minimum possible value. For example for ha=20m, dk=0.02.

The ducting is always computed in ITU-R P.1812 and ITU-R P.452 models, even in free space. This is to avoid discontinuity (but the calculations will be slower).

The "Ws" parameter (street width) has been added to the parameters of the 1812-4 propagation model. It can be now user defined.



Clutter code	Name	Clutter height (2->n-1)	Clutter height (1-n)	Equation
0	open	0	10	64b (open - 1)
1	village	10	10	64a (mask - 0)
2	suburban	10	10	64a (mask - 0)
3	urban	15	15	64a (mask - 0)
4	dense urban	15	15	64a (mask - 0)
5	forest	15	15	64a (mask - 0)
6	hydro	0	10	64b (open - 1)
7	high urban	20	20	64a (mask - 0)
8	park/wood	15	15	64a (mask - 0)
9	building	20	20	64a (mask - 0)
10	rail	0	0	64b (open - 1)
11	road	0	0	64b (open - 1)
12	airport	0	0	64b (open - 1)
13	Tunnel	0	0	64b (open - 1)
14	open rural	0	0	64b (open - 1)
15	b-plaster	0	0	64b (open - 1)
16	b-brick	0	0	64b (open - 1)
17	b-glass	0	0	64b (open - 1)
18	b-wood	0	0	64b (open - 1)
19	border	0	0	64b (open - 1)

DeltaN = [N(0m) - N(1000m)] 40.1

Sea level surface refractivity N0 306.2

DN50 and N0 from ITU ☑

Width of street (m) 27.0

If building layer, elevation returned = Building height (if >0), else Clutter height

3.3.1.6. ITU-R 452-16 (0.1-50 GHz)

The ITU-R P.452-16 model replaces version 452-15.

> Note: Equation 58 of the 452-15 is kept in order to be compatible with recommendation ITU-R P.1812-4.

1) Calculations of diffraction are applied exclusively on the altitude layer (neither building nor clutter is considered).
2) The height of the building (BLG layer) is sent to the DLL according to the following principle : we keep the maximum ,value between the Building height and the Clutter height, and the BLG layer is considered as clutter.
3) If a correction of the receiving height has to be applied (depending on the model) and if there is a BLG layer, then the correction is made according to the height of the building if Building height> Clutter height.

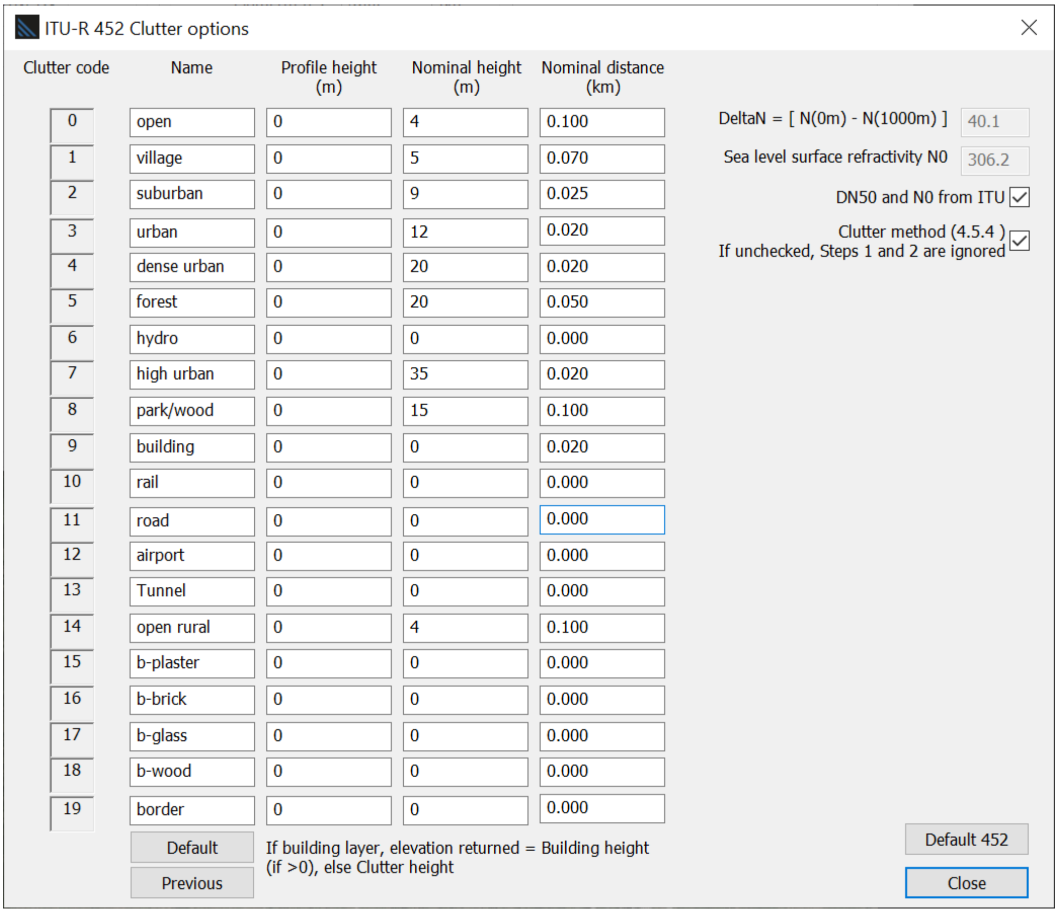
The DN50 and N050 maps are considered in the ITU-R P.1812 and ITU-R P.452 propagation models. In these models, the ducting is calculated if there is a part of the path over the sea and the tropospheric component is calculated if the path is diffraction and the percentage of time is less than 50%.

The DN50.BIN and N050.BIN files are included in the SW installation packages (also, the function *FILE/CONVERT/Import DN50 and N050 txt files…* imports the ITU DN50.TXT and N050.TXT files (http://www.itu.int/rec/R-REC-P.1812-4-201309-I/en) and creates the DN50.BIN and N050.BIN files in the root folder of the program).

New report in the profile window with the 1812-4 and 452-16 models.
The diffraction losses, tropospheric losses, ducting losses, Lb parameter (equation 54), Beta0 parameter and DN50 parameter have been added.
Diffraction, tropospheric and ducting components are provided before to the calculation of total attenuation. By default, the ducting is calculated automatically. It is computed if the path is mixed land/sea or sea only. When the ducting option is checked in the propagation model parameters, the calculation is constant in case of diffraction. The 452-16 line shows the different components of the model (for example with 50% of the time): Diffraction: Delta Bullington Tropo: n.a. if the percentage of time is greater than or equal to 50%. Ducting Clutter: unlike the 452-14, the clutter attenuation is computed only if the transmitting or receiving height is lower than ha (clutter height defined in the clutter settings). Lb = Total losses. Beta = Beta0
DN = DN50 calculated from the DN50.bin file located in the main installation folder. Same for 1812-4. If other models than the 452-16 or 1812-4 are selected, the ducting option requires loading one or more .DLN files.
The Deltan 900.DLN file is located in the main installation folder.
If the option is checked, the ducting is always computed in case of diffraction. If the option is unchecked, the ducting is computed in case of diffraction and if the path is mixed or sea. The percentage of time is configured in the propagation models settings.

When selecting the 452-14 model, there is no change of the clutter heights. In the Deygout 526-11 (RR) and 452-14 diffraction models, the clutter heights considered are the values defined in the clutter parameters. But for 452-16 and 1812-4 models, the clutter heights are modified when selecting the model. The calculation of the clutter attenuation is based only on the clutter height defined in the "Clutter parameters" box. Because of the low variation of the attenuation due to distance dk, the value chosen for dk for a given height is the minimum possible value. For example for ha=20m, dk=0.02.

The ducting is always computed in ITU-R P.1812 and ITU-R P.452 models, even in free space. This is to avoid discontinuity (but the calculations will be slower).



Clutter code	Name	Profile height (m)	Nominal height (m)	Nominal distance (km)
0	open	0	4	0.100
1	village	0	5	0.070
2	suburban	0	9	0.025
3	urban	0	12	0.020
4	dense urban	0	20	0.020
5	forest	0	20	0.050
6	hydro	0	0	0.000
7	high urban	0	35	0.020
8	park/wood	0	15	0.100
9	building	0	0	0.020
10	rail	0	0	0.000
11	road	0	0	0.000
12	airport	0	0	0.000
13	Tunnel	0	0	0.000
14	open rural	0	4	0.100
15	b-plaster	0	0	0.000
16	b-brick	0	0	0.000
17	b-glass	0	0	0.000
18	b-wood	0	0	0.000
19	border	0	0	0.000

DeltaN = [N(0m) - N(1000m)] 40.1

Sea level surface refractivity N0 306.2

DN50 and N0 from ITU ☑

Clutter method (4.5.4)
If unchecked, Steps 1 and 2 are ignored ☑

If building layer, elevation returned = Building height (if >0), else Clutter height

3.3.1.7. ITU-R 452-14 (0.1-50 GHz)

1) Calculations of diffraction are applied exclusively on the altitude layer (neither building nor clutter is considered).
2) The height of the building (BLG layer) is sent to the DLL according to the following principle : we keep the maximum ,value between the Building height and the Clutter height, and the BLG layer is considered as clutter.
3) If a correction of the receiving height has to be applied (depending on the model) and if there is a BLG layer, then the correction is made according to the height of the building if Building height> Clutter height.

The DN50 and N050 maps are considered in the ITU-R P.1812 and ITU-R P.452 propagation models. In these models, the ducting is calculated if there is a part of the path over the sea and the tropospheric component is calculated if the path is diffraction and the percentage of time is less than 50%.

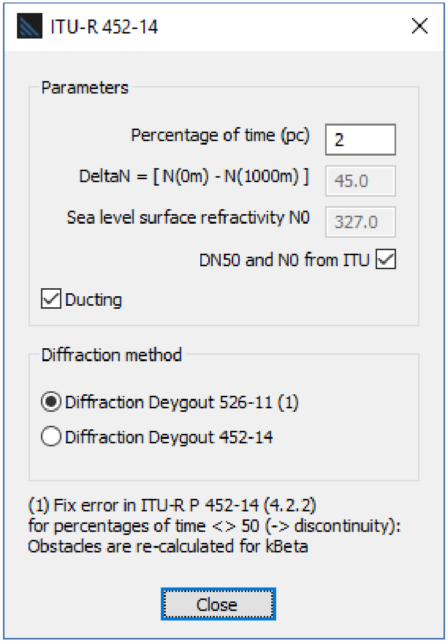
The DN50.BIN and N050.BIN files are included in the SW installation packages (also, the function *FILE/CONVERT/Import DN50 and N050 txt files…* imports the ITU DN50.TXT and N050.TXT files (http://www.itu.int/rec/R-REC-P.1812-4-201309-I/en) and creates the DN50.BIN and N050.BIN files in the root folder of the program).

New report in the profile window with the 1812-5 and 452-16 models.

The diffraction losses, tropospheric losses, ducting losses, Lb parameter (equation 54), Beta0 parameter and DN50 parameter have been added.
Diffraction, tropospheric and ducting components are provided before to the calculation of total attenuation. By default, the ducting is calculated automatically. It is computed if the path is mixed land/sea or sea only. When the ducting option is checked in the propagation model parameters, the calculation is constant in case of diffraction. The 452-16 line shows the different components of the model (for example with 50% of the time): Diffraction: Delta Bullington Tropo: n.a. if the percentage of time is greater than or equal to 50%. Ducting Clutter: unlike the 452-14, the clutter attenuation is computed only if the transmitting or receiving height is lower than ha (clutter height defined in the clutter settings). Lb = Total losses. Beta = Beta0
DN = DN50 calculated from the DN50.bin file located in the main installation folder. Same for 1812-4. If other models than the 452-16 or 1812-4 are selected, the ducting option requires loading one or more .DLN files.
The Deltan 900.DLN file is located in the main installation folder.
If the option is checked, the ducting is always computed in case of diffraction. If the option is unchecked, the ducting is computed in case of diffraction and if the path is mixed or sea. The percentage of time is configured in the propagation model settings.

When selecting the 452-14 model, there is no change of the clutter heights. In the Deygout 526-11 (RR) and 452-14 diffraction models, the clutter heights considered are the values defined in the clutter parameters. But for 452-16 and 1812-4 models, the clutter heights are modified when selecting the model. The calculation of the clutter attenuation is based only on the clutter height defined in the "Clutter parameters" box. Because of the low variation of the attenuation due to distance dk, the value chosen for dk for a given height is the minimum possible value. For example, for ha=20m, dk=0.02.

The ducting is always computed in ITU-R P.1812 and ITU-R P.452 models, even in free space. This is to avoid discontinuity (but the calculations will be slower).



Parameters

Percentage of time (pc): 2

DeltaN = [N(0m) - N(1000m)]: 45.0

Sea level surface refractivity N0: 327.0

DN50 and N0 from ITU ☑

☑ Ducting

Diffraction method

● Diffraction Deygout 526-11 (1)

○ Diffraction Deygout 452-14

(1) Fix error in ITU-R P 452-14 (4.2.2)
for percentages of time <> 50 (-> discontinuity):
Obstacles are re-calculated for kBeta

3.3.1.8. ITU-R 1147-4 (150-1700 kHz) (Sky-wave for LF/MF at night time)

This method predicts values of the night-time sky-wave field strength for a given power radiated from one or more vertical antennas, when measured by a loop antenna at ground level aligned in a vertical plane along the great-circle path to the transmitter.

The following ITU-R recommendations are implemented in this model:

- Rec. ITU-R PI. 435-7
- Rec. ITU-R P. 1147-2 (replacing Rec. ITU-R PI. 435-7)

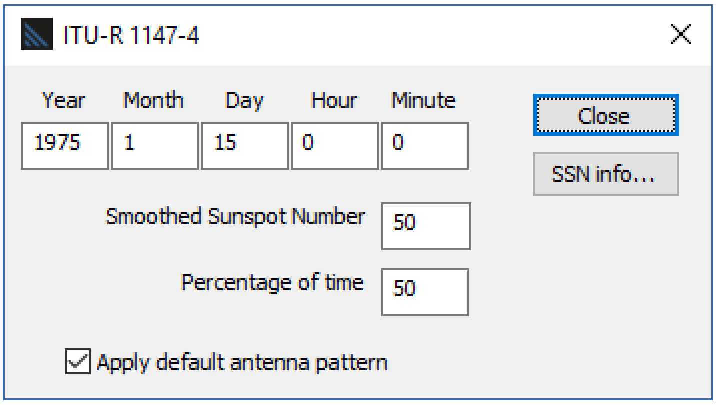
The only differences between these two recommendations are the following:

- § 2 : computation of A
- § 2.6 & 2.8 : ionospheric and solar losses
- § 3 : influence of the percentage of time

The annexes about the accuracy of the method and the modelling of day-time sky-wave propagation have not been implemented, except the paragraph about the reflection on the E or F layers.

This model is implemented through to two files:

- SkyWaveLFMF.dll, located in the installation folder of ATDI tools
- SkyWaveLFMF.cfg, located in the installation folder of ATDI tools, containing the parameters input in the dialog box


ITU-R 1147-4

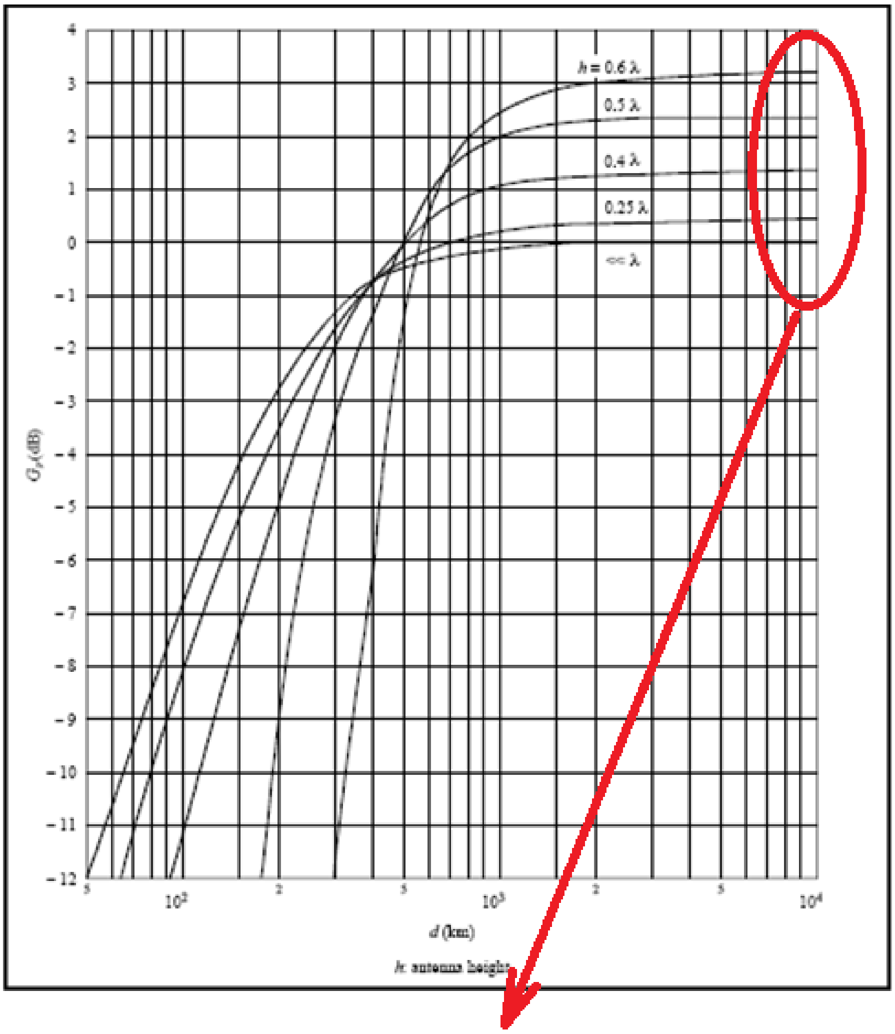
Year: 1975
Month: 1
Day: 15
Hour: 0
Minute: 0

Smoothed Sunspot Number: 50

Percentage of time: 50

☑ Apply default antenna pattern

Apply default vertical pattern: the curve given in the Figure 1 is applied. However, in order to maintain the coherence of the whole, the curves are normalized at 0 dB for long distances (i.e. for 0°), so that the gain set in the station parameters is indeed the gain of the antenna, and not only the gain due to the horizontal directivity. The vertical gain of the default antenna relatively to a short vertical monopole is given by the figure 1 of the recommendation:



h / Lambda	Vertical gain
0	0
0.25	0.4
0.4	1.4
0.5	2.3
0.6	3.2

Figure 1

The same values are displayed on Figure 2 below:

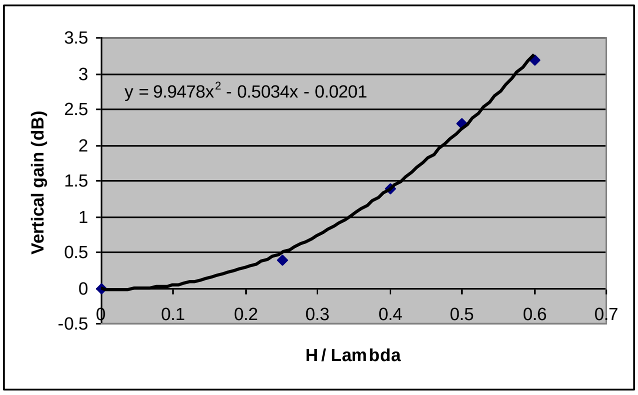


Figure 2

3.3.1.8.1. Percentage of time

For more details about the method to take into account the percentage of time, please refer to Rec. ITU-R P.1546-1, Annex 5, § 13, especially regarding the inverse complementary cumulative normal distribution function Qi.

The field strength for a given percentage of time is given in dBµV/m by the following formula:

$$E\ (x\%) = E\ (\text{median}) + Qi\ (x/100) * \sigma$$

Or similarly:

$$\Delta\ (x\%) = E\ (x\%) - E\ (\text{median}) = Qi\ (x/100) * \sigma$$

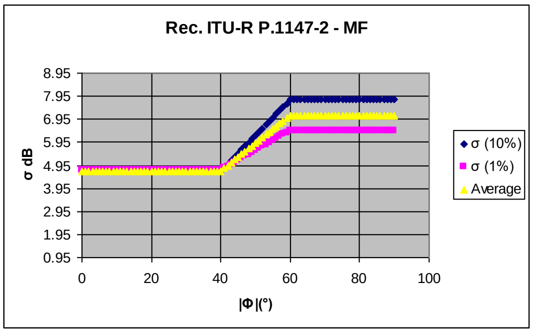
Rec. ITU-R PI. 435-7 gives the values of Δ (10%) in LF and MF in §3.

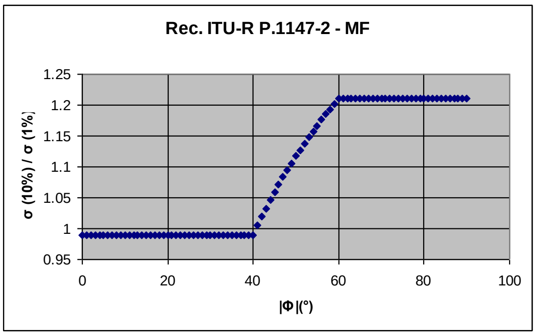
Rec. ITU-R P. 1147-2 gives the values of Δ (10%) and Δ (1%) in LF and MF in §3.

These values of Δ are used to determine the value of σ as illustrated in the table below:

	Unit	Rec. ITU-R PI 435		Rec. ITU-R P 1147			
		LF	MF	LF	MF		
Φ	Degrees				0.00	45.00	90.00
Δ (1)	dB			11.5	11.00	12.00	15.00
Δ (10)	dB	6.5	8	6.5	6.00	7.00	10.00
Δ (50)	dB	0	0	0	0	0	0
Q_i (1)				2.33	2.33	2.33	2.33
Q_i (10)		1.28	1.28	1.28	1.28	1.28	1.28
Q_i (50)		0	0	0	0	0	0
σ (1) = Δ (1) / Q_i (1)	dB			4.94	4.73	5.16	6.45
σ (10) = Δ (10) / Q_i (10)	dB	5.07	6.24	5.07	4.68	5.46	7.80
σ (10) / σ (1)	dB			**0.97**	**0.99**	**0.94**	**1.21**
σ = 1/2 [σ (10) + σ (1)]	dB			5.01	4.71	5.31	7.13

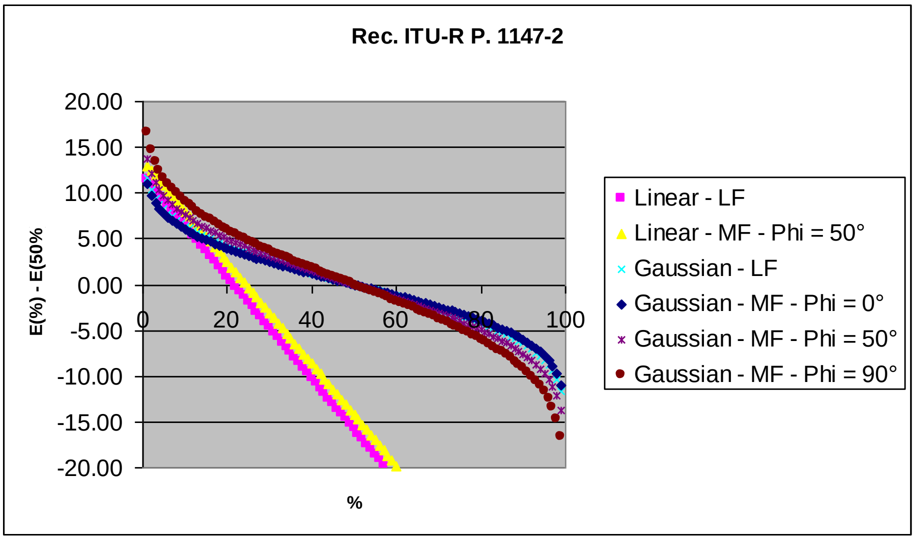
In the case of Rec. ITU-R P. 1147-2 in LF, it must be noted that the values obtained for 10% and 1% are very similar, which means that it is reasonable to assume that the distribution is Gaussian indeed.
In the case of Rec. ITU-R P. 1147-2 in MF, it must be noted that the values obtained for 10% and 1% are very similar, regardless the value of Φ (see figures below), which means that it is reasonable to assume that the distribution is Gaussian indeed.





However, since the value used for σ is the average of σ (1%) and σ (10%), it means that the values specified by the recommendation for 1% and 10% are not strictly obtained.

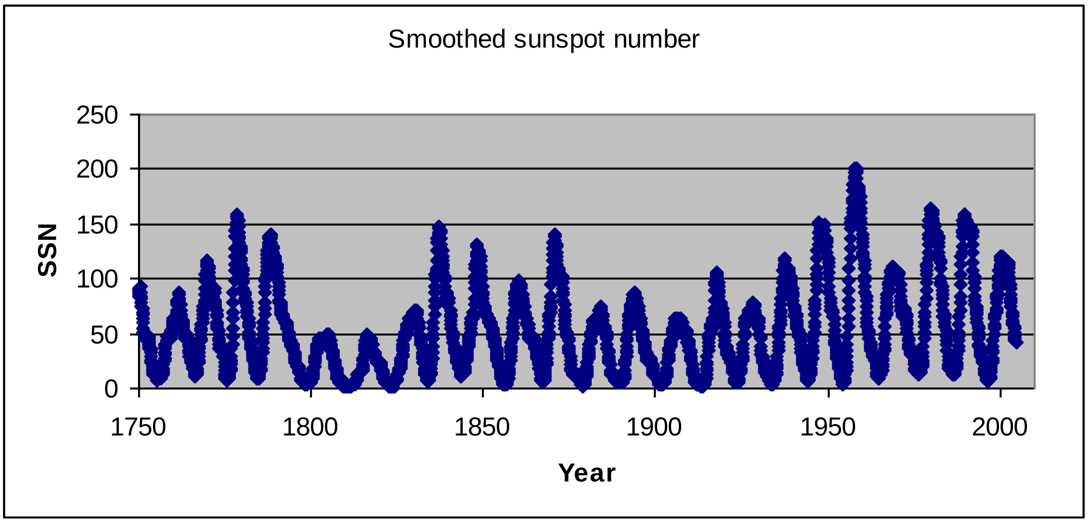
A linear distribution instead of a Gaussian distribution would have allowed obtaining strictly the same values. However, such a distribution would not have been realistic, as illustrated on the figure below, giving the value of Δ(%) in different configurations of Rec. ITU-R P. 1147-2. Especially, the value of Δ(50 %) would have been about -15 dB, while it should be by definition 0 dB.

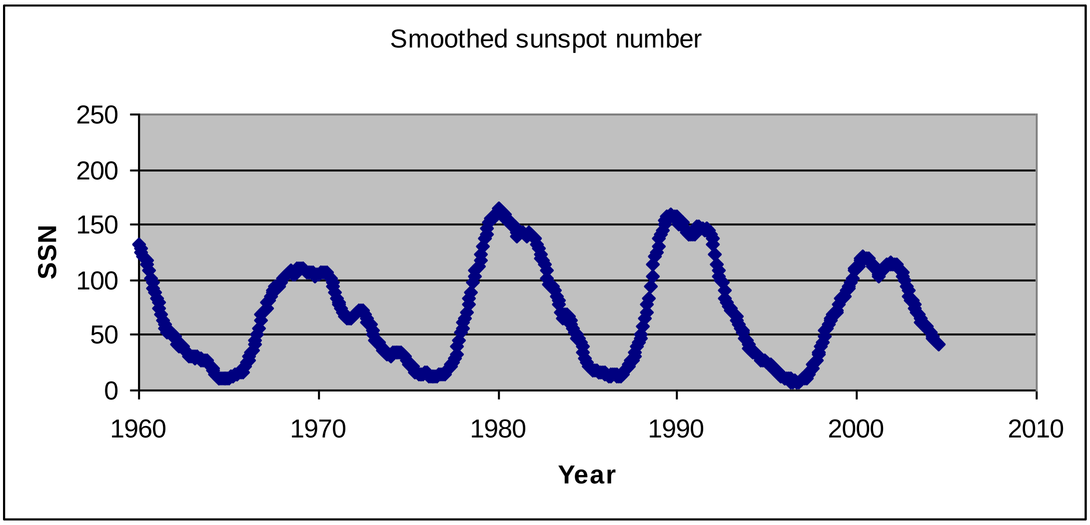


3.3.1.8.2. SSN

Reference values of smoothed international relative sunspot number calculated over twelve months can be found on http://sidc.oma.be/index.php3.

It is easy to see on the figures below the 11-years long lifecycle of the sun.

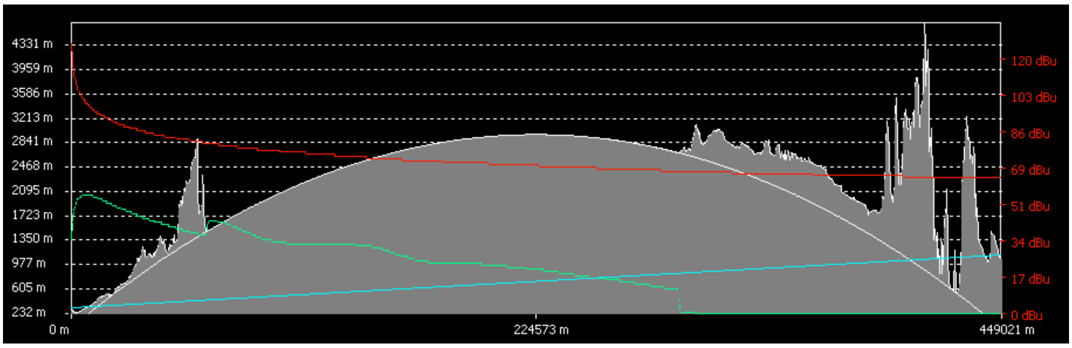




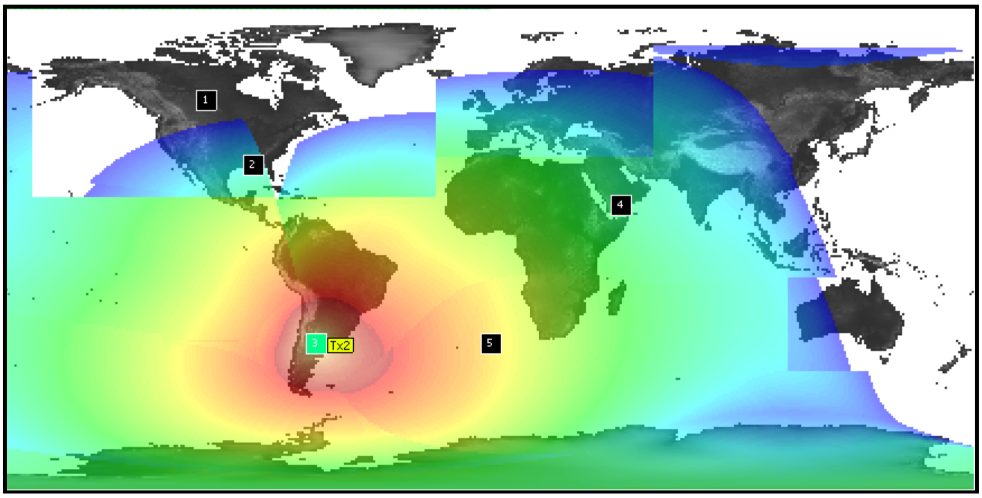
3.3.1.8.3. Discontinuities

Some discontinuities can be found. Different reasons can explain them:

- Sea gain in coastal areas



- Polarization coupling loss when I is about +/- 45°
- Boundaries of continents (North America, Europe and Australia)
- Hourly loss factor for paths above 2000 km



NOTE 1: This model is compatible with projects in WMAS projection.
NOTE 2: A returned value of -125 dBµV/m should be interpreted as non-valid result, i.e. the hourly-loss factor is not computable.

3.3.1.9. ITU-R 368-9 (10 kHz – 30 MHz) (Groundwaves)

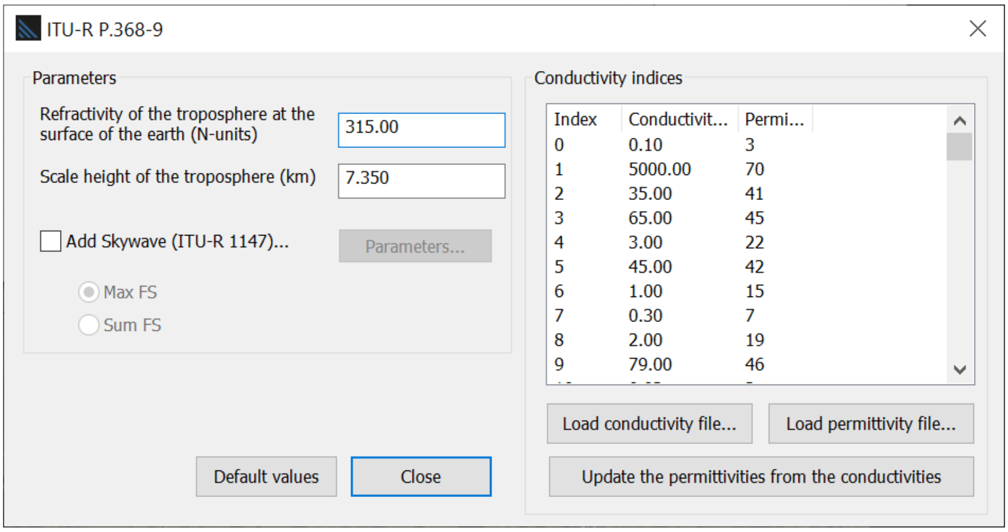
The recommendation ITU-R 368-9 specifies the propagation model to be used in the VLF/LF/MF/HF for both point-to-area and point-to-point calculations. This recommendation is based on a core set of curves derived from the software GRWAVE. These curves indicate the field strength received following the distance between Tx and Rx, the ground conductivity, the permittivity and the frequency. The recommendation specifies also how to compute the field strength for mixed paths, i.e. paths along which the conductivity and permittivity are not constant.

What has been implemented in ATDI tools is not the recommendation itself but the original Fortran source code of GRWAVE, available on the ITU website. That means that it possible to take into account more parameters than in the recommendation:

- Tx polarization (always vertical in the recommendation)
- Tx antenna height (always 0 m in the recommendation)
- Rx antenna height (always 0 m in the recommendation)
- troposphere height (always 7.35 km in the recommendation)
- refractivity index at the surface (always 315 in the recommendation)

This model is implemented through three files:

- GroundWaves.dll, located in the installation folder of ATDI tools
- grwave.dll, located in the installation folder of ATDI tools
- GroundWaves.cfg, located in the installation folder of ATDI tools, containing the parameters input in the dialog box



Refractivity of the troposphere at the surface of the earth (N-units): 315.00
Scale height of the troposphere (km): 7.350
☐ Add Skywave (ITU-R 1147)...
● Max FS
○ Sum FS

Index	Conductivit...	Permi...
0	0.10	3
1	5000.00	70
2	35.00	41
3	65.00	45
4	3.00	22
5	45.00	42
6	1.00	15
7	0.30	7
8	2.00	19
9	79.00	46

Add Skywave (ITU-R 1147): If checked, calculations are also made according to the ITU-R P.1147-4 model. At the end of the calculations, the maximum field strengths received is considered on each point ("Max FS" option) or the sum of field strength received values ("Sum FS" option).

3.3.1.9.1. Antennas

It is hard to understand which type of antenna is modelled in GRWAVE and what the physical values the parameters of receiving antenna height, transmitting antenna height and polarization exactly refer to.

Therefore, it is recommended to use the following settings:

- Set the Tx gain to a value equal to the gain of the Tx antenna relatively to the reference antenna in ATDI tools
- Set an omnidirectional Tx vertical pattern (if the pattern is not omnidirectional, the attenuation given for 0° is used)
- Set the Tx horizontal pattern, possibly non-omnidirectional

3.3.1.9.2. Conductivity and permittivity

The values of conductivity and permittivity are passed through the clutter codes (0 to 255) contained in the clutter file (*.sol), that is to say that each clutter code corresponds to a pair of values of conductivity and permittivity.

The relation between the clutter codes and the corresponding conductivity and permittivity values are specified by the user in the dialog box of the propagation model. These look-up tables can be loaded and saved in text files. The format is the following:

- First line: not used
- Following lines: clutter code, value

To build the maps of conductivity and permittivity, three solutions are available:

- The user can create these maps with ICS Map Server. The recommendation ITU-R 832-2 gives the maps of conductivity for the main regions of the world. Two sets of maps are given, one for VLF/LF bands and another one for MF/HF bands.
- The user can use the software library provided with the ITU software IDWM. The maps obtained with these libraries are the same as the ones given in ITU-R 832-2. However, in that case, the user should use this library to generate a file readable by ATDI tools as a clutter file.
- The maps can be provided on demand by ATDI.

As there is no map of permittivity available, the simplest solution consists in deducing the permittivity from the conductivity, considering the recommendation.

NOTE 1: Equivalent Earth radius comes from propagation model main dialog box (user defined).
NOTE 2: A returned value of -125 dBµV/m should be interpreted as non-valid result. A returned value of -124 dBµV/m should be interpreted as “GWFS and SWFS interfere each other”.

3.3.1.10. ITU-R 1009-1 (LoS)

Compatibility between the sound-broadcasting service in the band of about 87-108 MHz and the aeronautical services in the band 108-137 MHz. This model is to be used when SM 1009 compatibility analysis are performed.

3.3.1.11. ITU-R 528-3 (V/U/SHF) (Aeronautical propagation model)

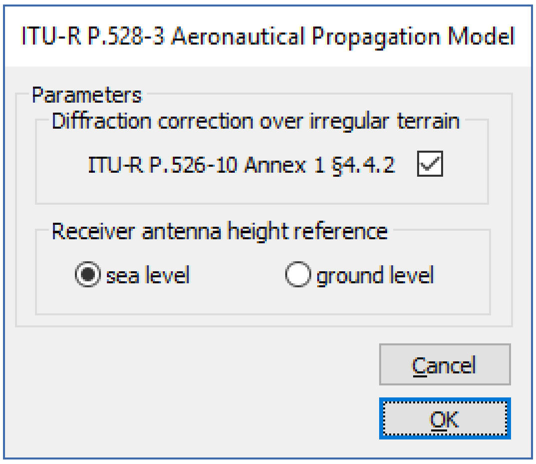
Propagation curves for aeronautical mobile and radio navigation services using the VHF, UHF and SHF bands.

Diffraction correction over irregular terrain:

- ***ITU-R P.526-10 Annex 1 4.4.2***: This mode can be used to improve accuracy when the path between Tx and Rx is obstructed

Receiver antenna height reference:

- ***Sea level***: Ensure that height reference is set to R/S
- ***Ground level***: Ensure that height reference is set to AGL



ITU-R P.528-3 Aeronautical Propagation Model

Parameters

Diffraction correction over irregular terrain

ITU-R P.526-10 Annex 1 §4.4.2 ☑

Receiver antenna height reference

● sea level ○ ground level

3.3.1.12. ITM NTIA (20 MHz – 20 GHz) (Longley-Rice model)

The ITM provides propagation models used to make prediction of radio field strength for broadcast in the range 20MHz – 20 GHz. Actually, ITM refers to more than just a propagation model. Three different components can be mentioned.

First, ITM derives from a theoretical and statistical study NBS 101 [1] by Longley, Rice and al. providing several methods to estimate field strengths in various situations (frequency, distance, terrain features…). The authors propose specific models for the following cases:

- Knife Edge diffraction over irregular terrain;
- Smooth Earth attenuation estimation;
- Two-ray attenuation method (modeling of reflections) in the line of sight range;
- Troposcatter modeling for large distances;
- Long term and short term statistical variation predictions.

Then, the ITM algorithm itself [2] tries to merge all these methods into 4 different synthetic prediction models:

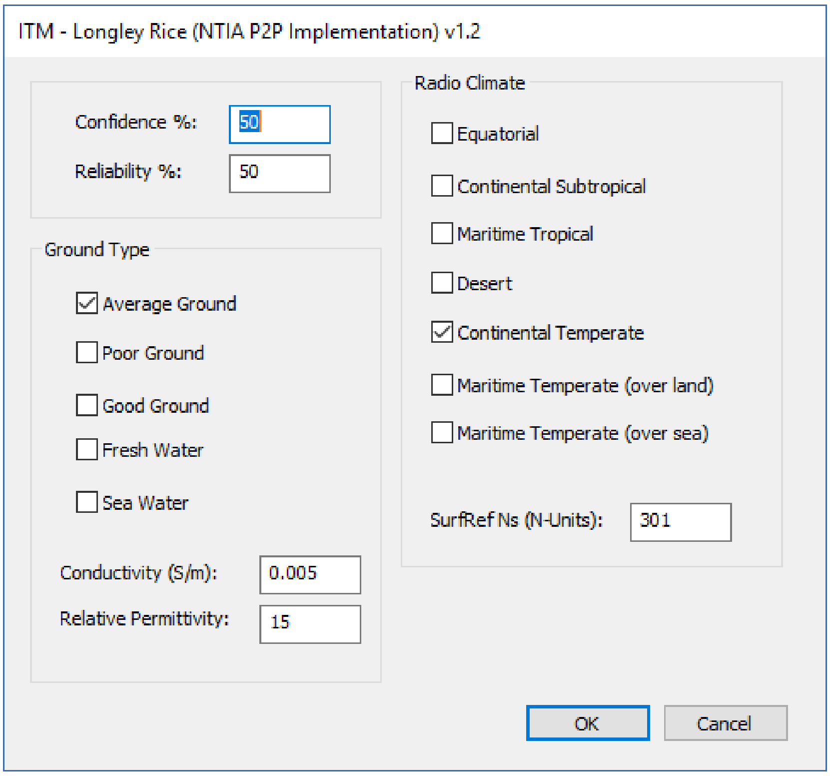
- Three "area" prediction methods: They are providing field strength estimations that are monotonically decreasing with distance. These methods roughly behave like the recommendation ITU–R P.370–7 with the Δh mode.
- One "point-to-point" (PTP) prediction: its behavior is closer to geometrical models or ITU–R P.370–7 with the clearance angle mode.

Eventually, ITM refers to a specific methodology (called the Longley-Rice methodology [3]) designed by the American FCC for evaluating Broadcast coverage and interference.

The implementation in ATDI tools refers to the second item. Somehow, an additional distinction can be made between the ITM algorithm itself and its computer implementation which requires the some more definitions or choices that are implicit or left to the designer's appreciation in the algorithm. Thus, we give here a short presentation of these choices that we had to do for programming the method, making a few qualitative remarks on the models. The reader who wishes to analyze it more accurately should refer to [2] and also to the implementation [4] (there is a slight difference between the implementation by G.A. Hufford and ours).

3.3.1.12.1. Presentation of ITM implementation

When ITM is selected in the model selection box, a dialog box appears that is specifically dedicated to ITM:



ITM - Longley Rice (NTIA P2P Implementation) v1.2

Confidence %: 50

Reliability %: 50

Ground Type

☑ Average Ground

☐ Poor Ground

☐ Good Ground

☐ Fresh Water

☐ Sea Water

Conductivity (S/m): 0.005

Relative Permittivity: 15

Radio Climate

☐ Equatorial

☐ Continental Subtropical

☐ Maritime Tropical

☐ Desert

☑ Continental Temperate

☐ Maritime Temperate (over land)

☐ Maritime Temperate (over sea)

SurfRef Ns (N-Units): 301

The user is invited to make several choices:

- selection of the climate for the statistical influences. The surface refractivity (SurfRef Ns) to be manually entered depends on local statistics. Values can be found in the recommendation ITU–R P.453-6;
- a variety of ground selection properties is offered, each of them providing a value for the local ground relative permittivity and conductivity. These values have an influence on the two-ray reflection and the rounded earth attenuation terms only.

Note about polarization: if the transmitter polarization is H, then the ITM model polarization will be set to H. Otherwise, the ITM polarization will be set to V.

3.3.1.12.2. Assumptions made in the implementation

Additional assumptions are made in the implementation of the model.

- Definition of the terrain irregularity parameter Δh: depends not only on each path profile but also on the location of the current Rx point on the profile. Parameter Δh plays a central role in the ITM since it is the only geometrical parameter that has to computed in every spatial mode. The definition adopted here is the definition adopted by the American FCC in the Part 73 of its rules concerning radio broadcast services (which is the same as ITU's definition for 370–7 model). Being sorted all the terrain altitudes between 10 and 50km away from the transmitter, Δh is equal to the differences between the altitude that is the closest to the 10 higher percent and the altitude the closest to the 10 lower percent.

  Somehow, in ATDI implementation, this definition is exact only for path profiles above 50km. For profile lengths below 10km, Δh is set equal to 50 m. And for path length d in [10;50]km, a first value Δh0 is computed from altitude values between 10 and d km and, for the sake of continuity, we set:

  $$\boxed{\Delta h = 50(50-d)/40 + \Delta h0\ (d-10)/40\ \text{m}}$$

  so that, if d=10km, Δh=50 m and if d=50km, Δh exactly identifies with its FCC definition.

3.3.1.12.3. Other parameters in the P2P mode

- **Height above average terrain HAAT**: About the HAAT or effective antenna height, G. Hufford says in [2]: "A difficulty with the model is that there is no explicit definition of the HAAT and the accuracy of the model sometimes depends on the skill of the user in estimating values for these effective heights". The philosophy of ATDI models is not to let the user define these quantities by himself but automatically compute them (on a coverage, there are hundreds of HAAT to estimate).

In the detailed implementation code [4], the author defines the HAATs he1 and he2 as the height of the top of the antenna above the average altitude of the ground portion located between the Tx/Rx antenna and the associated horizon. For cases where the horizon is not reached on the current profile, the author suggests the use of the estimated value used in the area mode. The underlying standpoint is that there is a uniform HAAT (i.e. a unique HAAT value, valid wherever the reciprocal antenna is on the profile).

Our view is rather that we have an adaptive definition of the HAAT, that may locally depend on the location of the other antenna on the path profile, but only on the points located between Tx and Rx. Keeping the previous definition would indeed result in discontinuous HAAT values (between points located in front of and beyond the horizon), implying discontinuous field strength estimations along the path: the propagation model would be ill-posed (cf. [5], report on the ill-posedness of the triple-knife-edge diffraction model by ITU–R P.526-5: Hadamard well-posedness conditions are not fulfilled).

As a result, we choose to use the FCC definition of the HAAT: height of the antenna above the average altitude of ground located between 3 and 16km. Like above, for the sake of continuity, if the distance d is in [3;16]km, the HAAT is computed from the average heights in [3;d]km. If the distance d is in [0;3]km, the HAAT is the altitude discrepancy between the antenna and the current altitude at d km from Tx/Rx.

Eventually, we implicitly have in [2], he1 ≥ hg1 and he2 ≥ hg2, where the hgi are the structural antenna heights. We keep this property by forcing hei = hgi when hei happens to be strictly lower than hgi.

- **Tx/Rx clearance angles:** The clearance angles are the elevation angles of the horizons from each terminal at the height of the antennas. We took here the approximated formula mentioned in recommendation ITU–R P.452–8. The clearance angle from the antenna, θant, is given by:

  θant=(hi-hant)/di–di/(2*Re),

  where Re is the effective earth radius, hi is the elevation at the horizon at distance di from the antenna, whose top elevation is hant. The major approximation in this formula is that

  tan[(hi-hant)/di] ≈ (hi-hant)/di,

  which is true if (hi-hant)/di<0.1, i.e. if distances are at least one order of magnitude larger than the altitude discrepancies. Whenever this condition is not fulfilled (at very close distance to antennas), we set the condition (suggested in [4]): if θant>0.2, θant←0.2.

- **Distances from terminals to horizons:** The PTP mode also requires the distance to the horizon to be used as distance to obstacle within the knife edge diffraction component. It is easy to see that keeping this distance as a distance to obstacle within the model also results in breaking Hadamard well-posedness conditions [5]. As a result, we choose here the estimated value of this distance that is used in the area modes, which is a direct continuous function of $\Delta h(d)$ and therefore, a continuous function of d.

3.3.1.12.4. Qualitative behaviour

Note that the model provides more realistic deviate magnitudes when the Rx antenna height is above 10 m.

The influence of ground impedance (if two-ray reflection and rounded earth diffraction attenuation components are activated) is often limited: 2-3dB at most. Somehow, large attenuations may occur in the two-ray reflection mode if the reflection coefficient (due to a specific impedance at some specific frequency) is close to –1. The scatter range implies a large distance from the transmitter. Within the diffraction range, the scatter component of the field strength is often negligible w.r.t. the diffraction term.

Eventually, note the algorithm is slow. Indeed, Rx clearance angle and Rx antenna height have to be computed for every new point on the profile and the global model calls a large number of analytical functions (root, power, log and sine) that are computationally heavy.

3.3.1.12.5. References

[1] Rice P.L., Longley A.G., Norton K.A. and Barsis A.P., Transmission loss for tropospheric communication circuits, National Bureau of Standards, Technical note 101, Vol. 1 and 2, U.S. department of commerce, May 1965.

[2] Hufford G., The ITS Irregular Terrain Model, version 1.2.2, The Algorithm, National Telecommunications and Information Administration Institute for Telecommunication Sciences, 325 Broadway, Boulder, CO 80303–3328, U.S.A.

[3] OET Bulletin n°69, Longley-Rice methodology for evaluating TV Coverage and Interference, Federal communications commission, U.S.A, July 2, 1997.

[4] Hufford, G., The Irregular Terrain Model, January 26, 1999.

[5] T.Martin, Commentaires qualitatifs sur le modèle de propagation multi-obstacles de la recommandation UIT–R P.526–5, ATDI internal technical report, ATDI - Paris, le 17 juin 1999.

3.3.2. 3GPP / COST (empirical)

3.3.2.1. Durkin method

The Durkin model (associated to Deygout 66) does not provide field strength received values above the free space.

Reference:
http://books.google.fr/books?id=3ad7AAAAQBAJ&pg=PA96&lpg=PA96&dq=durkin's+propagation&source=bl&ots=HI2akn42ww&sig=g2n0NKtp1CZqsWtST952RFBcN1I&hl=fr&sa=X&ei=4T6gUq_YIae60QWM_4CYAQ&ved=0CFwQ6AEwBDgK#v=onepage&q=durkin's%20propagation&f=false

3.3.2.2. 3GPP LTE urban (0.9-2 GHz)

LTE specific propagation model as defined in the 3GPP recommendations for "urban" environments.

NOTE: the attenuation is limited to the theoretical free space (20*log ((4*PI*distance)/lambda)).

3.3.2.3. 3GPP LTE rural (0.9-2 GHz)

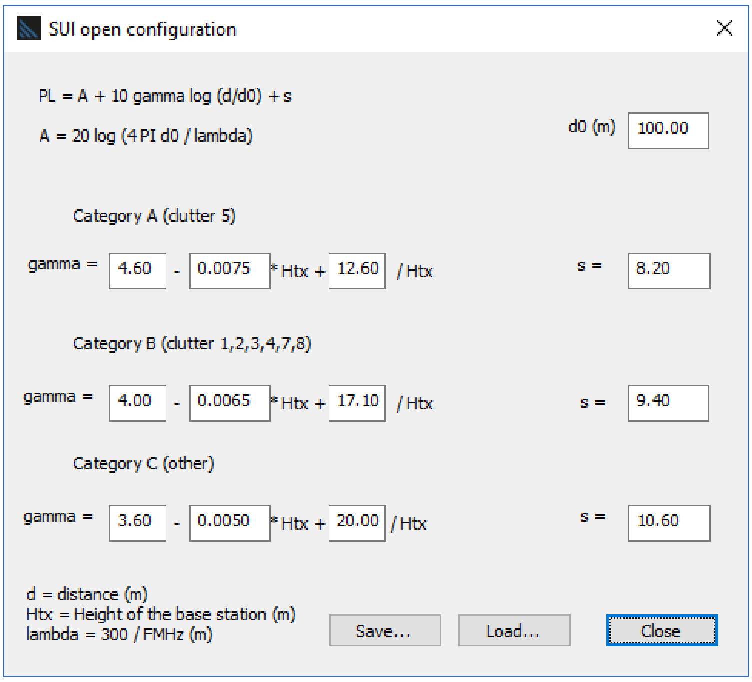
LTE specific propagation model as defined in the 3GPP recommendations for "rural" environments.

NOTE: the attenuation is limited to the theoretical free space (20*log ((4*PI*distance)/lambda)).

3.3.2.4. SUI method (2.5-2.7 GHz)

Stanford University Interim method is used for WiMAX applications in suburban environments.

Reference: https://www.xirio-online.com/help/en/sui.html



SUI open configuration

PL = A + 10 gamma log (d/d0) + s

A = 20 log (4 PI d0 / lambda)

d0 (m) 100.00

Category A (clutter 5)

gamma = 4.60 - 0.0075 * Htx + 12.60 / Htx s = 8.20

Category B (clutter 1,2,3,4,7,8)

gamma = 4.00 - 0.0065 * Htx + 17.10 / Htx s = 9.40

Category C (other)

gamma = 3.60 - 0.0050 * Htx + 20.00 / Htx s = 10.60

d = distance (m)
Htx = Height of the base station (m)
lambda = 300 / FMHz (m)

3.3.2.5. Okumura-Hata/D. (150-1500 MHz)

It includes the Davidson model (to extend the Okumura Hata model to higher frequencies).

This method is based on curves like ITU-R P.370-7, but for distances between 1 and 100km, mostly for urban or suburban areas. It is recommended, particularly for mobiles, for frequencies located between 150 and 1500MHz. Contrary to 370, Okumura curves were analytically interpolated before publishing so that the propagation equation can be divided into a unique basic propagation “free-space like” formula plus a diffraction loss term plus other corrections terms. Taking advantage of the uniqueness of the basic propagation formula, the proposed implementation of the model is a compromise between a purely statistical model and a geometrical model. Actually, it was implemented like a geometrical model with a term Lmodel comprising a large portion of attenuation terms because the model does not exactly match with standard geometrical attenuation terms.

See point ***3.3.2.10 Area table control***

3.3.2.6. Hata – COST 231 (150-2000 MHz)

This model, based on Okumura main model, is derived from the COST 231 working group.

There are two main differences from Okumura method:

- Equations are expressed differently.
- No diffraction term is contained in the model.

For the sake of simplicity or compatibility with ATDI tools inner structure, terms can be added:

- a degree of freedom with the choice of a diffraction and subpath attenuations methods is added. The use of no diffraction loss and no subpath loss is recommended.
- possibility to add more losses (if selected in the propagation model window) : Indoor losses, gas attenuation and rain attenuation.

The received power on a given point (Pr) can be determined by:
Pr = P - Lu, with:
P = Effective Radiated Power in dBm.
Lu = Total losses.

When selecting the "COST 231" model in the propagation model box, the HATA's model is used for frequencies lower than 1500MHz and the COST 231-HATA's model is used for frequencies greater than 1500MHz.

- **HATA's model:** This model can be used for frequencies between 150 and 1000MHz.

Lu = 69.55+26.16*log10(Freq)-13.82*log10(Heff)+(44.9-6.55*log10(Heff))*log10(Dist) - Ah - Az , with :
Freq = Frequency in MHz;
Dist = Distance between the transmitter and the mobile in km.
Heff = Effective antenna height of the base station in m. Heff is supposed to be between 30 and 200m. Then if Heff<30, then Heff=30 and if Heff>200, then Heff=200.
Az = Ground occupancy attenuation term for close obstacles.
Az = 2.0*log10(Freq/28)^2 +5.4, for suburban areas, with Freq=Frequency in MHz.
Az = 4.78*log10(Freq)^2 - 18.33*log10(Freq) + 40.94, for rural areas, with Freq=Frequency in MHz.
Ah = Correction term for antenna whose height is greater than 1,5 m.

Ah = (1.1*log10(Freq)-0.7)*ant-(1.56*log10(Freq)-0.8) , for medium cities, with Freq=Frequency in MHz and ant = Mobile's antenna height in m.
Ah = 8.29*log10(1.54*ant)^2 - 1.1, for big cities, with Freq=Frequency in MHz lower than 200MHz and ant = Mobile's antenna height in m.
Ah = 3.2*log10(11.75*ant)^2 - 4.97, for big cities, with Freq=Frequency in MHz greater than 200MHz and ant = Mobile's antenna height in m.

- **COST 231-HATA's model**: This model can be used for frequencies between 1500 and 2000MHz.

Lu = 46.33+33.9*log10(Freq)-13.82*log10(Heff)+(44.9-6.55*log10(Heff))*log10(Dist) + Cm - Ah, with :
Freq = Frequency in MHz;
Dist = Distance between the transmitter and the mobile in km.
Heff = Effective antenna height of the base station in m. Heff is supposed to be between 30 and 200m. Then if Heff<30, then Heff=30 and if Heff>200, then Heff=200.
Cm = Correction term that is equal to :
* 0dB for medium cities and suburban.
* 3dB for large cities.
Ah = Correction term for antenna whose height is greater than 1,5 m.
Ah = (1.1*log10(Freq)-0.7)*ant-(1.56*log10(Freq)-0.8) , for medium cities, with Freq=Frequency in MHz and ant = Mobile's antenna height in m.

NOTE: the attenuation is limited to the theoretical free space (20*log ((4*PI*distance)/lambda)).

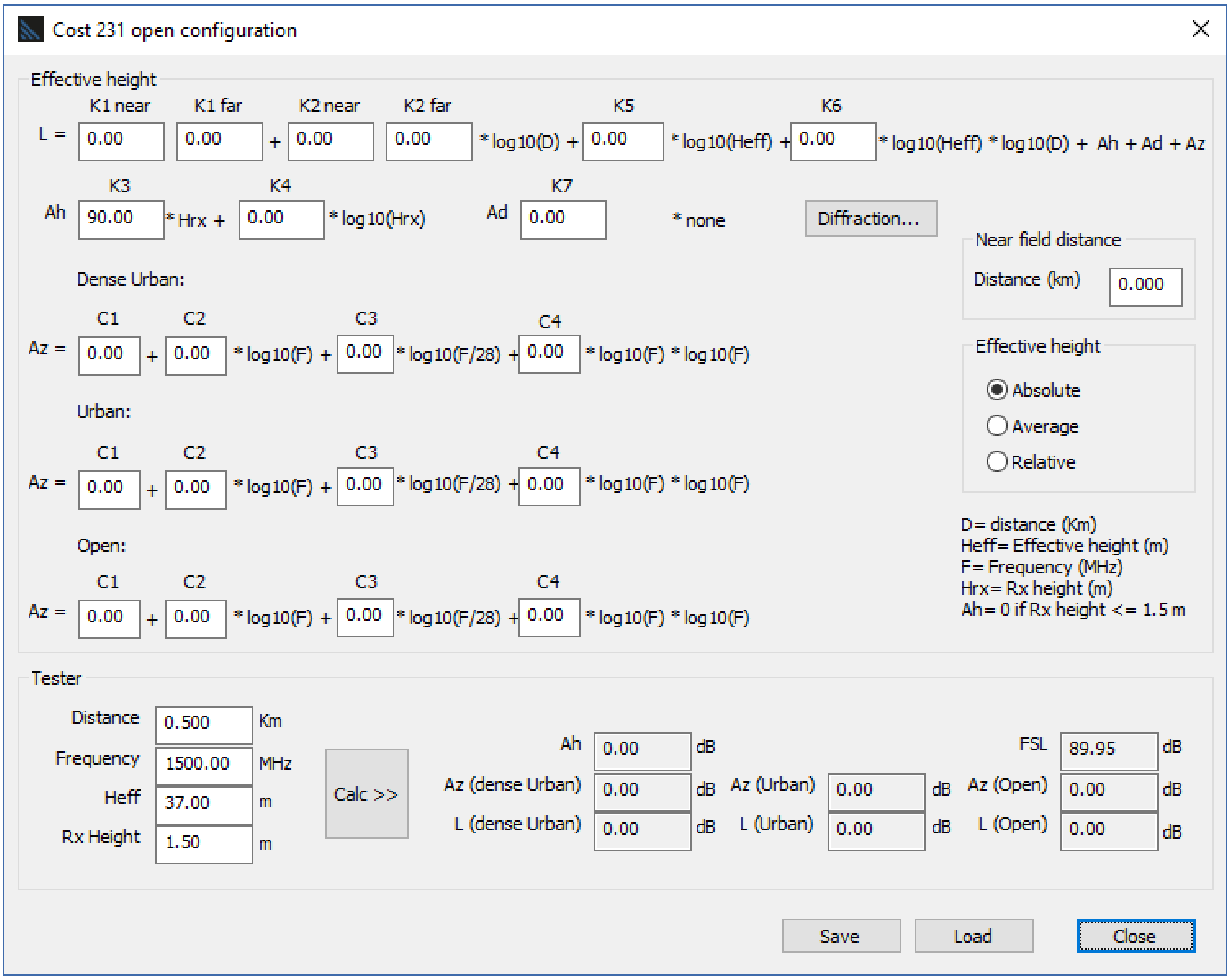
See point ***3.3.2.10 Area table control***

3.3.2.7. Extended Hata (30-3000 MHz)

This model is compatible with SEAMCAT (CEPT). It does not consider the terrain, and only considers the Tx and Rx heights.

3.3.2.8. COST 231 open

In the version “open” of the COST 231 model, each coefficient of the different equations can be user defined:



Cost 231 open configuration

Effective height

L = K1 near 0.00 K1 far 0.00 + K2 near 0.00 K2 far 0.00 * log10(D) + K5 0.00 * log10(Heff) + K6 0.00 * log10(Heff) * log10(D) + Ah + Ad + Az

Ah K3 90.00 * Hrx + K4 0.00 * log10(Hrx)

Ad K7 0.00 * none

Dense Urban:

Az = C1 0.00 + C2 0.00 * log10(F) + C3 0.00 * log10(F/28) + C4 0.00 * log10(F) * log10(F)

Urban:

Az = C1 0.00 + C2 0.00 * log10(F) + C3 0.00 * log10(F/28) + C4 0.00 * log10(F) * log10(F)

Open:

Az = C1 0.00 + C2 0.00 * log10(F) + C3 0.00 * log10(F/28) + C4 0.00 * log10(F) * log10(F)

Near field distance

Distance (km) 0.000

Effective height

● Absolute

○ Average

○ Relative

D= distance (Km)
Heff= Effective height (m)
F= Frequency (MHz)
Hrx= Rx height (m)
Ah= 0 if Rx height <= 1.5 m

Tester

Distance 0.500 Km
Frequency 1500.00 MHz
Heff 37.00 m
Rx Height 1.50 m

Ah 0.00 dB
Az (dense Urban) 0.00 dB
L (dense Urban) 0.00 dB
Az (Urban) 0.00 dB
L (Urban) 0.00 dB
FSL 89.95 dB
Az (Open) 0.00 dB
L (Open) 0.00 dB

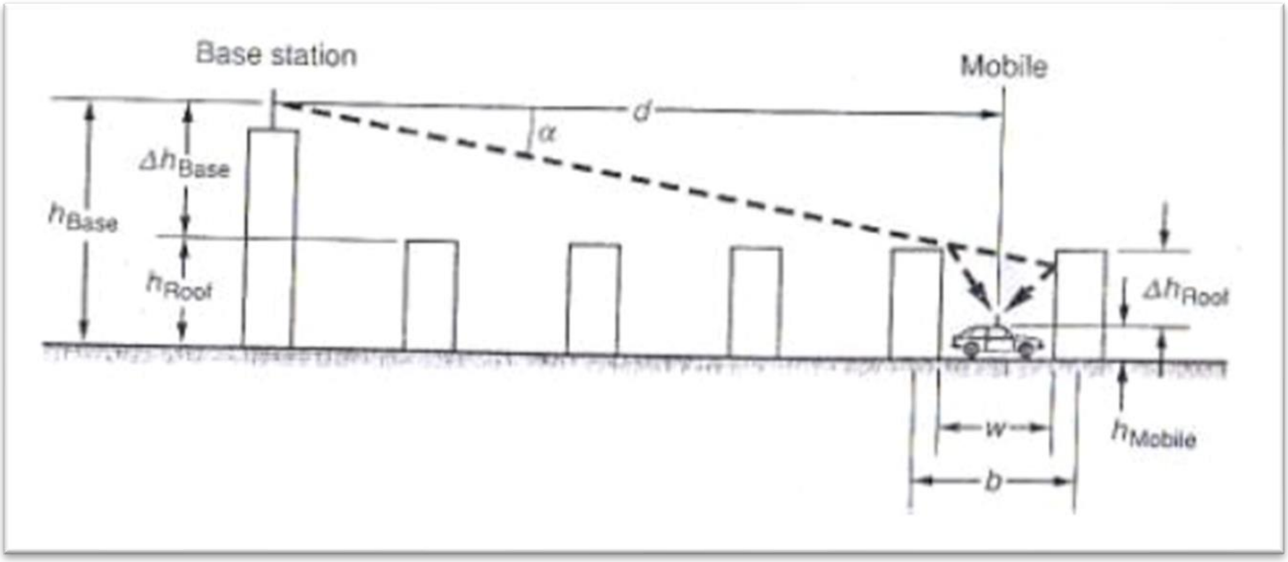
See point ***3.3.2.10 Area table control***

3.3.2.9. Walfisch-Ikegami (800-2000 MHz)

The Walfisch-Ikegami model is available with the COST 231 diffraction model.

The parameters, excess path loss from Walfisch-Bertoni model and final building path loss from Ikegami Model, are combined in this model with a few empirical correction parameters. This model is statistical and not deterministic because you can only insert a characteristic value, with no considerations of topographical database of buildings. The model is restricted to flat urban terrain.

The parameters used in Cost 231 Walfisch- Ikegami are denoted in the following figure:



Geometry of Cost 231 Walfisch- Ikegami

3.3.2.10. Area table control

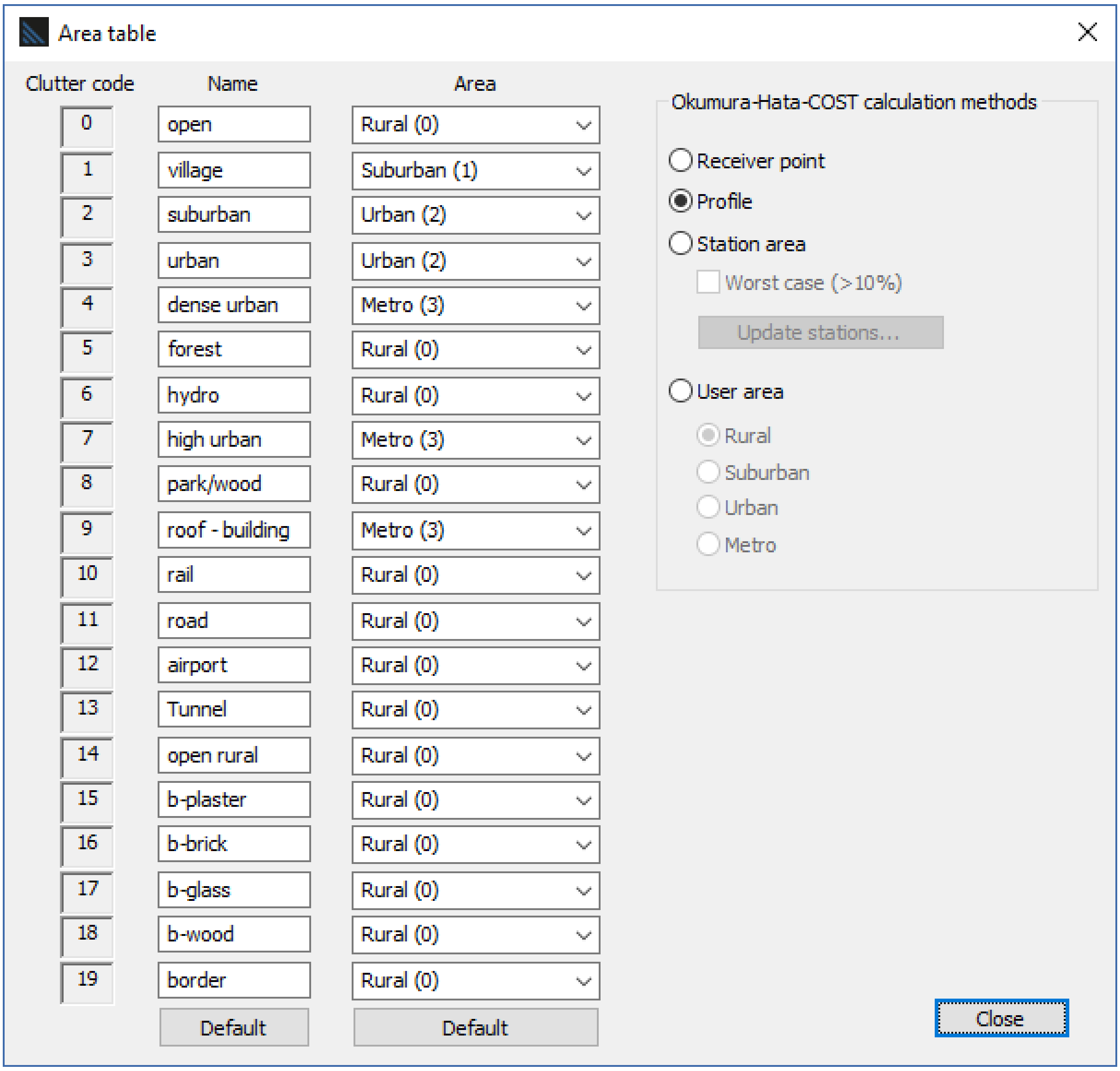
The "Area table" function is used to define the calculation method (Rural, Suburban, Urban, Metro) of the propagation models of Okumura, Hata and COST types.

The "Receiver Point" option automatically calculates the type of clutter environment according to where the receiving point is.

The "Profile" option will analyze the profile for each receiving point from the transmitting station and choose the worst case for the environment.

With the "Station area" option, the "Update stations ..." function will analyze the environment of the station in a user-defined radius and will choose the one corresponding to the largest area. The "Area" from the "Site" tab is updated for each activated station.

In "User area" mode, the user selects the environment that will be considered for all stations.



Clutter code	Name	Area
0	open	Rural (0)
1	village	Suburban (1)
2	suburban	Urban (2)
3	urban	Urban (2)
4	dense urban	Metro (3)
5	forest	Rural (0)
6	hydro	Rural (0)
7	high urban	Metro (3)
8	park/wood	Rural (0)
9	roof - building	Metro (3)
10	rail	Rural (0)
11	road	Rural (0)
12	airport	Rural (0)
13	Tunnel	Rural (0)
14	open rural	Rural (0)
15	b-plaster	Rural (0)
16	b-brick	Rural (0)
17	b-glass	Rural (0)
18	b-wood	Rural (0)
19	border	Rural (0)

Okumura-Hata-COST calculation methods

- ○ Receiver point
- ● Profile
- ○ Station area
  - ☐ Worst case (>10%)
  - Update stations...
- ○ User area
  - ● Rural
  - ○ Suburban
  - ○ Urban
  - ○ Metro

3.3.3. Specific / External

3.3.3.1. BR method (1/2 wave 75 ohms) (former Fresnel model)

This is the former Fresnel model.

The Fresnel method provides an additional specific attenuation term which is constant w.r.t. the parameters: 3.8dB. This constant can be introduced in the global attenuation term Lprop through the term Lmodel=3.8dB.

This additional attenuation was introduced and theoretically justified by Thomson Broadcast services.

This model can be used for field-strength calculations on the margins of VHF bands while showing good performance in UHF and SHF bands.

From experience and comparison with measurement, the following are recommended options:

- Diffraction geometry: Deygout 1994;

- Subpath attenuation: Coarse integration.

For lower frequencies, a spherical wave correction term can be selected (click Spherical wave in the dialog box).

3.3.3.2. Wojnar method (1-1000 MHz)

This method, derived from ITU Report No. 567-4, is used for VHF frequencies. It integrates the notion of effective antenna height with electrical characteristics of the ground. In fact, this model automatically includes an additional attenuation term which is the same as the standard subpath loss:

$$\boxed{L_{model} = Lg\ r= 20\log(75000d) - 20\log(\pi h1h2f)}$$

It is recommended for frequencies between 30 to 100MHz. The Deygout 1994 diffraction method is recommended to use with.

Extension of the model for frequencies greater than 100MHz. But there is a discontinuity of the model for frequencies around 100MHz. Reference: http://www.piast.edu.pl/Files/doc/papers/1984_1.pdf.

3.3.3.3. CCIR - MF (550-1700 kHz)

This is an empirical medium-wave model.

3.3.3.4. External models (DLL)

Access to the external library of propagation models, in the SW main installation path.

Composite output: Check this option to combine in the result, the attenuations calculated by the external DLL, with the rest of attenuations available (diffraction, subpath…)

Use Tx/Rx effective heights: applies the effective heights defined for each station in their parameters boxes.

Flat Earth profile sent to DLL: check it to apply flat Earth profile to the terrain when using an external DLL.

Reverse profile: Option available only for 1546 and 452-14 models. If checked, this option will reverse the profile sent to the model (from receiver to transmitter).

3.3.4. Maritime propagation

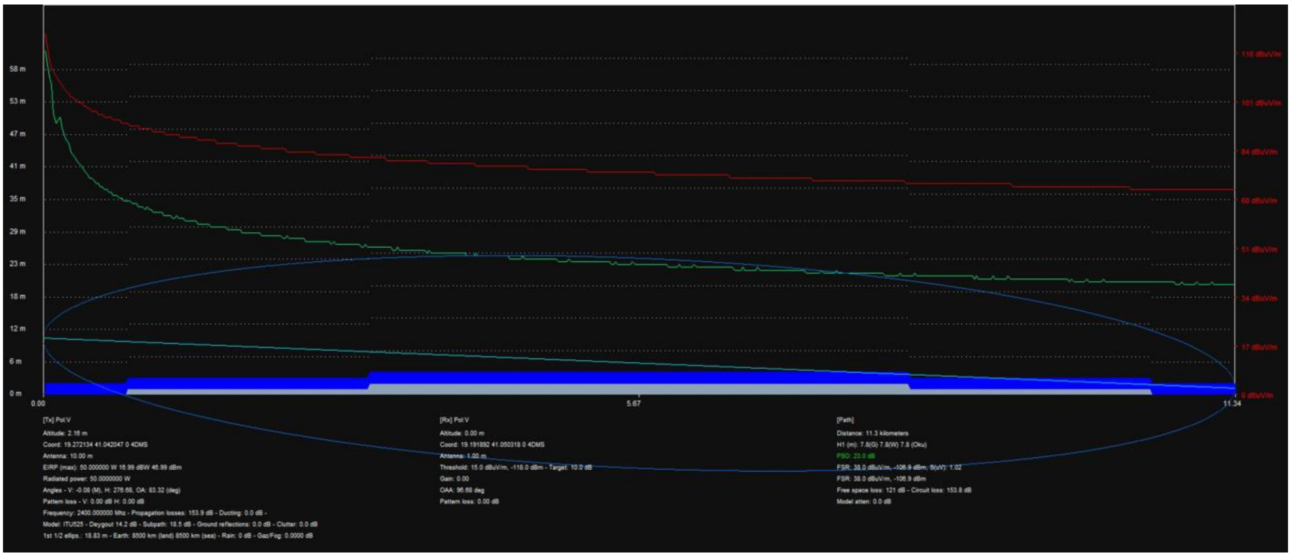
MF Groundwave Propagation Modelling for Maritime Networks.

Introduction to modelling MF band propagation (3 kHz – 30 MHz) for Maritime Networks with ATDI tools: For the past seventeen years ATDI has been integrating and developing software for modelling anomalous radio wave propagation for the purposes of RF network design. This includes propagation phenomenon such as ducting, troposcatter and their applications over terrain and water.

A generic model can be used, with specific parameters:

- Equivalent Earth Radius adapted to sea environment (cold, warm, …).
- Additional diffraction obstacles due to wave heights. Depending on the wave height, the receiver or transmitter height is changed. Example:

  Strong wind conditions:

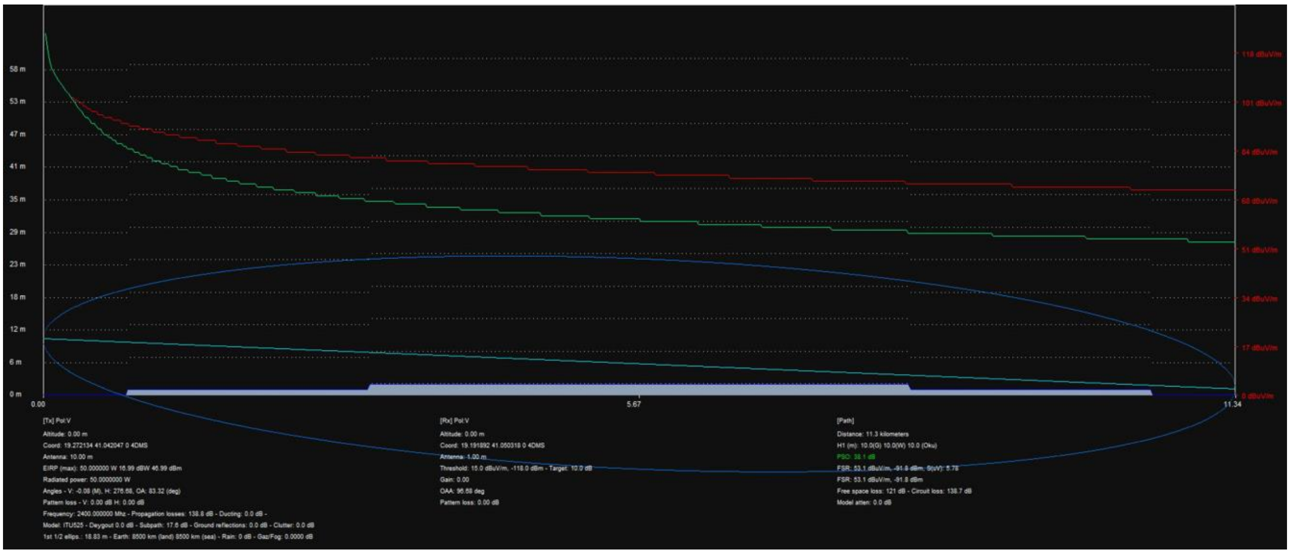


```
[Tx] Pol:V
Altitude: 2.16 m
Coord: 19.272134 41.042047 0 4DMS
Antenna: 10.00 m
EIRP (max): 50.000000 W 16.99 dBW 46.99 dBm
Radiated power: 50.0000000 W
Angles - V: -0.08 (M), H: 276.68, OA: 83.32 (deg)
Pattern loss - V: 0.00 dB H: 0.00 dB
Frequency: 2400.000000 Mhz - Propagation losses: 153.9 dB - Ducting: 0.0 dB -
Model: ITU525 - Deygout 14.2 dB - Subpath: 18.5 dB - Ground reflections: 0.0 dB - Clutter: 0.0 dB
1st 1/2 ellips.: 18.83 m - Earth: 8500 km (land) 8500 km (sea) - Rain: 0 dB - Gaz/Fog: 0.0000 dB
```

```
[Rx] Pol:V
Altitude: 0.00 m
Coord: 19.191892 41.050318 0 4DMS
Antenna: 1.00 m
Threshold: 15.0 dBuV/m, -118.0 dBm - Target: 10.0 dB
Gain: 0.00
OAA: 96.68 deg
Pattern loss: 0.00 dB
```

```
[Path]
Distance: 11.3 kilometers
H1 (m): 7.8(G) 7.8(W) 7.8 (Oku)
PSO: 23.0 dB
FSR: 38.0 dBuV/m, -106.9 dBm, S(uV): 1.02
FSR: 38.0 dBuV/m, -106.9 dBm
Free space loss: 121 dB - Circuit loss: 153.8 dB
Model atten: 0.0 dB
```

Flat sea:



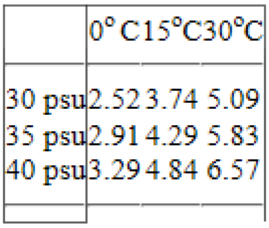
```
[Tx] Pol:V
Altitude: 0.00 m
Coord: 19.272134 41.042047 0 4DMS
Antenna: 10.00 m
EIRP (max): 50.000000 W 16.99 dBW 46.99 dBm
Radiated power: 50.0000000 W
Angles - V: -0.08 (M), H: 276.68, OA: 83.32 (deg)
Pattern loss - V: 0.00 dB H: 0.00 dB
Frequency: 2400.000000 Mhz - Propagation losses: 138.8 dB - Ducting: 0.0 dB -
Model: ITU525 - Deygout 0.0 dB - Subpath: 17.6 dB - Ground reflections: 0.0 dB - Clutter: 0.0 dB
1st 1/2 ellips.: 18.83 m - Earth: 8500 km (land) 8500 km (sea) - Rain: 0 dB - Gaz/Fog: 0.0000 dB
```

```
[Rx] Pol:V
Altitude: 0.00 m
Coord: 19.191892 41.050318 0 4DMS
Antenna: 1.00 m
Threshold: 15.0 dBuV/m, -118.0 dBm - Target: 10.0 dB
Gain: 0.00
OAA: 96.68 deg
Pattern loss: 0.00 dB
```

```
[Path]
Distance: 11.3 kilometers
H1 (m): 10.0(G) 10.0(W) 10.0 (Oku)
PSO: 38.1 dB
FSR: 53.1 dBuV/m, -91.8 dBm, S(uV): 5.78
FSR: 53.1 dBuV/m, -91.8 dBm
Free space loss: 121 dB - Circuit loss: 138.7 dB
Model atten: 0.0 dB
```

- Impact of the salinity: The salinity will have an impact of the reflection and refraction (penetration for under-water propagation).

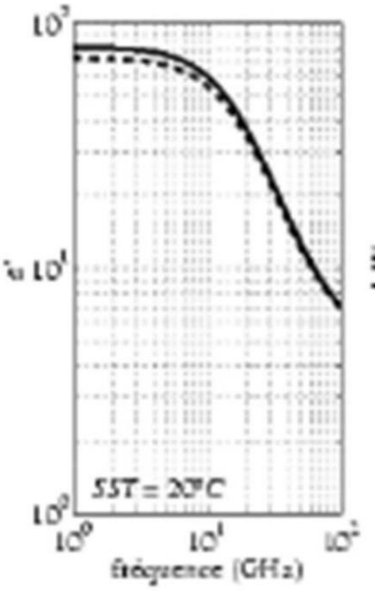
  Ionic conductivity of sea water as a function of temperature and salinity:



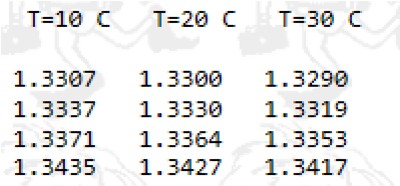
	0° C	15°C	30°C
30 psu	2.52	3.74	5.09
35 psu	2.91	4.29	5.83
40 psu	3.29	4.84	6.57

The salinity range (20-40 psu) covers most of the surface of the oceans.

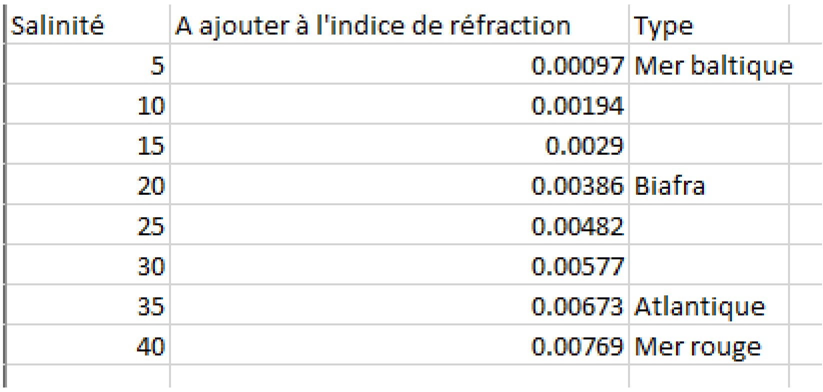
Relative permittivity of sea water at a salinity of 35psu (dashed) and pure water (solid line) as a function of frequency (GHz):



As a general matter, the refractive index of sea water varies between 1.33 and 1.34, i.e. a reflection coefficient of 0.0201 and 0.0211. Different measured values:

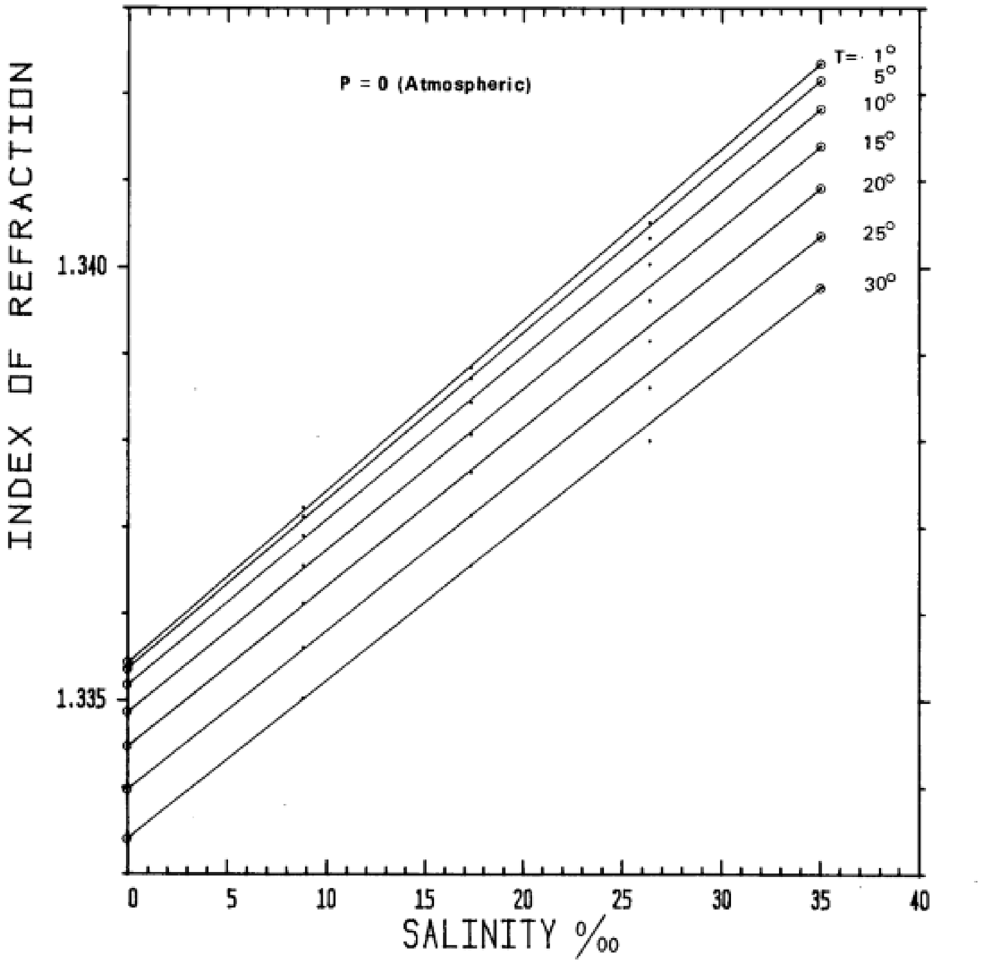


T=10 C	T=20 C	T=30 C
1.3307	1.3300	1.3290
1.3337	1.3330	1.3319
1.3371	1.3364	1.3353
1.3435	1.3427	1.3417



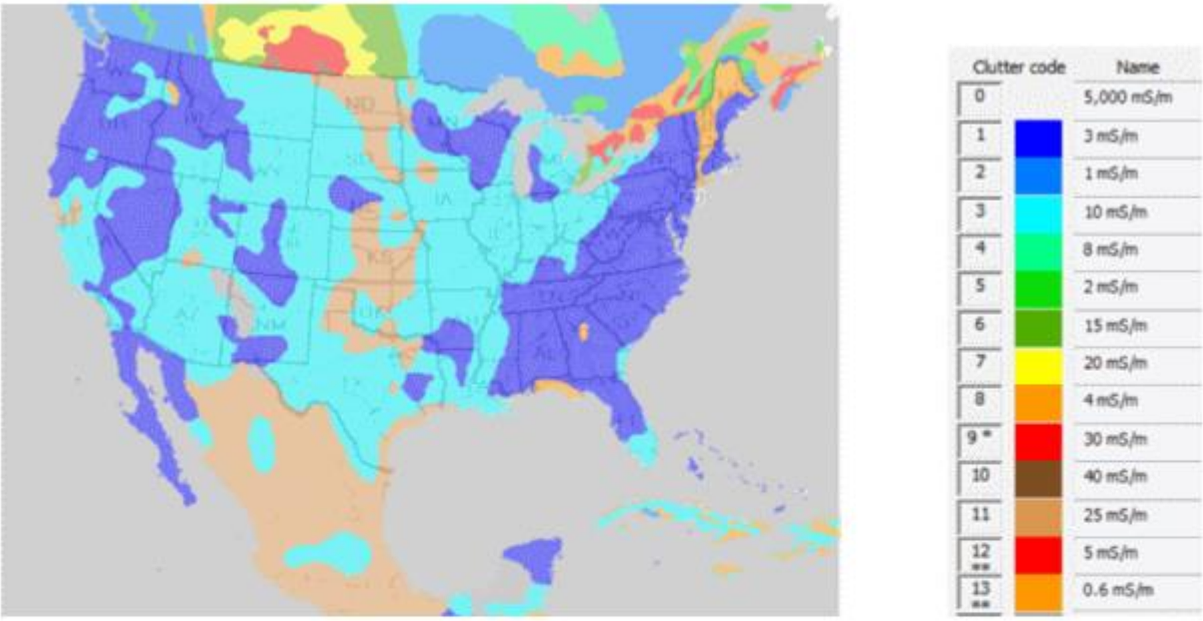
Salinité	A ajouter à l'indice de réfraction	Type
5	0.00097	Mer baltique
10	0.00194	
15	0.0029	
20	0.00386	Biafra
25	0.00482	
30	0.00577	
35	0.00673	Atlantique
40	0.00769	Mer rouge

Mehu-Gilles tables (1968):



Modelling of MF Groundwave propagation from ship to shore along coastlines.

The below information is focused on developments in the areas of cartographic map data preparation, integration of propagation standards and calibration information and custom reporting options available to users of ATDI tools for the purposes of modelling Maritime Networks.



Clutter code		Name
0		5,000 mS/m
1	🟦	3 mS/m
2	🟦	1 mS/m
3	🟦	10 mS/m
4	🟩	8 mS/m
5	🟩	2 mS/m
6	🟩	15 mS/m
7	🟨	20 mS/m
8	🟧	4 mS/m
9 *	🟥	30 mS/m
10	🟫	40 mS/m
11	🟫	25 mS/m
12 **	🟥	5 mS/m
13 **	🟧	0.6 mS/m

Conductivity map of the United States from ITU IDWM sources

Preparation of a Conductivity/Permittivity Map from the ITU IDWM database:

In the case of MF propagation, terrain obstruction information provided by the classic Digital Terrain Model used with most RF network modelling packages is of greatly diminished importance. More important, are the electromagnetic properties of the terrain in particular the Conductivity and Permittivity of the ground.

These types of maps are usually available from the local national spectrum authority. ATDI's GIS management tool, ICS map server tool can create these maps from any type of source (digitized map, vector map, etc.) in a format compatible for RF analysis with ATDI planning tools.

ATDI cartographic services can also provide this type of information for any country in the world using the ITU Digital World Map (IDWM) database as a global source of conductivity and permittivity data in all varying regions. Note, that this is the same source for the conductivity map in the FCC 47 CFR 73.190.

The map above is provided in the form of ATDI tools classic clutter layer. Since the clutter layer can serve as a generic skin or blanket of morphological information layered over the terrain model, and can contain user defined propagation characteristics per clutter class/code, this layer was perfect to reuse as a conductivity map layer.

The units of each region of conductivity are in milli-Siemens/meter (mS/m) and can be configured as labels of each clutter class/code to give the map distinction in the SW interface.

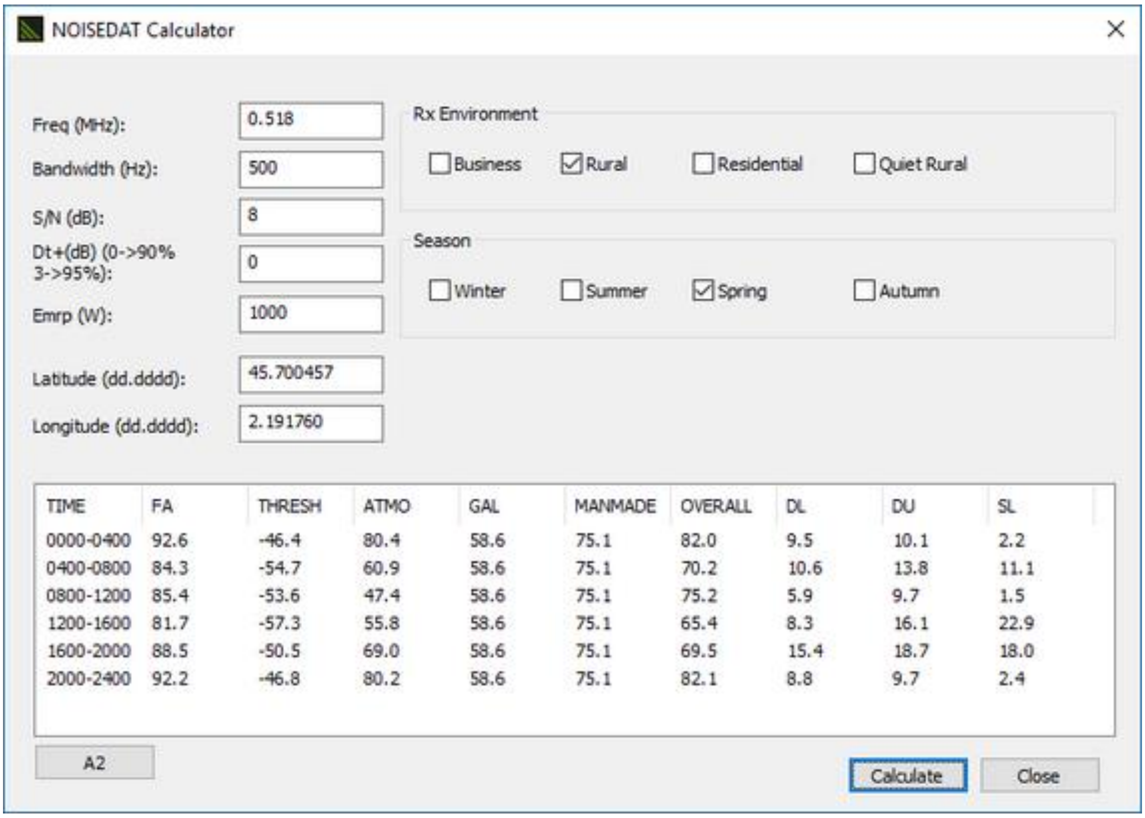
In order to properly model the radio wave propagation of MF signals, ATDI has also integrated the latest ITU recommendations specific to MF Groundwave propagation: ITU-R P.368-9 and ITU-R M.1467-1.

Calculation feature used to generate the field strength received predictions for each pixel on the map is based on the integration of ITU-R P.368-9 into ATDI tools propagation engine.

The ITU-R P.368-9 model depends on the input of conductivity and permittivity data which is provided by the ITU maps described previously.

These values provide the ITU-R P.368 Groundwave model with the appropriate attenuation information to model MF propagation over land and sea allowing ATDI tools to generate MF Groundwave coverage plots.

In order to make sure that the receive sensitivity of each radio network element is configured appropriately, with respect to their immediate environmental conditions and time of year, HTZ has also integrated a NOISDAT calculator derived from ITU-R M.1467-1.



Freq (MHz): 0.518
Bandwidth (Hz): 500
S/N (dB): 8
Dt+(dB) (0->90% 3->95%): 0
Emrp (W): 1000
Latitude (dd.dddd): 45.700457
Longitude (dd.dddd): 2.191760

Rx Environment: ☐ Business ☑ Rural ☐ Residential ☐ Quiet Rural

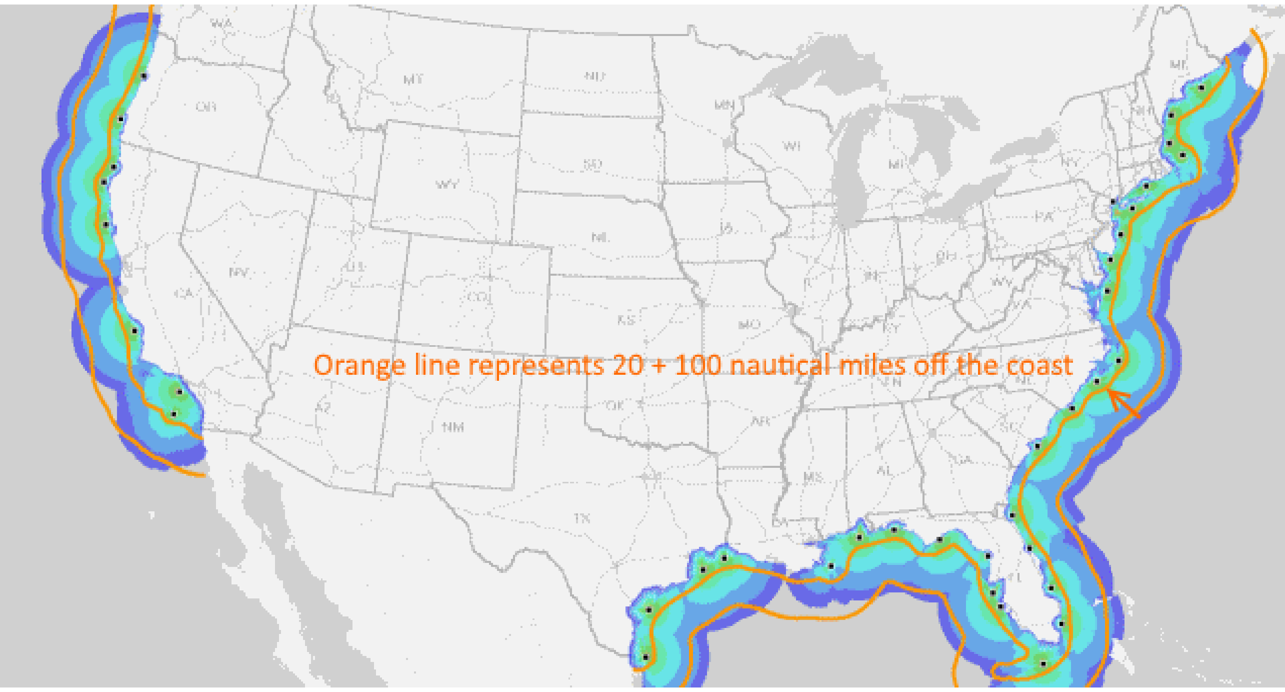
Season: ☐ Winter ☐ Summer ☑ Spring ☐ Autumn

TIME	FA	THRESH	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL
0000-0400	92.6	-46.4	80.4	58.6	75.1	82.0	9.5	10.1	2.2
0400-0800	84.3	-54.7	60.9	58.6	75.1	70.2	10.6	13.8	11.1
0800-1200	85.4	-53.6	47.4	58.6	75.1	75.2	5.9	9.7	1.5
1200-1600	81.7	-57.3	55.8	58.6	75.1	65.4	8.3	16.1	22.9
1600-2000	88.5	-50.5	69.0	58.6	75.1	69.5	15.4	18.7	18.0
2000-2400	92.2	-46.8	80.2	58.6	75.1	82.1	8.8	9.7	2.4

The NOISEDAT Calculator takes into consideration the operating frequency, bandwidth, signal-to-noise ratio, 90% fade margin and estimated radiated power as well as specifications of the receiver environment and season to model the variability in Noise contribution to radio propagation in the MF band.

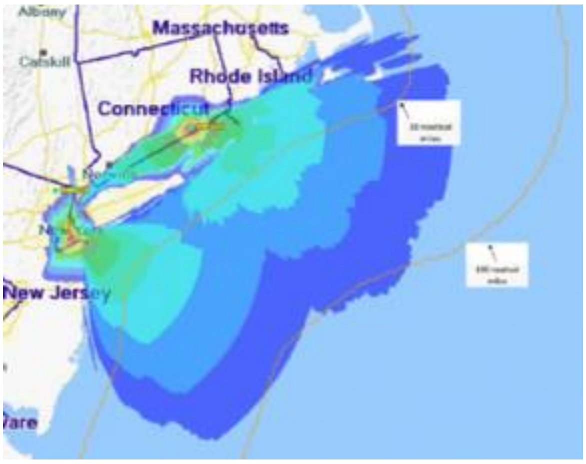
Essentially, the NOISEDAT calculator serves as a reference to model the expected Noise Rise and respective threshold degradation at a given site of interest.

ATDI has even integrated consideration for A2 sea region in order to generate an output based on ITU-R M.1467-1 NOISEDAT calculation to give the predicted receive sensitivity in dBm and dB-V/m as well as range in nautical miles and kilometers. This information is used to calibrate ATDI SW propagation engine appropriately for ship to shore (reverse coverage) calculations.



Reporting options specific to modelling Maritime Networks

ATDI tools also includes reporting features specific to modelling Maritime Communications including the ability to generate nautical mile boundaries from the coastline or from the locations of the shore stations:



ATDI continues to refine its modelling processes for MF Groundwave propagation studies in response to emerging requirements from the spectrum authorities of Coast Guards and Naval agencies all over the world.

ATDI's strong association with the ITU, and expertise in integrating ITU recommendations into its product line allow ATDI to be the world leader in translating complex propagation phenomenon to simple, intuitive graphics that can be understood by the various policy makers and stake holders involved utilizing and managing a country's spectral resources.

In upcoming parts of this series on modelling Maritime Communications, we will focus on newly developed features for generating probability of coverage per season and frequency for HF Skywave propagation as well as modelling HF antennas and ultimately VHF coverage and traffic analysis for Maritime Communications.

3.4. Global parameters

Earth radius (km): Enter the earth radius above land (Land field) and the earth radius above sea (Sea field), in kilometers. The 3-points button opens the *Earth radius converter* box allowing the conversion of earth radius in K/DN/RADIUS.

RMS wave height (m): Enter the RMS wave height for maritime propagation. Additional diffraction obstacles may appear due to wave heights. Depending on the wave height, the receiver or transmitter height is changed. Please refer to the point ***3.3.4 Maritime propagation.***

Field strength offset: Use an offset (-100 to +100 dB) to allow the simulation of coverages with negative field strength values or values greater than 253dBµV/m.

Example:

- The minimum FS that can be displayed is 1 dBuV/m. To display negative FS values:
    1. Set a negative threshold (e.g. -10 dBuV/m), and a lower value for the offset (e.g. -11 dBuV/m).
    2. Calculate the coverage of the network.
    3. The result will display FS values up to -10 dBuV/m (threshold).
    4. All values lower than threshold will be equal to offset (-11 dBuV/m).

- Reciprocally, the maximum FS that can be displayed is 253 dBuV/m. Positive offset allow to display values greater than 253dBuV/m.

- **Variability area:**

Variability (P2P unwanted signal): It offers the possibility to consider another percentage of time for the unwanted signal during point to point interference calculations.
Note: It changes the percentage of time for the following models: ITU-R P.1812, ITU-R P.452, ITU-R P.1546, ITU-R P.370 and external DLL models. For other models, two profiles are calculated for equivalent Earth radius 8500km and 19113km.

Indoor…: opens the Indoor parameters box. For further information about this box, please refer to the document ***Indoor calculations.pdf*** (http://www.data.atdi-group.com/doc/130.pdf)

Clutter…: opens the Clutter parameters box. For further information about this box, please refer to the document ***Clutter attenuations in ATDI tools.pdf*** (www.data.atdi-group.com/doc/118.pdf)

Conductivity…: Access to the conductivity and Permittivity box, that allows the user to update the conductivity and permittivity indexes, that are used in some propagation models, like ITU-R 368-9. For detailed information, please refer to the point ***3.3.1.9.2 Conductivity and permittivity***.

ITU zones…: Loads ITU zones RFL file in memory (note: max size = Max blocsize^2).

Save…: Saves the model settings in a .PRM parameter file.

Load…: Loads a .PRM parameter file containing the calculation settings.

Close : Confirms the calculation settings and closes the Propagation models box.

4. User defined propagation model

ATDI tools allow the user to create a user-defined model.

The user-defined model may be created by using Visual C++. It consists in (programming) a dynamic link library (.dll) file that can be called by ATDI tools either for PTP, profile or coverage calculations. The model is called by ATDI tools at any new point of the DTM where the field strength computation is needed.

When one creates a new model in C++, one must open a new project including 2 mandatory elements:

- a header file that must not be modified: usrdll.h, and
- a locally “main” file whose name can be defined by the user but its input/output cannot be changed.

Additional files for functions can naturally be included in the project.

We present here a simple example with files used to create a DLL that performs computations with the Millington/Bullington diffraction method.

1. header file: usrdll.h

```
//-----------------------------------------------
#ifdef __cplusplus
 extern "C" {
#endif
#pragma pack(push,8)            // structures are aligned 8 bytes
//-----------------------------------------------

typedef struct {
 float altitude;            // corrected by earth curvature in meter
 char veget;                    // clutter code 0 to 20
 unsigned char alt_veget;       // clutter altitude
 short x,y;                     // DTM point (coordinates)
 float distance;            // distance ray Tx/Rx in meter
}ALT2;

typedef struct {
 long count;                    // number of path values
 long TxX, TxY;             // Tx position (point dtm)
 float TxAntennaHeight, RxAntennaHeight;        // meter
 float RadiatedPower;           // WATT
 float Frequency;               //MHz
 short dx,dy;                   // DTM step meter
 double EarthRadius;            // meter
 unsigned char Seen;            // 0 = not seen - 1 = seen
 float h_eff1;                  // effective height 1 --> 15km
 float h_eff3;                  // effective height 3 --> 15km
 unsigned char iso;             // 0: ½ wave dipole convention, 1: iso
} InModel;
```

```
// the second argument is a pointer to an OutModel structure that is filled by the DLL:

typedef struct {
  double LossFreeSpace;          //dB
  double LossDiffraction;        //dB
  double LossFresnel;            //dB
  double LossUser;               // information field
  double LossClutter;            //dB
  double FieldFreeSpace;         //dBµV/m
  double FieldReceived;  //dBµV/m
  unsigned char LineOfSight;     // 0=not seen, 1 = seen
  char Obstacle;                 // -1=no computation, 0=0 obsta 1=1 obs...
} OutModel;

#ifdef USERMOD_DLL_COMPILING        // this expression has to be defined in DLL
  #define DLLENTRY _declspec(dllexport)
#else
  #define DLLENTRY _declspec(dllimport)
#endif

DLLENTRY void UserModel(ALT2 *profil,InModel inparam,OutModel *outparam);

//-----------------------------------------------
#pragma pack( pop )              // restore previous alignment
#ifdef __cplusplus
  }
#endif
//-----------------------------------------------
```

The first input structure ALT2 depends on the point where a field has to be computed while the second structure InModel provides global parameters. The first input is actually a pointer on a ALT2 structure (*profil). The number of elements is in the second structure InModel (inparam.count). If the index i is defined from 0 to inparam.count, profil[i].* provides parameters from the first point of the profile (Tx) to the last point (Rx). When a field strength is computed along a path of n points, ATDI tools successively calls the DLL, providing it first with a 2 elements pointer on a ALT2 structure, then a 3 elements pointer on a ALT2 structure (the third element is new), ..., until a n element pointer is provided. Thus, the DLL is called n-1 times for a profile of length n. The name of structure component is explicit. Let us precise that inparam.Seen is a boolean value that states whether there is a direct visibility between Tx and Rx and that, if inparam.h_eff1=-9999 or inparam.h_eff3=-9999, the calling program require that the DLL file performs the computation of the effective antenna height (if needed in the model).

Output structure, with a subdivision defined w.r.t. standard geometrical model components:

- outparam->LossFresnel: this field is for the attenuation when there is visibility (inparam.Seen=1);
- outparam->LossDiffraction: this field is for the attenuation when there is no visibility (inparam.Seen=0);
- outparam->LossClutter: this field receives the clutter attenuation term;

- outparam->FieldFreeSpace: this field receives the freespace field strength term.

All the previous terms are mandatory and contribute additively or (if they start with the prefix “Loss”) negatively to the global field strength. Thus, if not used, they must be set to zero. Regarding the remaining terms:

- outparam->LossFreeSpace: this field is aimed at receiving the free space attenuation term but has not been used so far by ATDI tools;
- outparam->FieldReceived: this term is not taken into account by ATDI tools but is mandatory for HerTZ Mapper;
- outparam->LossUser: this term does not contribute to the global field strength but is displayed in an “info” field when a field strength profile is drawn (it may contain an attenuation component);
- outparam->Obstacle: used to display the number of obstacles encountered by the model (when geometrical);
- outparam->LineOfSight: plays the same role as inparam.Seen, but as output (for example if the user wishes to recompute this value with a different Earth radius).

As a result, the field strength displayed by ATDI tools reads:

F=outparam->FieldFreeSpace–outparam->LossFresnel–outparam->LossDiffraction–outparam->LossClutter- Lgas–Lrain,

where Lgas and Lrain are pre computed by ATDI tools (Lrain is activated only if the user switches the rain attenuation term on within the Tools/Propagation model box). The aforementioned example is now presented with 3 additional files to include in the project:
- mill.h;
- mill.c;
- milloss.c.

2. *additional header file: mill.h*

```
#define USERMOD_DLL_COMPILING          1
#include "usrdll.h"
#include <math.h>
#include <stdio.h>

double milloss(ALT2 *profil,InModel inparam,OutModel *outparam);
```

3. *DLL “main” file: mill.c*

```
#include "mill.h"

void UserModel(ALT2 *profil,InModel inparam,OutModel *outparam)
{
 double FSR;

 //Free space
 FSR=76.99+10.0*log10(inparam.RadiatedPower)
  -20.0*log10(profil[inparam.count].distance/1000.0);
 if (inparam.iso)
  FSR-=2.15;
 outparam->FieldFreeSpace=FSR;
```

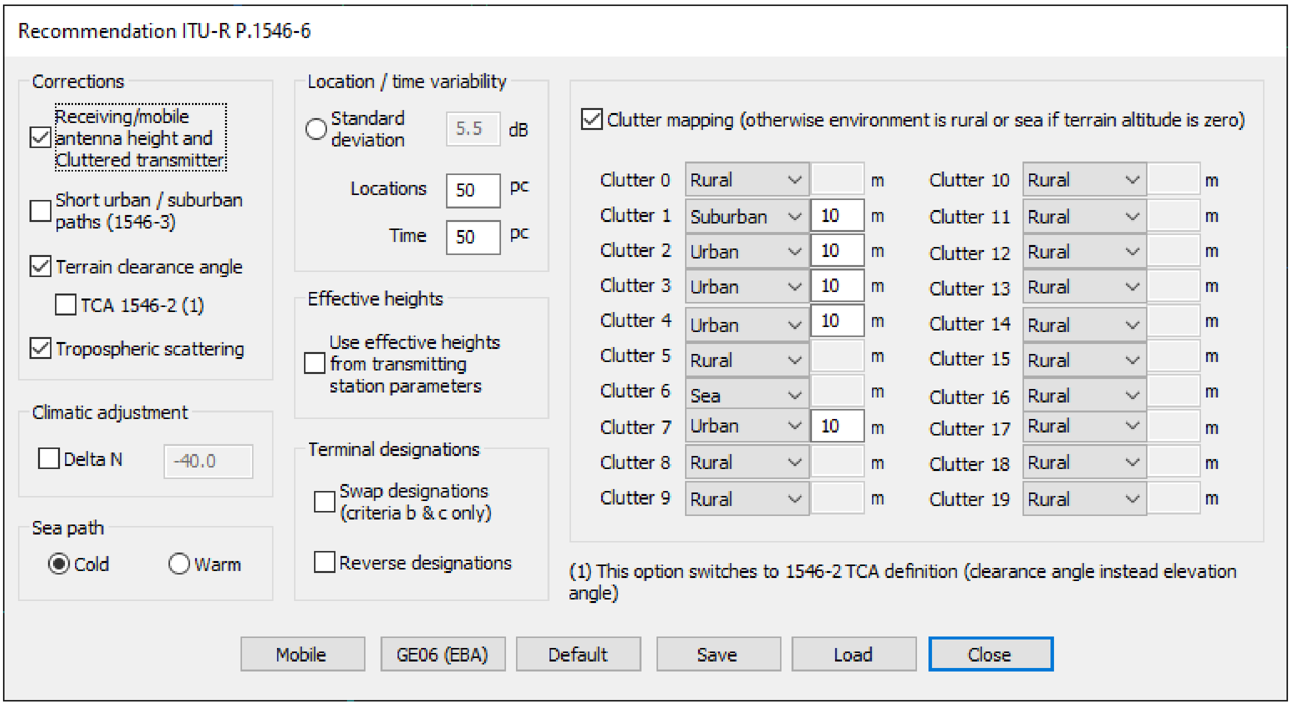
```
  outparam->LossDiffraction=0.0;
  outparam->LossFresnel=0.0;
  outparam->LineOfSight=0;
  outparam->LossUser=0.0;
  outparam->LossClutter=0;

  if(!inparam.Seen)
  {
   outparam->LossDiffraction=milloss(profil,inparam,outparam);
   outparam->Obstacle=1;
  }
  else
  {
   outparam->LossFresnel=milloss(profil,inparam,outparam);
   outparam->Obstacle=0;
  }
  outparam->FieldReceived=outparam->FieldFreeSpace
   -outparam->LossDiffraction-outparam->LossFresnel-outparam->LossUser
   -outparam->LossClutter;
}
```

4. *Diffraction function: milloss.c*

```
#include "mill.h"

double milloss(ALT2 *profil,InModel inparam,OutModel *outparam)
{
  double nu,KnifeEdgeLoss,distsol,hsol,r1;
  double slope,txalt,txtalt,rxalt,rxtalt,rxd,interm;
  double disti,alti,TxTan,RxTan,TxClTan,RxClTan;
  int i,iTx;

  // Useful variables
  iTx=0;                                  // Tx position
  rxd=(double)profil[inparam.count].distance;
  txalt=(double)profil[iTx].altitude;
  rxalt=(double)profil[inparam.count].altitude;
  txtalt=txalt+inparam.TxAntennaHeight;
  rxtalt=rxalt+inparam.RxAntennaHeight;

  // distance Tx-Rx and slope
  slope=(double)(rxalt+inparam.RxAntennaHeight-txtalt)/rxd;

  // Pass n°1:
  // Research for Tx clearance and Rx clearance points
  TxClTan=-1e10;
  RxClTan=-1e10;
  interm=547.7*547.7/(2.0e3*(double)inparam.Frequency);

  for (i=iTx+1;i<inparam.count;i++)
  {
   disti=(double)profil[i].distance;
```

```
   alti=(double)profil[i].altitude;
   TxTan=(alti-txtalt)/disti;
   RxTan=(alti-rxtalt)/(rxd-disti);
        if (TxClTan<TxTan)
     TxClTan=TxTan;
   if (RxClTan<RxTan)
     RxClTan=RxTan;
 }

 // Special case where TxClTan+RxClTan==0.0, LOS tangent obstacle
 if (TxClTan+RxClTan==0.0)
 {
   KnifeEdgeLoss=6.4;
   return(KnifeEdgeLoss);
 }
 else
 {
   // Distance of the hypothetical obstacle
   distsol=((rxtalt-txtalt)+RxClTan*rxd)/(TxClTan+RxClTan);
   // height above the LOS
   hsol=(rxd*rxd*RxClTan*TxClTan+rxd*(TxClTan-RxClTan)*(rxtalt-txtalt)-
     (rxtalt-txtalt)*(rxtalt-txtalt))/(rxd*(TxClTan+RxClTan));
   r1=sqrt(300.0/inparam.Frequency*distsol*(rxd-distsol)/rxd);
   // Clearance ratio
   nu=sqrt(2)*hsol/r1;
   KnifeEdgeLoss=6.4+20.0*log10(sqrt(nu*nu+1.0)+nu);
   if (KnifeEdgeLoss<0.0)
          KnifeEdgeLoss=0.0;
   return(KnifeEdgeLoss);
 }
}
```

Appendix 1



Recommendation ITU-R P.1546-6

Corrections

☑ Receiving/mobile antenna height and Cluttered transmitter

☐ Short urban / suburban paths (1546-3)

☑ Terrain clearance angle

☐ TCA 1546-2 (1)

☑ Tropospheric scattering

Climatic adjustment

☐ Delta N -40.0

Sea path

● Cold ○ Warm

Location / time variability

○ Standard deviation 5.5 dB

Locations 50 pc

Time 50 pc

Effective heights

☐ Use effective heights from transmitting station parameters

Terminal designations

☐ Swap designations (criteria b & c only)

☐ Reverse designations

☑ Clutter mapping (otherwise environment is rural or sea if terrain altitude is zero)

Clutter 0	Rural		m	Clutter 10	Rural		m
Clutter 1	Suburban	10	m	Clutter 11	Rural		m
Clutter 2	Urban	10	m	Clutter 12	Rural		m
Clutter 3	Urban	10	m	Clutter 13	Rural		m
Clutter 4	Urban	10	m	Clutter 14	Rural		m
Clutter 5	Rural		m	Clutter 15	Rural		m
Clutter 6	Sea		m	Clutter 16	Rural		m
Clutter 7	Urban	10	m	Clutter 17	Rural		m
Clutter 8	Rural		m	Clutter 18	Rural		m
Clutter 9	Rural		m	Clutter 19	Rural		m

(1) This option switches to 1546-2 TCA definition (clearance angle instead elevation angle)

TCA 1546-2: This option fixes error in 1546-3/4/5/6 (clearance angle replaced by elevation angle adds attenuation by diffraction even in case of LOS / free Fresnel zone). It computes clearance angle according 1546-2 release.

In ATDI, we consider that the lack of information from ITU-R 1546-3/4/5 reveals a real ITU SG-3 working group specification problem and can make these recommendations unworkable because they are too subject to interpretation.

When ITU-R1546-3 was issued, we maintained also the TCA rule defined in version 2, what seems to be a “Elsewhere if we accept the fact that there are free space links”.

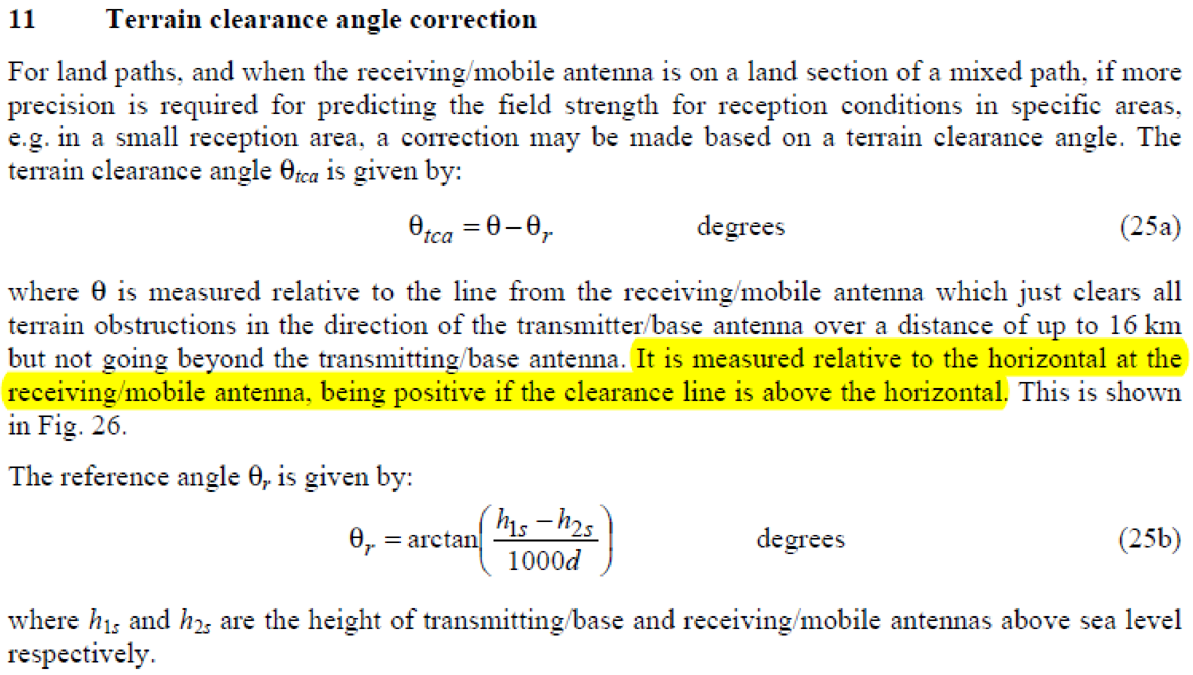
NOTE: Exceptions from the analysis: 229 MHz, 1kW ERP, Tx 25m AGL, Rx 10m AGL, T-DAB, DTM 100m (identical for both applications), no clutter.

Model ITU-R 1546-5 (We have created a compatible model to analyze the differences):

Rx Clearance angle is the angle between Tx-Rx and Rx-obstacle

Rx_TCA=angle between Rx-obstacle and 0°

ITU-R 1546-2 gives two angles: theta (angle between Rx-obstacle and 0°) and theta_r (reference angle) (please keep in mind the sentence in yellow – for theta calculation). Theta_tca=Theta-Theta_r:



11 Terrain clearance angle correction

For land paths, and when the receiving/mobile antenna is on a land section of a mixed path, if more precision is required for predicting the field strength for reception conditions in specific areas, e.g. in a small reception area, a correction may be made based on a terrain clearance angle. The terrain clearance angle θ_{tca} is given by:

$$\theta_{tca} = \theta - \theta_r \qquad \text{degrees} \qquad (25a)$$

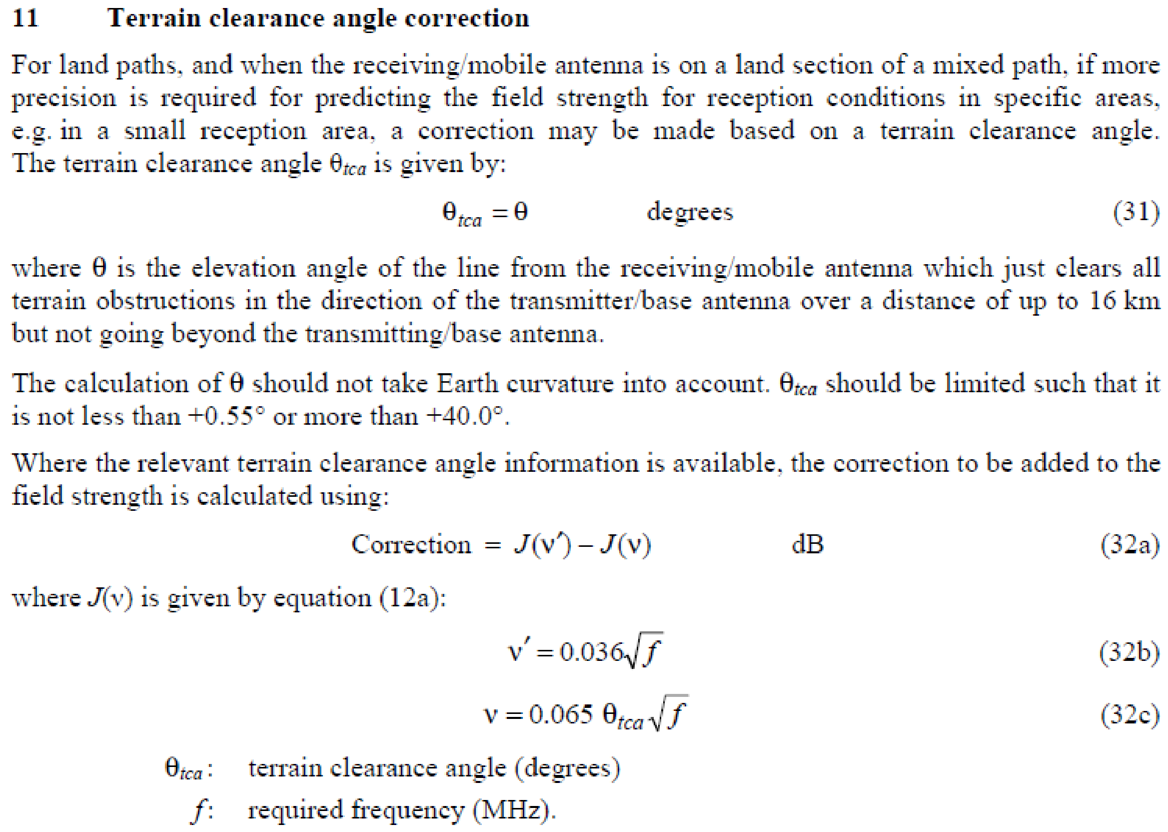
where θ is measured relative to the line from the receiving/mobile antenna which just clears all terrain obstructions in the direction of the transmitter/base antenna over a distance of up to 16 km but not going beyond the transmitting/base antenna. It is measured relative to the horizontal at the receiving/mobile antenna, being positive if the clearance line is above the horizontal. This is shown in Fig. 26.

The reference angle θ_r is given by:

$$\theta_r = \arctan\left(\frac{h_{1s} - h_{2s}}{1000d}\right) \qquad \text{degrees} \qquad (25b)$$

where h_{1s} and h_{2s} are the height of transmitting/base and receiving/mobile antennas above sea level respectively.

ITU-R 1546-3,4,5 give only one angle: theta_tca = theta:



11 Terrain clearance angle correction

For land paths, and when the receiving/mobile antenna is on a land section of a mixed path, if more precision is required for predicting the field strength for reception conditions in specific areas, e.g. in a small reception area, a correction may be made based on a terrain clearance angle. The terrain clearance angle θ_{tca} is given by:

$$\theta_{tca} = \theta \qquad \text{degrees} \qquad (31)$$

where θ is the elevation angle of the line from the receiving/mobile antenna which just clears all terrain obstructions in the direction of the transmitter/base antenna over a distance of up to 16 km but not going beyond the transmitting/base antenna.

The calculation of θ should not take Earth curvature into account. θ_{tca} should be limited such that it is not less than +0.55° or more than +40.0°.

Where the relevant terrain clearance angle information is available, the correction to be added to the field strength is calculated using:

$$\text{Correction} = J(\nu') - J(\nu) \qquad \text{dB} \qquad (32a)$$

where $J(\nu)$ is given by equation (12a):

$$\nu' = 0.036\sqrt{f} \qquad (32b)$$

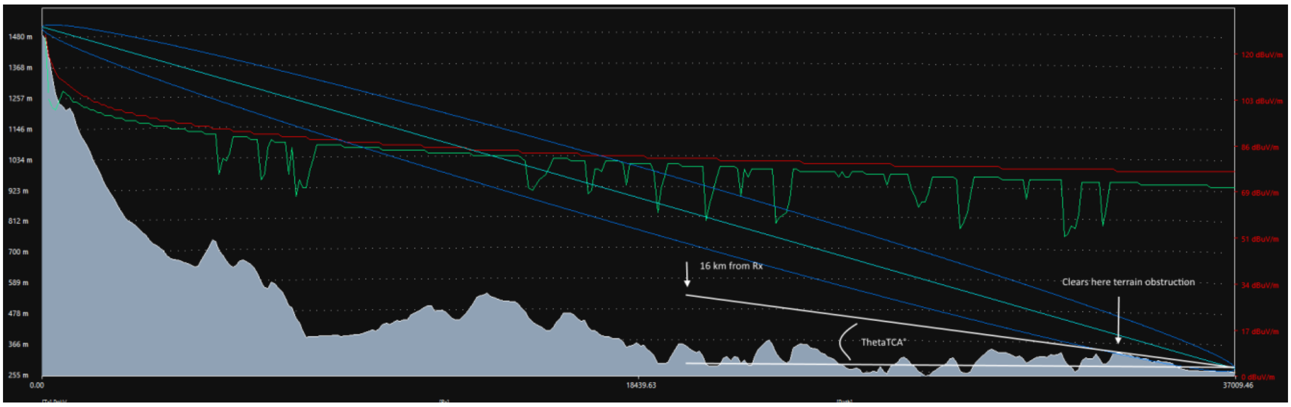
$$\nu = 0.065\ \theta_{tca}\sqrt{f} \qquad (32c)$$

θ_{tca}: terrain clearance angle (degrees)

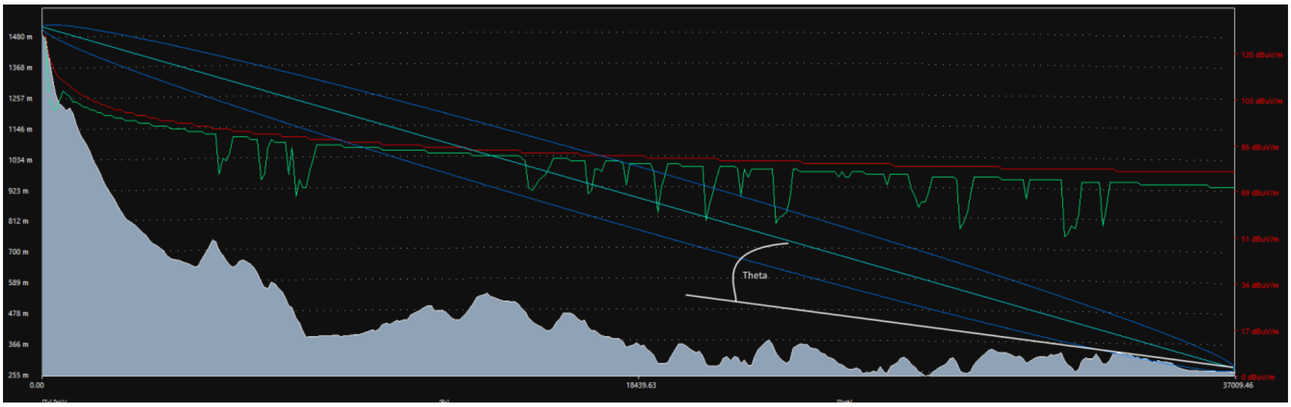
f: required frequency (MHz).

The definition of theta has changed in ITU-R 1546-3/4/5.

With 1546-5 implementation, n the case of LOS, we can find a positive clearance angle giving an additional attenuation on a complete LOS profile:



1546-2 implementation: clearance angle is negative, so no additional attenuation:



With 1546-5 implementation, if the Rx is lower than a given obstacle (<= 16 km) you will find always an attenuation even in the case of line-of-sight / Fresnel-ellipsoid-free profile.

Please refer to Final acts GE06 RRC06 for further information.