k&k engineering

Planning digital radio-relay networks

Radio-Relay Planning Tool

RLTool

for the design and planning of
digital radio-relay networks

Version 3.10 and higher

Functional description

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Introduction

RLTool is a Windows[1]-supported program for planning Radio-Relay Hops, Circuits and Networks. The program runs only on an MS Windows platform, either from MS Windows 98 or NT (or higher).

It includes

- element *PRO* for the determination of antenna heights, and for the analysis of path profiles, both with respect to path clearance and ground reflections
- element *PAC* for the prediction of hop and circuit performance and unavailability (including hardware unavailability) - and
- element *FRPLAN* for frequency planning and interference prediction.

The program version *RLToolProPac* consists of the two first elements, *RLToolNet* includes all three elements. (*RLToolProPac* can at any time be upgraded to *RLToolNet*)

The program is transparent with respect to radio-frequency ranges, capacities, transmission hierarchies (PDH or SDH), type of equipment and manufacturers. The network to be designed may include different capacities and radio frequency (r.f.) ranges. *RLTool* facilitates the use of passive repeaters; it provides for the planning and design of individual hops as well as complete networks. Cable lines can be included in order to predict the overall performance and unavailability of mixed-media circuits and connections.

The formulae used in the program are based on the relevant ITU recommendations (if such exist), they are described in detail in *K&K Engineering's Technical Paper KKE 5201/5*: *Performance and unavailability - Principles and formulae*. For a more profound understanding of the methods and formulae utilized in this program, reference should be made to *K&K Engineering's Monographs: Planning and engineering, Performance and availability* and *Frequency planning*[2].

The number of hops and circuits (or *links*), which can be handled by the program, as well as the number of hops included in a circuit, are only limited by the capacity of the PC used. The results are presented as tables, and for the profiles, as profile charts. For a better overview, the radio-relay network and its associated hops, as well as the various links established over this network, and the harmful interference paths are shown as geographical network layout charts. The tables and the charts are presented on the VDU as different windows, they can be printed on paper. All data, input data and results, are stored in a data file[3].

The man-machine interface is based on menus and sub menus. The input data are inserted via dialogue boxes or from data files respectively. Indata boxes not valid for particular indata combinations are greyed. The dimension for each indata is shown in the corresponding indata box. The input data for the equipment - radios, antennas, feeders - and/or the terrain profiles can also be loaded from databases. The equipment database can either be generated and edited from the program or in a database file, or ac-

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[1] Windows is a registered trademark of Microsoft Corporation

[2] More information about these booklets can be found in *K&K Engineering*'s Website

[3] The save of data and the printing of tables and charts are not available in the DEMO-version of *RLTool*.

quired from *K&K Engineering.* The input data from earlier planned networks, stored in data files, can be loaded at any later time.

A DEMO-version of *RLTool* can be loaded free of charge from *K&K Engineering's* Website `http://www.kk-engineering.a.se/download.html`. The demo version differs from the licensed version by not having the facilities of saving input data and results from the calculations. Neither can the results be printed out.

1 Program elements

1.1 General

The ***RLTool*** consists of:

- the execution file: `rltool.exe`,
- supported by a number of `*.dll` files, and
- the help file **.hlp*, for on-line program instructions, accessible by the ***Help*** command, the ***Help*** button, or the ***F1*** button.

The program CD includes four more files:

- `Example-1-RF_G826.rl`
- `Example-1-RF_G821.rl`
- `Example-G826.eqm`
- `Example-G821.eqm`

`Example-1-RF_G826.rl` and `Example-1-RF_G821.rl` are data files for test and training purpose. They include data for a small radio-relay network, consisting of two hops and one radio link (or circuit). The first one includes equipment data referring to G.826, the second one for G.821.

The files `Example-G826.eqm` and `Example-G821.eqm` are databases for the above examples.

The project related data, both input data as well as the results from the calculations can be saved in a file of the type `projet_name.rl` – the *project file*.

The program ***RLTool*** is available in two versions:

➢ ***RLToolProPac***, consisting of the 2 elements *PRO* and *PAC*

➢ ***RLToolNet,*** consisting of all 3 elements *PRO, PAC* and *FRPLAN*

The basis for the program is the *Network layout*. The chart shows the complete network - see below. Most of the input data insertion can be controlled from this chart.

1.2 Element PRO

The element *PRO* generates the profile charts for the individual hops. The charts show the profile contour, the 1st Fresnel zone and the type of surface crossed - *forests, meadows, build-up areas, lakes,* etc. The profile can be drawn for freely selectable *k* factors. The profile data can be inserted from a menu window or loaded from a file or from the topography database. (Contact *KK Engineering* in order to learn whether your *RLTool* version is supporting your topography database format.)

PRO analyses the terrain profiles: For given antenna heights both the clearance for the most critical obstacle and the risk for ground reflections are investigated. Alternatively, it calculates the antenna heights necessary for defined clearances and *k* factors with respect to the most critical obstacle. If both antenna heights are unknown, *PRO* proposes optimised antenna heights.

Concerning ground reflections, the type of surface - *reflective* or *not reflective* - is considered. In case of harmful ground reflections, *PRO* calculates the optimum antenna spacing to counteract the ground reflections, and evaluates the antenna spacing's efficiency with respect to the variation of the *k* factor. When analysing the profile, regard has been taken that the real slope of the terrain may differ from the slope obtained from maps or data banks.

1.3 Element PAC

The element *PAC* calculates the performance of individual radio hops and of complete links, considering the relevant ITU recommendations. Some of the parameters involved in the performance prediction are derived from ITU published databases. These databases are included in *RLTool*. Passive repeaters, both plane reflector types and antenna back-to-back repeater can be included in the network. (*A link consists of one or more tandem connected hops over which the connections between the outgoing and the incoming terminal are routed. It is identical with the radio circuit. The link can also include cable lines*.) The predicted performance and unavailability of the links are compared with the corresponding planning objectives. The default planning objectives are according to ITU Rec. G.826, but can also be according to ITU G.821 or own ones.

1.4 Element FRPLAN

The element *FRPLAN* governs the frequency planning and interference prediction of a complete network, inclusive the influence of passive repeaters on the interference. The hops included in the network may operate in different r.f. bands, utilizing different frequency-channel arrangements, and/or different RL equipment. The channel arrangement can be either ITU-R recommended channel plans or own. The interference signal levels at the input of each receiver are shown in a table. The interference paths can be displayed in the network chart.

1.5 Terrain data base

A decisive parameter for the calculation of multipath fading and distortion probability is the so-called terrain roughness. This parameter is defined as the *standard deviation* of the terrain altitude samples (in metre) within an 110x110 *sqkm* area around the centre point of the radio hop. ITU-R recommends to obtain the sample data from eg the Globe

gtopo30 data, which give the sample data with a resolution of 30”. The data files are available on Internet under address
http://edcdaac.usgs.gov/gtopo30/gtopo30.html

The *gtopo30* data cover the whole Globe, but are split up into 32 segments, each covering its part of the Globe. It is, thus, sufficient to download only that segments which covers the area of your interest. However, for your convenience, the *gtopo30* data are included in the program CD.

2 Program activities

2.1 General

This chapter is a review over the various calculations carried out by *RLTool*, emphasising the features included.

It should also be emphasised, that the calculation methods used are based on the relevant ITU-R recommendations, in case those exist. The main reference is Rec.P.530. The methods and formulae employed can be studied in detail in *K&K Engineering's Technical Paper KKE 5201/5*: *Performance and unavailability - Principles and formulae*.

2.2 Network layout

See figure in chapter 1.

The network layout is a geographical presentation of the network. It can be build-up, either

- manually by the operator, or
- semi-automatically via the site co-ordinates

In the first case, the operator places the sites on the network layout chart with the help of the mouse. This procedure is mainly intended for the first stage of planning a network, eg during the offering process, when the co-ordinates are not known yet, or if there is no time to obtain the co-ordinates. The network layout will not be due to scale.

In the second case, *RLTool* determines the position of the sites on the network layout chart by utilising global spherical co-ordinates (*International Spheroid*). The co-ordinates can be inserted individually for each site or á block via a site list. The sites have to be interconnected with help of the mouse. The scale for the chart can be either be determined by the operator, eg to 1:250 000, 1:100 000, etc, or *RLTool* selects the scale which gives the best utilization of the chart.

A manually designed network layout can, at any time, be transferred to the co-ordinate controlled layout by applying either individual or á block co-ordinate insertion.

The network chart generated by *RLTool* can be printed on any paper size.

2.3 Hop geometry

2.3.1 Co-ordinates, distance and bearing

For a network layout due to scale, and for the interference calculation it is necessary to know the exact position of the RL sites. The positions are to be defined by their co-ordinates. The co-ordinate system used is the global spherical co-ordinate system (*International Spheroid*).

Based on the co-ordinates, *RLTool* calculates the length of the radio hop, the beam path length[4] and the bearing.

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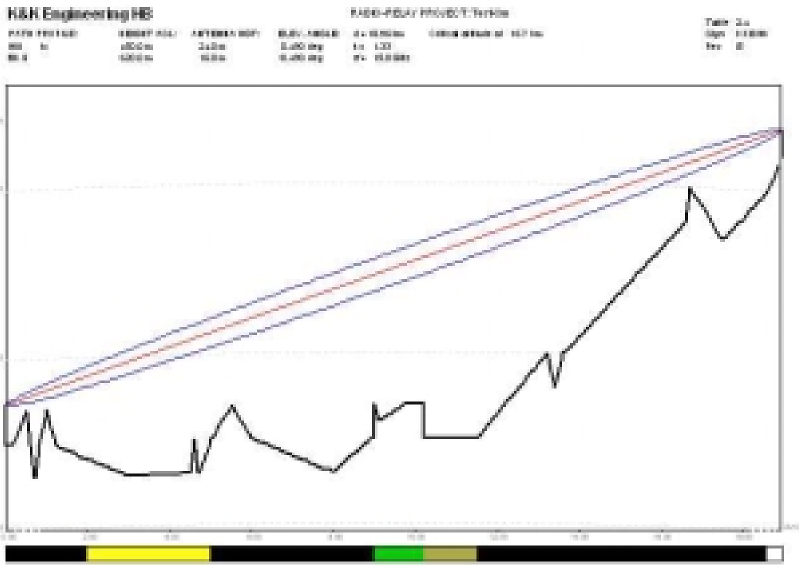
[4] For certain paths, particularly in mountainous regions, with one station down in the valley and the opposite station up on a high mountain top, the real distance between transmitting and receiving antenna – *the beam path length* – may differ substantially from the hop length obtained by the co-ordinates or read from a topographical map. *RLTool* uses the beam path length for the calculation of a number of propagation dependent parameters, eg the free-space attenuation etc.

2.3.2 Profile chart

RLTool presents the path profile as a chart - see the figure below. It shows

- the contour of the terrain crossed by the radio beam,
- superimposed objects, such as *single trees, forests, buildings* etc.,
- the 1st Fresnel zone for the selected antenna heights,[5]
- the surface type as a colour bar below the distance-axis, and
- if relevant, ground reflections.

As default, the profile chart is presented for a *k* factor = 1.33. It can, however, be shown for any other *k* factor.



The input data, samples for distances referred to site A and associated altitudes, can be given by the operator via an input data dialogue window, a data file, or be loaded from a map database. At the same time the surface type can be defined. (For the various surface types, reference should be made to § 2.3.5.1.) If no surface type is specified, *RLTool* sets it to *Other reflective area*.

Additionally to the map data, objects not shown on a map – *buildings, trees,* etc., can be inserted and overlaid on the profile.

To utilize the chart space for the profile by the best way, the program selects the scale for the x and the y-axis accordingly.

In case the path includes a passive repeater, two profile charts will be shown, one for each partial hop (or *leg*). Likewise, the below calculations (sections 2.3.3 to 2.3.5) will be performed for each leg.

2.3.3 Calculation of antenna heights

If only one site's antenna height is known (or assumed), *RLTool* calculates the opposite site's antenna height. To perform this calculation, the program

[5] In case of space-diversity operation, the Fresnel zone is shown between the two main antennas, ie the two upper antennas

- investigates the profile for the most critical point over a *k* factor range between 0.5 and ∞,
- considers 2 clearance criteria, normally
  - 100% for k = 1.33, and
  - 30% for k_{min}

Other figures for clearance percentage and *k* factor can be selected. For k_{min}, the value according to ITU-R Rec.P.530 can be obtained from an internal data bank.

If both antenna heights are unknown, the program can be directed to propose the two antenna heights: both heights will be of the same height, within a difference of 5 m. The clearance criteria will be the same as above.

All antenna heights, either given as input data or calculated ones, can be edited at any time.

Note:

> If this calculation – and the calculations according to the following sections 2.3.4 to 2.3.5.7 - have been made once, it will not be necessary to repeat these calculations during an ongoing optimisation of performance and availability and/or during the frequency planning. To cut down the run time of the computer, the operator can switch off this calculation facilities.

2.3.4 Calculation of path clearance

If both antennas heights are given as input data, and also when the heights have been calculated according to the above §, *RLTool* performs a clearance analysis, where the clearance of the 1st Fresnel is calculated versus a *k* factor range between 0.5 and infinite.

2.3.5 Ground reflection and its calculation

2.3.5.1 General

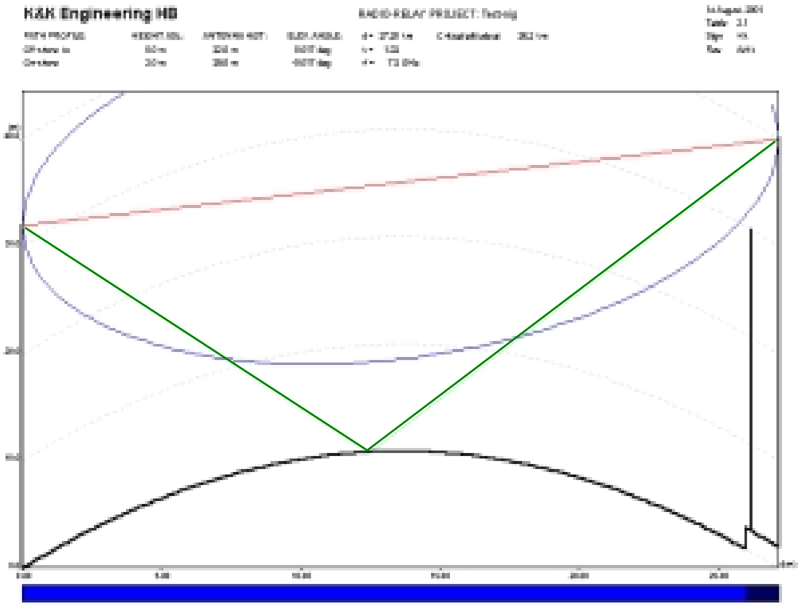
In order to investigate the profile with respect to ground reflections, *RLTool* splits the terrain up into a number of sections, each section identical with the interval between two profile samples. The program investigates section for section.

Ground reflections are only investigated for those sections of the hop, which surface is classified as *reflective*. The following reflective surfaces can be selected:

- water (sea, lakes rivers etc.)
- glacier, snow-covered area
- mash, bog or swamp
- meadows, acres or savannas
- sand gravel
- other reflective areas

No reflections are calculated for the below surface types, which are considered to be *non-reflective*:

- rocks
- forest
- bush or tree-covered ground
- build-up areas



Over-water path with one reflection point

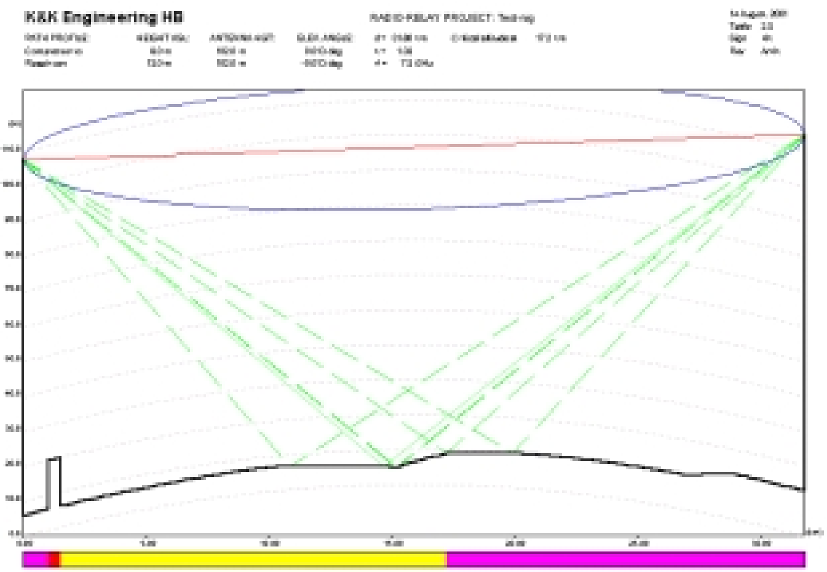
Identified ground reflections are indicated on the profile by a (green) line between the antennas and the reflection point as shown in the figure above.

2.3.5.2 Transformation of antenna heights

When calculating the position of a potential reflection point, the antenna heights are referred to the altitude of the reflection area. If the reflection area is a slope, eg a sloping meadow, *RLTool* transfers the antenna heights *above sea level (asl)* into antenna heights above the terrain section subject to investigation.

2.3.5.3 Location of a reflection point

If the reflective area is a horizontal one, eg an over-water path, only one reflection point is possible. If, however, the terrain consists of reflective surface lying on different alti-



More than one reflection point on over-land paths tudes or having different inclinations, more than one reflection point is possible.

***RLTool* feature:**

- *RLTool* calculates all possible reflection points on a profile.

The calculation is performed for a *k* factor range between 0.5 and infinite.

Tests:

- If the location of the reflection point lies outside the investigated terrain interval, no reflection is possible.
- The clearance is tested for the reflected ray. If any obstacle, man-made or natural, interrupts the path for the reflected ray, this will be indicated in the printout.

2.3.5.4 Difference in path length between direct and reflected ray

This calculation shows the severity of the reflection by calculating the phase difference between direct and reflected ray, again for the above range of *k* values. The difference is shown in terms of wavelength. Each time, the difference is an integer, the influence of the reflected ray on the wanted signal is a maximum, ie the receiver input level passes through a minimum.

This calculation is only carried out in case a reflected ray affects the receiver antenna.

2.3.5.5 Antenna discrimination

RLTool calculates the angle between the direct and the reflected ray at both the transmitting and receiving antenna. Knowing this angle, the antenna discrimination can be read from the antenna's radiation pattern.

Note:

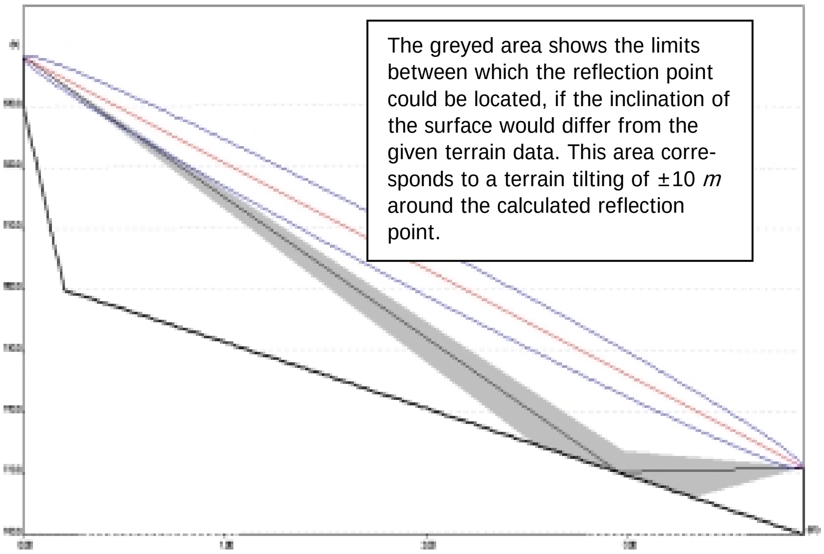
- The angle between the direct and the reflected ray shown on the profile chart is not correct due to the large-scale distortion (*km* for the distance and *m* for the height).

2.3.5.6 Optimum antenna spacing with space diversity protection

Space diversity can be applied to protect the hop against ground reflections. Optimum antenna spacing is achieved when the difference between direct and reflected ray corresponds to $n + 0.5$ wavelengths (n = 0, 1, 2…). However, the optimum spacing is a function of the *k* factor. As we cannot change the spacing with varying *k* factor, we have to decide for a particular spacing. Thus, the effectiveness changes with the *k* factor. This will also be shown in the printout.

2.3.5.7 Consideration of sloping terrain

Normally, topographical maps or database don't offer information about the correct course of the slope between two contour lines. The *PRO* element of *RLTool* assumes a linearly increase or decrease of the terrain's altitude between these contour lines. Thus, the location of a reflection point is only correct, if the terrain at that location has the calculated slope. This will hardly coincide with the real terrain. Consequently, there is a risk that this section of the terrain may cause harmful reflections, also if the reflection analysis - which is based on a continuously varying slope - says: No reflection point.



***RLTool* feature:**

- To consider the above problem, the slope of the section is tilted ±10 *m* [6], and new calculations are carried out. If the result is still: No reflection point, one can be quite sure, that no reflections will be present. If the result is the opposite, the result is a reflection area, in which a reflection point may be located. It is not possible to calculate the exact location of a reflection point on sloping terrain, unless we know the sloping at that point, but we get an indication in which area we have to expect the risk for ground reflected waves.

2.4 Hop attenuation and receiver input level

2.4.1 Total hop attenuation during fading-free time

The following parameters are included in the calculation:

- free-space basic attenuation
- additional attenuation(s), which may be attenuations due to
  - obstacles
  - partial clearance
  - r.f. attenuators
  - periscope antenna
  - passive repeater in the near field (where the repeater's contribution is considered as an additional attenuation)
- attenuation due to atmospheric gases
- attenuation in the antenna feeder at the transmitting and receiving end
- attenuation in the RF-branching assembly of the radio-relay equipment
- antenna gain at the transmitting and receiving end
- gain in a passive repeater (If the passive repeater is operating in the far field, its contributing to the total hop attenuation is considered as a gain)

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[6] On many topographical maps of the scale 1:50 000 or 1:100 00, the equidistance between two contour lines is 20 *m*. The tilt of ±10 *m* corresponds thus to the difference in altitude between two contour lines.

2.4.2 Free-space basic attenuation

2.4.2.1 Hop distance

For almost all hops, the length of the radio path, ie the distance between the transmitter and receiver antenna, is practically the same as the geodetic distance, as read from the map or calculated with the help of the co-ordinates. On short, but steep paths, however, the difference between antenna-to-antenna distance – the *beam path length* - and geodetic distance can be significant. When eg, in a 500 *m* wide valley, the RL in the down station is connected to a repeater on the close-by mountain top, and the difference in height is 900 m, the beam path has a length of 1030 m, and not 500 m. This corresponds to a free-space attenuation, which is 6.3 dB higher than it would be for the geodetic distance.

RLTool **feature:**

- *RLTool* uses always the beam path length when calculating the free-space attenuation, taking the difference in altitude between the sites into consideration. This is also the length shown in the performance report.

2.4.2.2 Radio frequency

The free-space attenuation is calculated applying the centre frequency of the r.f. band utilized, irrespective of the frequency given as input data:

The radio path will always operate with two r.f., one for the go and one for the return direction. The difference between these r.f. is in the magnitude of 154 *MHz* (at 7.4 *GHz*) to 1120 *MHz* (at 19 *GHz*). This would correspond to a difference of ±0.08 *dB* … ±0.25 *dB* compared with the free-space attenuation calculated with the centre frequency. However, these deviations from the centre-frequency attenuation will be compensated by the antenna gain, which varies with about the same magnitude, but in opposite direction. Remaining differences are negligible.

Tests:

- If an r.f. lies outside the range of the ITU-R stated r.f. bands, *RLTool* will perform all calculations with the stated frequency. However, a warning message will be displayed.

2.4.3 Antenna feeder attenuation

RLTool offers 3 options to consider the antenna feeder attenuation:

- The correct length of the waveguide between RL equipment and antenna is known.
- No waveguide length is known for the moment. *RLTool* takes the antenna height above ground level *(agl)* as the waveguide length, extended with 10 *m* to consider a probable horizontal distance between RL room and antenna bearer.
- No antenna feeders are used at all, as it is for tower mounted RL equipment with integrated antenna.

If tower mounted RL equipment is separated from the antenna, and a short waveguide interconnects these two devices, eg an ultraflexible, twistable waveguide, this case has to be considered as correct waveguide length is known.

***RLTool* feature:**

- The typical waveguide attenuation in *dB/100m* can be obtained from an internal database or given by the operator.

2.4.4 Antenna gain

As for the free-space attenuation, the antenna gain used is that for the midband.

***RLTool* feature:**

- The typical antenna midband gain in *dBi* can be obtained from a database or given by the operator.

2.4.5 Loss in atmospheric gases

The upper frequency limit for the calculation is 350 *GHz.* For the following input data:

- average lowest ambient temperature during the worst month
- lowest air pressure during the worst month
- water vapour density

default values are preset, but the operator can edit them. They will be valid for the entire project.

No gas absorption loss will be considered for r.f. < 15 *GHz,* neither will it be shown in the print out.

2.4.6 Gain or loss in a passive repeater

RLTool handles both antenna-back-to-back repeaters and plane reflector type repeaters. When considering their attenuation and their interference contribution, they are treated as an integrated part of the radio path, which is defined as a connection between two active RL stations. (Passive repeater stations are integrated in the interference calculations.)

2.4.6.1 Antenna-back-to-back repeaters

This type of repeater is considered the following way:

The radio path is split into two "legs", one between site A and repeater, the second one between repeater and site B. Each leg having its own free-space attenuation. The antennas in the repeater contribute with their antenna gain to the compensation of the cumulated free-space attenuation.

2.4.6.2 Plane reflector type repeater in the far field

If the plane reflector operates in the far field of the closest antenna, its contribution to the total path attenuation is considered the same way as that for the antenna-back-to-back repeater. The plane reflector contributes with a gain.

2.4.6.3 Plane reflector type repeater in the near field

The above way of considering passive repeaters cannot be applied when the plane reflector operates in the near field of the nearest antenna. In this case, that site, which is closest to the repeater, is virtually moved to the repeater site, and the free-space attenuation is calculated for the longer leg. The shorter leg's attenuation and the reflector contribution are considered as an additional attenuation. No formulas are known to perform that calculation, only a diagram that represents measured data for such cases.

RLTool **feature:**

- The diagram is incorporated in *RLTool*, ie the program finds out the additional attenuation from the digitalized diagram.[7]

2.5 Effective radiated power (ERP)

The ERP in *dBm* is the power radiated from the transmitter antenna in the direction of transmission. It is the sum of the transmitter power increased by the antenna gain minus the loss in the feeder run (waveguide and waveguide components) minus losses in antenna branching attenuation, r.f. attenuators etc. The ERP is not directly a planning parameter, but it has to be reported to the frequency allocation agencies for their interference planning.

The calculated ERP will be shown in the Path Performance report.

2.6 Performance calculation

The performance calculation is always performed for both directions of transmission. This is considered in the performance report.

2.6.1 Multipath occurrence factor

2.6.1.1 Parameters

The following parameters are considered:

- r.f. (centre frequency) in *GHz*
- the beam path length in *km*
- the point refractivity gradient in the lowest 65 *m* of the atmosphere not exceeded for 1% of an average year. The figure can be obtained on a 1.5^o grid resolution in latitude and longitude from a database available from ITU-R. This database is incorporated in *RLTool*
- the area terrain roughness, defined as the standard deviation in *m* of the terrain heights (in *m*) within a 110 *km* x 110 *km* area with a 30” resolution. Terrain data are available from Internet, eg the Globe *gtopo30* data.
- the antenna altitudes, ie the antenna heights above seal level (*asl*) in *m*
- the hop inclination in *milliradians*, see the next section.

The parameters have to be set individually for each hop.

2.6.1.2 Hop inclination

The hop inclination is the angle between the radio beam and the horizontal. It describes the ability for the radio beam to pass through air layers without loosing energy by reflection at the boundaries between air layers. The higher the inclination, the less is the loss.

No input data are necessary, all necessary data for the calculation are already known.

[7] In the printout of the results, however, this additional attenuation is shown as *Repeater gain*, but with minus sign.

2.6.1.3 Point refractivity gradient and area terrain roughness

To obtain these parameters from the corresponding database, the geographical position of the hop concerned is necessary. If the network layout is based upon co-ordinates, *RLTool* calculates the hop's geographical position. If no co-ordinates are given, an approximate position of the network has to be given by the operator. In this case, the refractivity gradient and the area terrain roughness for this position will be valid for all hops.

2.6.2 Performance prediction considering multipath fading and related mechanisms

2.6.2.1 Parameters

The following parameters are considered:

- multipath occurrence factor as calculated above
- fading margin in *dB* according to section 2.6.2.2 below.

These parameters have to be known for each hop, *RLTool* will calculate them from other input data.

2.6.2.2 Fading margin

This parameter is based on the receiver's threshold level for the bit-error ratio *(BER)* concerned, ie based on an equipment parameter. The fading margin has to be considered for two different bit-error ratios:

- applying ITU Recommendation G.821[8]: *BER* = 10^{-3} and10^{-6}
- applying ITU Recommendation G.826: *BER* = BER_{SES} and *RBER*

***RLTool* feature:**

➢ The typical receiver threshold level in *dBm* can be obtained from the equipment database or given by the operator.

2.6.3 Performance prediction considering distortions caused by selective multipath fading and related mechanisms

2.6.3.1 Parameters

The following parameters are considered:

- multipath occurrence factor (from above)
- mean value of the width of the signature in *MHz*
- mean value of the signature (or notch) depth in *dB*
- reference delay in *ns* used when the signature has been obtained
- hop length in *km*

2.6.3.2 Signature and reference delay figures

These figures are equipment parameters. They have to be selected for the *BER* concerned – see kap.2.6.2.2

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[8] For the significance of G.821 and G.826 reference should be made to chapter 2.7.3

RLTool **feature:**

- The typical signature data and the co-ordinated reference delay can be obtained from the equipment database or given by the operator.

2.6.4 Unavailability caused by multipath fading and distortions

The practice to consider the exceeding of BER_{SES} or $BER = 10^{-3}$ due to the above mechanism as performance degradation is based on the assumption that the fading activities responsible for that excess lasts shorter than 10 consecutive seconds. However, measurements have shown, that this is not always true. During a certain percentage of time, *Y*, the exceeding of BER_{SES} or $BER = 10^{-3}$ lasts longer than 10 consecutive seconds and should, consequently, be treated as unavailability. However, ITU has so far not published any figures for the parameter *Y*. For the moment *Y* should be set to 0%.

RLTool **feature:**

- *RLTool* offers the facility to select a value for *Y* other than 0%. The program considers this percentage of the SES as unavailability and combines it with the unavailability figures due to rain and hardware faults to a total unavailability figure. The default value for *Y* is 0%.

2.6.5 Small-time-percentage prediction considering attenuation caused by precipitation

2.6.5.1 General

The following parameters are considered:

- radio frequency in *GHz* and its polarisation
- rain attenuation coefficient in *dB/km*
- hop length in *km*
- the hop length in *km* influenced by rain - the *effective* path length
- clock-minute *average annual* rainfall rate (or rainfall intensity) in *mm/h* exceeded for 0.01% of the time
- fading margin

The radio frequency is again the midband frequency. The hop length is the geodetic one. For the other parameters see below.

Rain attenuation will only be considered for r.f. > 7.1 *GHz.*

2.6.5.2 Clock-minute *average annual* rainfall intensity

This parameter can be obtained from meteorological data and inserted by the operator as input data. It can be set to be valid for the entire project or individually for each hop.

However, the rainfall intensity can also be calculated from WMO data with a 1.5^{o} grid resolution in latitude and longitude. The necessary databases are available from ITU-R. They are incorporated in *RLTool*. Again, the knowledge of the co-ordinates is the precondition for this calculation.

2.6.5.3 Rain attenuation coefficient

The program calculates this parameter. For that, two parameters, which are measured figures, have to be obtained from a table. The figures are frequency and polarisation dependent.

RLTool **feature:**

- The parameters necessary to determine the attenuation coefficient are included in *RLTool* as an internal database. *RLTool* picks up the correct figures with respect to r.f. and polarisation.

2.6.5.4 *Effective* hop length

This parameter considers that the dimension of a rain cell may be shorter than the length of a radio hop, and that a rain cell can cross a radio path in different directions. It considers also, that the rain cell dimension decreases with increasing rainfall intensity. However, ITU-R has set a limit of 100 *mm/h* for this consideration.

RLTool **feature:**

- If the rainfall rate during 0.01% of the average year exceeds 100 *mm/h, RLTool* limits it to 100 *mm/h*[9] (but only for the calculation of the effective hop length).

2.6.5.5 Calculation of the small-time percentage

For very low rainfall rates combined with large fading margins, the formula used cannot be solved. This is the case, if the relationship between rain attenuation and fading margin will be < 0.154024. But then, the risk for rain fading will be less than $8x10^{-7}$%, ie negligible.

RLTool **feature:**

- If the relationship between rain attenuation and fading margin is $\leq$ 0.154024, the program sets the small-time percentage for rain fading to 0.000001% or 10^{-8}.

2.6.5.6 Performance and unavailability

The excess of the receiver threshold level for the BER_{SES} or $BER = 10^{-3}$ respectively due to rain is considered as unavailability. The calculation acc. to § 2.6.5.5 above results in an unavailability figure. If, however, the calculation is carried out for a threshold level < BER_{SES} (< 10^{-3} resp), the excess percentage has no longer to be treated as unavailability, but as performance. As the performance is referred to the average worst month, the result from the calculation has to be transferred from an average year to a worst month value.

RLTool **feature:**

- *RLTool* takes care of the above transformation.

The practice to consider the exceeding of BER_{SES} or $BER = 10^{-3}$ as unavailability is based on the assumption that the rain intensity responsible for that excess lasts at least 10 consecutive seconds. However, measurements have shown, that this is not always true. Only during a certain percentage of time, *X,* the exceeding of BER_{SES} or $BER = 10^{-3}$ lasts at least 10 consecutive seconds. The remaining percentage should, consequently, be treated as performance degradation. However, ITU has so far not published any figures for that parameter *X*. For the moment *X* should be set to 100%.

RLTool **feature:**

- *RLTool* offers the facility to select a value for *X* other than 100%. The program considers the (100 – *X*) percentage of the SES as performance degradation and com-

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[9] In the printout of the results, the actual rainfall rate is shown.

bines it with the performance degradations due to multipath fading and distortion. The default value for *X* is 100%.

2.6.6 Calculation with passive repeaters

Passive repeaters divide the radio path into two legs, each crossing its type of terrain, normally with different lengths and different inclinations. This, of course, gives different propagation conditions for these two legs, both concerning fading, distortions and rain.

RLTool **feature:**

- *RLTool* considers the different propagation conditions on paths with passive repeaters.

2.6.7 Improvement of the performance by diversity reception

2.6.7.1 Frequency diversity

The prediction method used has the following limitation:

- The maximum separation considered between the two r.f. is 0.5 *GHz.* If the separation is larger, no further improvement is achieved.

This limitations is not included in the formulae, it has to be observed by the operator or the program.

RLTool **feature:**

- *RLTool* tests the above condition and limits the frequency separation to 0.5 *GHz.*

2.6.7.2 Space diversity

RLTool performs this calculation, provided that the relevant control commands are activated.

2.6.7.3 Improvement by combined frequency and space diversity

Two diversity configurations are possible:

- combined diversity with 2 Rx
- combined diversity with 4 Rx

RLTool **feature:**

- *RLTool* supports both configurations, incl the limitation for frequency diversity.

2.7 Overall performance and unavailability

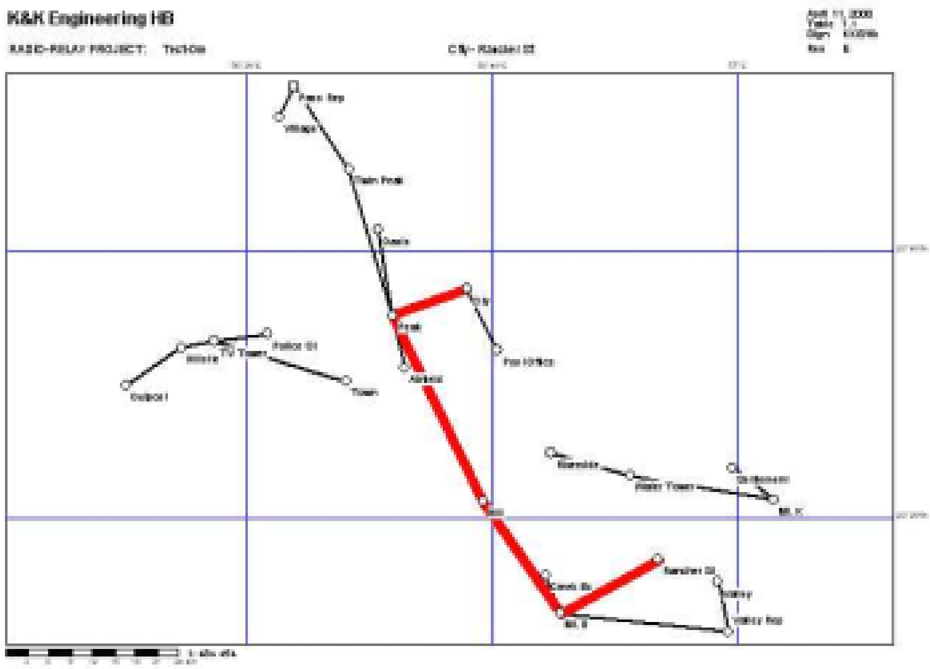
2.7.1 General

According to the ITU-R, the planning objectives are defined for the radio-relay link, ie the radio circuit, and not for the individual hop. In order to compare the predicted performance and unavailability with the planning objectives, the hops have to be combined to radio links.

The link consists of a number of tandem connected hops. The minimum number of hops in a link is 1 hop.

2.7.2 Radio-relay link layout

In principal, the link layout is a copy of the network layout. On that layout, the hops included in the link have to be set by clicking the hop (ie the interconnection line between two



sites) - see the above figure. The link shown below consists of 4 hops connecting Rancher St with City.

This operation has to be carried out for each link, ie each link has its own layout chart.

The program keeps count of that the link is build up of only tandem-connected hops. Also cable lines may be included in a link.

RLTool **feature:**

- *RLTool* tests that the selected link capacity does not exceed the capacity of the hop with the lowest capacity.

2.7.3 Planning objectives

2.7.3.1 ITU error performance and unavailability definitions

The operator can either select its own planning objectives or the ITU-R recommended ones.

Until 1999, the error performance was defined by ITU Recommendation G.821 and the unavailability by Rec. F.557. Due to unsatisfying correspondence between definition and measured error performance, the error performance was redefined in Rec. G.826, involving also a redefinition of the unavailability in Rec. G.827.

Since the end of 1999, methods are available to predict the error performance with reference to G.826.

However, as a great number of networks have been designed applying G.821 and F.557, operators may wish to utilize these recommendations for some longer time, eg when existing networks shall be extended.

RLTool **feature:**

- *RLTool* allows to run the performance and unavailability calculations with either own planning objectives, or to select ITU-R planning objectives according to G.821 and F.557, or G.826 and G.827.

2.7.3.2 ITU Rec. G.821 and F.557

Three performance-planning objectives are defined:

- the severely errored seconds - *SES*
- the degraded minutes - *DM*
- the residual bit-error ratio - *RBER*

They refer to the average worst month.

The planning objective for the unavailability refers to the average year.

The numerical values for these planning objectives are dependent on whether the link belongs to

- the high grade portion of the network
- the medium grade portion, or to
- the local grade portion.

As this affiliation can differ between different links, it has to be selected individually for each link.

The planning objectives are expressed in percentage of time, during which the planning objectives may be exceeded. Consequently, the predicted figures are also expressed in %.

2.7.3.3 ITU Rec. G.826 and G.827

Again three performance-planning objectives are defined:

- the severely errored seconds - *SES*
- the errored seconds - *ES*
- the background block errors - *BBE*

They, again, refer to the average worst month.

The planning objective for the unavailability refers to the average year.

The numerical values for these planning objectives are dependent on whether the link belongs to

- the international portion of the network
- the long-haul portion of the national network
- the short-haul portion of the national network, or to
- the access network.

As this affiliation can differ between different links, it has to be selected individually for each link.

The planning objectives are expressed as the ratio between the number of errored bits related to the number of bits conveyed during the observation period. Consequently, the predicted figures are also expressed as a ratio.

***RLTool* feature:**

- *RLTool* has all the numerical values for the ITU-R planning objectives in its internal database. By activating one of the alternatives stated above, the corresponding data will apply for the link concerned.

Only for the custom-defined planning objectives, the numerical figures have to be inserted by the operator.

2.7.4 Performance evaluation

RLTool combines the performance data from the individual hops to the overall performance of the circuit and processes the data in accordance with the selected ITU-R recommendations. In case the performance for the two directions of a hop are different, the worse performance of the two will be considered.

If a cable line is included in the circuit, its performance is also included in the overall performance.

The results of the performance evaluation are summarised in a link report, one for each link.

2.7.5 Unavailability evaluation

2.7.5.1 General

The unavailability is defined for the average year. Only three unavailability events are predictable:

- unavailability due to rain
- unavailability due to multipath propagation
- hardware faults.

However, all causes for unavailability have to be considered, as long as they are unintentional. To consider unpredictable events, such as human factor etc, a part of the unavailability objective should be reserved for these events.

***RLTool* feature:**

- *RLTool* allows to reserve a selectable margin of the unavailability objective for unpredictable events. The default figure is 20%.

2.7.5.2 Unavailability due to rain

The calculation is carried out acc. to section 2.6.5. The figures from the individual hops are added together and shown in the link report.

2.7.5.3 Unavailability due to multipath propagation

The calculation is carried out acc. to section 2.6.4. The figures from the individual hops are added together and shown in the link report.

2.7.5.4 Hardware unavailability

To predict this figure, the following data have to be known:

- the system configuration
- failure rate (failures per time unit) - the sum of the failure rates for the individual tandem connected units in the system
- mean-time-to-repair *(MTTR)* for the single structure, in the same time unit as the failure rate

and additionally for duplicated structures:

- failure rate (failures per time unit) for the (non-duplicated) splitting and switching device(s) proper
- mean-time-to-repair for the (non-duplicated) splitting and switching device(s) proper, in the same time unit as the failure rate

It should be noted, that the *MTTR* for the single structure differs from that for the splitting and switching devices.

The hardware unavailability includes also that from cable lines.

2.7.5.5 Comments

It should be observed, that for the hardware unavailability both the figures for the *go* and the *return* direction have to be added, while the rain and multipath unavailability counts only once, as these affect both directions simultaneously. This is taken care of by *RLTool*.

***RLTool* feature:**

- The equipment failure rates can be obtained from a database or given by the operator. For the *MTTR* figures, editable default values are stated.

2.8 Frequency planning and interference prediction

2.8.1 General

This facility is only available in *RLToolNet*.

The following data have to be known:

- co-ordinates of all radio sites
- equipment data, incl. interference sensibility
- antenna data, incl. radiation pattern
- all radio frequencies.

Existing sites or networks – not subject to the planning - operating in the planned frequency band(s) may interfere with the planned network. To consider their contributions the corresponding data have to be known.

***RLTool* feature:**

- The radio frequencies can be selected from an ITU-R recommended r.f. channel plan, or selected freely.
- Most of the ITU-R recommended r.f. channel plans are stored in the program-internal database.
- When an ITU-R recommended r.f. channel applies, the frequencies are selected by stating the channel No. *RLToolNet* will automatically set the correct frequencies for the hops' go and return direction, thus avoiding errors by mistyping.

Note:

The frequency planning and interference calculation can only be performed, when the site co-ordinates are given and activated.

2.8.2 Interference calculations

All frequencies within the same r.f. band are tested against each other. Hereby, the bandwidth of the disturbed receiver and the spectrum bandwidth of the disturbing transmitter are considered, as well as the modulation scheme (4FSK, 4PSK, 16QAM, 128QAM etc.) for both the disturbing and the disturbed signal, as these will influence the interference effect.

In the first calculation, free-space propagation is assumed for all interference paths. If necessary, additional attenuations due to obstacles in the interfering paths can be inserted before the next run.

If one site contains RL systems operating both in the lower (*L*) and in the upper (*U*) halfband of an r.f. band[10], the risk for interference between the antenna of the 1st system and the antenna of the 2nd system is very high. This is also valid if their antennas are placed on different towers, but close to each other. If, furthermore, one of the antennas is inside the nearfield[11] of the 2nd antenna, the antennas' REP is not longer valid. In this case, the worst condition is assumed, which is direct interference between the two radiators. If the resulting interference level is harmful, the antenna manufacturer should be consulted about the antenna discrimination for the particular application.

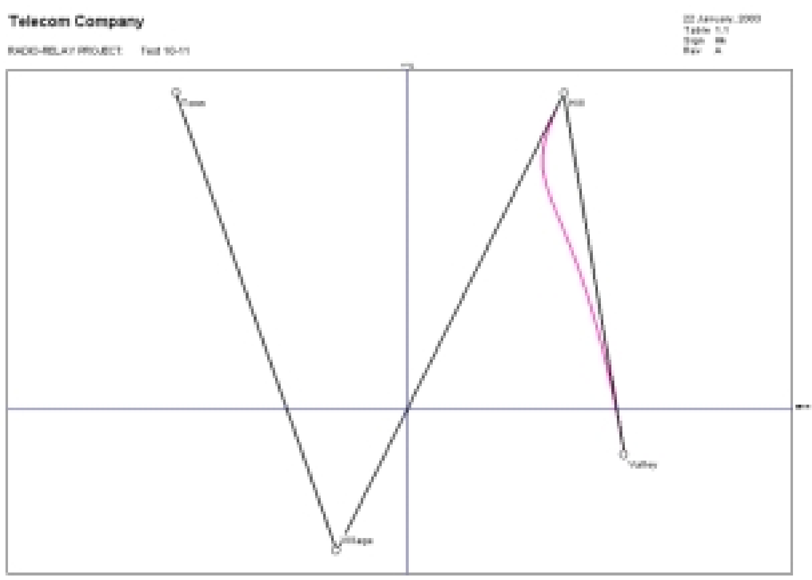
***RLTool* feature 1:**

RLToolNet facilitates the possibility to perform interference calculations also if one radio site operates both as an *L* and *U* station.

***RLTool* feature 2:**

If a radio path includes a passive repeater, interfering signals reaching a disturbed receiver via this repeater are included in the calculation.

It should be noted, that the calculation of the interfering signal level is based on the r.f. midband frequency.



[10] This type of operation is not in conformity with the relevant ITU-R recommendations and should, thus, be avoided.

[11] Concerning the definition of the antenna nearfield – and the nearfield/farfield crossover distances – reference should be made to *K&K Engineering's* Monograph: *Planning and engineering of radio-relay systems.*

For each receiver the individual interfering levels and the total interference loading is calculated.

2.8.3 Interference network chart

In addition to the *Frequency list* and the *Cumulative interference calculation* report, *RLToolNet* generates an *Interference network* chart. This chart shows all individual interference connections with a signal level higher than a selectable threshold.

Clicking an interference path leads one directly to the associated interference report.

The example shown in the above chart indicates a harmful interference between the paths Hill – Village and Hill – Valley.

2.9 ATPC functionality

If the selected RL equipment utilizes ATPC (Adaptive Transmitter Power Control), *RLTool* will include in its performance and interference prediction.

When ATPC is employed, *RLTool* calculates all path and performance parameters related to fading-free time with the equipment's operating maximum Tx output level decreased by the figure of the selected ATPC range, and the fading-related performance and unavailability with the operating maximum Tx output.

2.10 Bit stream disposition

Each hop in a network may belong to more than one link, where each link occupies one or more 2 Mbit/s channels. In order to facilitate the design and the extension of a network, the utilization of the hops' capacity is displayed: In the link layout chart, the number of 2 Mbit/s channels employed by the respective link is shown for each hop, together with the number of free 2 Mbit/s channels still available on each hop. A table summarises the total 2 Mbit/s disposition for the complete network.