Introduction

RFProp is a utility for calculating signal characteristics of radio propagation paths. It runs on Windows versions 3.x and higher, and includes algorithms for line-of-sight, free space, through-building and obstructed (diffracting) paths.

Range and path budget margin can be rapidly calculated and viewed while modifying the model parameters conveniently using the graphic mode main window.

Model parameters

Results

Menu Items:

- Main Window:
  - File
  - Recalculate
  - Params
  - Help

- Text Window:
  - File
  - Options

System Requirements

Licence Conditions

Contacting Central Research Laboratories

Limitations

Limitations

The propagation calculation algorithms are mainly limited to line-of-sight and diffracted paths. Other types of propagation that occur over long distances or at low radio frequencies may not be accounted for, such as: Ionospheric reflection and atmospheric refraction, troposcatter, ducting, E-layer superionisation, meteor trail scatter, ground wave, and surface waves. Under some conditions, a loss or gain factor can be estimated by other means for other propagation factors and incorporated by adding to the fading margin, building loss or antenna gain, or a modified range law may be used.

The program is aimed mainly at short range radio applications, such as in-building LAN and point-to-point links up to a few km where there is a direct line-of-sight or a simple diffraction profile, or a modified range law model, but it can also support calculations for satellite, aeronautical and space communications where the line-of-sight model can be applied.

Main Window

The main window contains a graphic display which illustrates the scenario of a radio transmitter and a receiver, separated by some distance, and with (optionally) an obstruction (or hill) in between. The parameters used in the model to calculate the range are arranged on this graphic display in relation to the transmitter, receiver and environment

The intention is to make it convenient to navigate around the various parameters when experimenting with the options that can be changed to arrive at a viable radio link, while viewing key range and signal margin on the same window.   More detailed results are given in a text window that can be opened when needed and used to list results to a file.

Model Parameters

All variable parameters are displayed on the main graphic screen and can be changed using floating edit boxes. Scientific notation can be used, i.e. 2.45E9

The calculation of results is not performed while parameters are being edited, since a partly completed number can be invalid or produce erroneous results. When you have completed editing a changed parameter, press the Enter key to update the results, or click with left or right mouse button on the graphic part of the program's display window.

A control button selects whether diffraction parameters are included in the graphic window's results, and another button selects which type of rounded hill excess loss is allowed for (rough or smooth) in the diffraction calculation.

The values entered will be saved (in RFProp.ini in your Windows directory) and re-loaded when you next run the program.

Nominal Range

This is the range that is *required* between the transmitter and receiver. It also plays a part in defining the effects of diffraction when there is an obstacle between the transmitter and receiver. This doesn't mean that the radio link will actually work at this range- to determine the viability of the link, you need to look at the path budget margin (abbreviated to just "margin"). This is displayed at the bottom of the main window together with the maximum feasible range. If the margin is, say, 10dB, that means at the specified nominal range, you have 10dB signal strength over the minimum needed for a feasible link taking into account all the model parameters.

The nominal range is measured between the transmitter location and receiver location points as projected on to the baseline, for the purpose of diffraction calculations. It is assumed that the slant range is the same as the projection on the baseline. If your receive-transmit antenna height difference becomes a significant part of the range, you need to redefine the baseline. For example, for a vertical path (such as up to a satellite, or between floors in a building)
points on or near each antenna.

Fading margin

Fading occurs when wave interference occurs at the receiver as a result of transmitted waves having travelled via different paths (e.g. by reflection from walls), or when a variable loss is involved (e.g. rainfall, atmospheric refraction, ionospheric attenuation, vehicles or persons blocking the line of sight). A great deal of literature exists to describe the effects of fading in various circumstances. A simple method for accounting for fading is to set a marginal loss figure which represents a maximum bound for the fading losses, which will guarantee a radio link except for a small fraction of down time representing the low-probability statistical tail of the fading distribution. The fading margin is typically selected on a statistical basis, with various types of distribution function applicable dependent on the environment in question. The statistics depend strongly on whether there is a strong direct, unobstructed signal from the transmitter, or whether the received signal tends to arrive more by scattering of multiple reflections of the transmitted signal. These two cases illustrate extremes of the different types of signal statistics. There are also statistical models treating the in-between cases, where a variable mixture of direct and reflected signals are received. There are also empirical studies that give signal statistics in measured environments.

As a matter of convenience, any other fixed losses (e.g. antenna pointing errors, atmospheric attenuation over a fixed path) can be added in to the fading margin parameter.

In cellular radio systems, fading loss can vary rapidly over up to 20 or 30 dB due to Rayleigh-statistics fading, caused by multipath propagation, where multiple received signals arrive via different routes from the transmitter, with different phases and amplitudes.

Carrier frequency

The frequency of the radio wave being transmitted = 2.99792458E8/wavelength.

Temperature

The temperature used for calculating the thermal noise generated at the receiver. Expressed in degrees Kelvin, which is approximately 273 degrees higher than the equivalent in Celsius/Centigrade. A figure of 290 or 300 degrees K is often used.

Propagation Range law

Radio waves travel in free space according to an inverse square law, i.e. the power per unit area in the direction of travel is inversely proportional to the distance from the transmitter (since the energy is being distributed on part of an expanding sphere, and the area of a sphere is proportional to the square of the radius). An approximation to the extra distributed losses in certain urban/indoor environments can be made by changing the propagation range law- on a largely empirical basis. This modified law may be described by convention as "R-4", denoting that the power per unit area is taken as being inversely proportional to the fourth power of the distance.
An R-4 law is sometimes used to describe the propagation in urban cellular radio environments.

In the VHF frequency range, ground reflection is often at a high level and not diminished sufficiently by narrow antenna beamwidth obtainable at higher frequencies, and this modifies the free space range equation such that the power decreases with an inverse fourth power law.

Building Loss

This is a loss factor included in the attenuation factors taken into account in the signal path. In some models, the propagation of signals through buildings are assessed by estimating the loss caused by each obstruction (wall) and adding them up to form the building loss figure. Another model estimates the signal inside a building from, for example, radio paging transmissions, by specifying a building penetration loss to account for the absorption and reflection of radio waves as they pass through the walls of a building. Naturally, these losses depend on the construction of the building and the radio frequency. For line of sight unobstructed operation, the building loss factor can be set to zero.

See also: Further Information

Tx antenna gain

The gain of the transmitter's antenna in dBi (relative to an isotropic antenna).

Typical antenna gains:

Isotropic (theoretical concept, radiates equally in all directions): 0 dBi

Small lossless dipole: 1.76 dBi
Half wave dipole: 2.1 dBi
Microwave horn, 3 by 1.5 wavelengths across aperture: 16.5 dBi
Parabolic dish, 1 metre diameter, efficiency 55%, at 12 GHz: 34 dBi

Tx Power

The RF power transmitted by the antenna (after transmitter to antenna cable losses have been allowed for).

Rx antenna gain

The gain of the receiver's antenna in dBi (relative to an isotropic antenna).

Rx noise figure

The amount by which the receiver noise (equivalent noise referred to the antenna input) exceeds the noise that would be generated by thermal noise in an otherwise noise-free receiver. This can range from fractions of a dB for microwave low noise downconverters through typically 2 to 10 dB for most receivers, and up to 30 or 40dB for test instruments such as a spectrum analyser.

Rx required detector S/N

This is the signal to noise ratio required for a specified performance level (e.g. bit error rate), which depends on many factors such as the type of modulation, whether the detector is coherent or not, fading and multipath, etc.

Signal bandwidth

The effective bandwidth for the overall baseband signal transmission path, normally dominated by the receiver filter bandwidth. In spread spectrum systems, this is the baseband bandwidth after despreading, not the spread signal bandwidth, as the despreading process allows most of the noise in the spread bandwidth to be filtered out before detection.

Diffraction parameters:

Tx antenna height
Rx antenna height
Obstruction height

These heights, relative to a baseline, determine the relative position of the obstruction with respect to the line of sight between the transmitter and receiver antennas, and hence allow diffraction losses to be calculated.

Tx to obstruction distance

This distance is measured between the transmitter location and obstruction location points as projected on to the baseline.

Obstruction to Rx distance

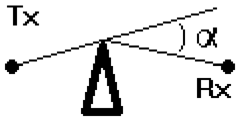
This distance is measured between the obstruction location and receiver location points as projected on to the baseline.

When you enter a nominal range, the Tx and Rx to obstruction distances are automatically scaled to add up to the nominal range. If you change one of the distances to the obstruction, the range will be modified assuming that the other distance to the obstruction is unchanged, and the nominal range must add up to the two distances to the obstruction.

The knife-edge diffraction loss is calculated from the distances entered as described above. The physics of this model assumes that the obstruction is an infinitely wide and deep sharp wedge, perpendicular to the propagation path. An additional "excess loss" is calculated to allow for rounded obstructions; this excess loss also depends on whether the rounded obstruction is "smooth" or "rough" (an example of a rough versus a smooth case is a forested hill as opposed to a grassy hill).

Caution: If the obstruction height is set very low (negative) or high compared to the line of sight, the algorithm used to calculate diffraction will run slowly (the hourglass cursor may appear for some time). To assess paths without diffraction, simply read the results listed for no diffraction rather than setting a negative obstruction height.

A parameter sometimes quoted in connection with diffraction is the diffraction angle, which is calculated and listed on the text output window:



Example 1

From "Radio wave propagation and antennas", J. Griffiths, Prentice-Hall, 1987, p. 129:

Tx to obstruction: 22 km
Rx to obstruction: 2 km
Diffraction angle 0.033 radians (1.9 degrees)
Rough rounded hill with radius 3km

Adjusting the hill height results in the angle 1.89 degrees when the height is 62.5m. RFProp calculates the knife-edge diffraction loss to be 23 dB and the excess diffraction loss to be 38 dB (within 0.01 dB), which agrees with L(ke)=23 dB and L(ex)=38 dB as stated in the book.

Diffraction loss will be 6dB when the obstruction is directly in-line. The excess loss for rounded obstructions is zero when the obstruction is below the line of sight.

Example 2

Another example, also from "Radio wave propagation and antennas":

Find the minimum signal power from a direct broadcast TV satellite with minimum CNR(R) 12dB, receiver noise figure 5dB, bandwidth 27MHz, and temperature 290K.

Entering the CNR(R) value as the Rx required detector S/N, plus the noise figure, bandwidth and temperature figures, the receiver power level is listed on the text output window as -82.66 dBm, i.e. -112.66 dBW, which agrees with the book. The rest of the parameters do not affect the required receiver power level, but determine the actual received power, which after subtracting the required receiver power gives the margin.

Further Information (Building Loss)

Building penetration losses are measured across the interior to exterior wall, and Skomal & Smith (1) have presented detailed charts for steel multistory, concrete masonry low-rise and residential structures. The table below represents a brief summary of that data:

Frequency (MHz)	Structural Attenuation (dB)					
	Multi-storey		Single storey		Residential	
	H	E	H	E	H	E
0.1	32	>80	10	>40	1	33
1	41	68	10	26	0	16
3	38	52	12	19	1	12
10	31	32	18	18	3	10
30	20	20	16	16	4	9
70	17	17	10	10	3	8
100	16	16	8	8	3	6
150	16	16	5	5	3	5
400	17	17	4	4	6	6

The sample standard deviations in these surveys vary, but are generally less than or equal to 10.3dB.

A worst-case loss can be estimated, not to exceed Ls = L + phi*sd,
where phi*sd is the location variability,
sd is the sample standard deviation in dB,
based on the probability P that building loss L exceeds the value Ls given by equation 4-8 in Skomal & Smith:

P(L>Ls) = 0.5 (1-erf(phi/Sqrt(2)))

Location variability for sd=10dB:

phi*sd (dB)	P
0	0.5 i.e. 50% likely to exceed the average loss
8.4	0.2
10.0	0.159
12.8	0.1
16.5	0.05
20.5	0.02
23.3	0.01 i.e. 1% likely to exceed average + 23.3 dB loss
25.8	0.005
28.8	0.002
30.9	0.001

Davies, Simpson & McGeehan (2) measured internal wall & floor losses at 1.7GHz inside the Queens Building at Bristol University, a prestressed concrete and brick 1950's building, finding a vertical floor loss of 27dB between corridors, and of 13dB between rooms.

Cox et. al. (3) measured RF signals in and around suburban houses, finding range laws between 3 and 6.2, typically 4.5 (attributed to ground effects). Building penetration losses were between 0.7 and 12.1 dB to first and second floors, and 0 to 21.3 dB into basements.

In the VHF frequency range, ground reflection is often at a high level and not diminished sufficiently by narrow antenna beamwidth obtainable at higher frequencies, and this modifies the free space range equation such that the power decreases with an inverse fourth power law.

Walker (4) at 850MHz found urban building penetration losses in Chicago to average 18 dB, while suburban buildings averaged 13.1dB. Windows reduced average penetration loss by 6 dB. However, the copper-sputtered windows of the Chrysler building blocked all measurable signals. Open areas had 3dB lower penetration loss than hallways or enclosed areas.

At 60GHz, P. W. Huish et. al. (5) quote 3 to 7dB loss for a double glazed window, 4dB for 1cm plasterboard, 13 dB for 1.9 cm chipboard, and more than 40dB for 10cm autoclaved aerated concrete blocks.

Chia et. al (6) quote 12dB for 2cm of wood, 2dB for 1cm plasterboard, and 6dB for 3mm glass.

References

(1) E. N. Skomal, A. A. Smith, Jr., Measuring the Radio Frequency Environment, Van Nostrand Reinhold 1985.

(2) R. Davies, A. Simpson, J. P. McGeehan, Preliminary Wireless Propagation results at 1.7 GHz using a half wave dipole and a leaky feeder as the transmitting antenna, 1993.

(3) 800-MHz Attenuation measured in and around suburban houses, D. C. Cox, R. R. Murray, and A. W. Norris, AT&T Bell Labs Tech. J., V. 63, No. 6, July-Aug 1984.

(4) E. H. Walker, Penetration of Radio Signals into Buildings in the Cellular Radio Environment, Bell System Tech. J., V. 62, No. 9, Nov. 1983.

(5) P. W. Huish & G. Pugliese, A 60 GHz Radio System for Propagation Studies in Buildings, 3rd int. conf., on antennas & propagation.

(6) S.T.S. Chia, D.R.Greenwood, D. C. Rickard, C. R. Shepherd, R. Steele, Propagation studies for a point-to-point 60GHz microcellular system for urban environments.

File (main window)

There are two options here; Text Output, which opens a text output window showing a list of the parameters and results of the calculation and allows an Ascii text file to be saved, and Exit, which shuts down the program.

Recalculate

This causes the results to be recalculated using the current values of the parameters. If there are any parameters that were in the process of being changed in their edit boxes but haven't been entered by using the return key, they will be restored to the previous values.

Results

The maximum range, and margin available at the specified nominal range, are displayed on the main graphical window.

More detailed results are available in the text output window. First, the parameters entered for the calculation are listed. This is provided so that the text can be saved for documentation and future reference.

Next, the diffraction parameters are listed. The auxiliary parameter v is used in the evaluation of Fresnel integrals to calculate the knife-edge diffraction. The calculations will be accurate to around 0.015% (in terms of power loss) for values of v up to +/-80. The knife-edge diffraction loss is always 6.0dB at v=0. The loss increases rapidly as v increases negatively. The loss decreases as v increases positively, and actually shows an interference phenomenon due to the reflected wave, with the signal peaking by 1dB at v=1, then oscillating asymptotically above and below the ideal free space loss (i.e. zero) as v increases.

The knife edge parameters d1 and d2 are not simply the distances from the antennas to the obstruction. The diffraction theory is based on the shape of the triangle joining the two antennas and the obstruction. The distances d1 and d2 are the distances between the antennas and the perpendicular from the obstruction to the line joining the two antennas (line of sight) measured on the line of sight. The knife edge parameter h is the height of the perpendicular distance from the obstruction to the line of sight.

The Fresnel zone clearance is a distance between the obstruction and the line of sight joining the two antennas. The first Fresnel zone is the minimum distance at which the reflected signal path is a half wavelength longer than the direct path. Further Fresnel zones occur at integral multiples of a half wavelength path difference. The first Fresnel zone is the one listed here. Minimum clearance specifications to guarantee an "unobstructed" path can be set typically at around 0.7 times the first Fresnel zone clearance. Note that this distance is relative to the line of sight, not the baseline.

A list in tabular form shows the knife edge diffraction loss calculation, and the angle between the transmitted ray to the obstruction and the diffracted ray from the obstruction to the receiver (positive angle means the path is obstructed, negative angle means the obstruction is not blocking the line of sight between the transmitter and receiver). It also shows the correction factors, or excess losses, that allow the knife-edge theory to be adjusted for a more realistic rounded hill or obstruction. Correction factors are given for "rough" and "smooth" hills or obstructions. A "rough hill" bends more signal through a given diffraction angle than a "smooth hill". The correction factors are attributed to K. Hacking, in "Propagation over rounded hills", BBC Research Report RA-21, 1968. According to J. D. Parsons, in "Land Mobile Radio Systems", Peter Peregrinus (Chapter 2), although strictly valid for horizontal polarization only, measurements have shown that at VHF and UHF Hacking's corrections can be applied to vertical polarisation with reasonable accuracy.

General propagation results are listed next. The wavelength is given, which is calculated from the radio frequency as: wavelength (m) = 2.99792458E8/frequency (Hz).

The thermal noise at the Rx i/p is the noise caused by thermal motion of electrons and is calculated from kTB, where k is Boltzmann's constant, T is the temperature in degrees Kelvin and B is the bandwidth.

The thermal noise & Rx noise result includes the effect of receiver noise figure on the effective receiver input noise, which is to increase the real noise above that expected from thermal considerations alone.

The Rx G/T figure of merit is often used in satellite and microwave link work, indicating the performance of the receiver antenna and low noise front end combination. The T in this case is the noise temperature of the receiver = 290 * (Noise figure - 1), the noise figure in this formula being expressed as a ratio rather than dB.

The path loss is the component of signal attenuation between the transmitter and receiver that is attributed to the distance between the antennas.

The propagation results for the limiting case of the minimum receivable signal that will give the required S/N ratio are listed next. These results depend only on the receiver characteristics, namely required signal/noise, temperature, noise figure, and antenna gain.

Receiver power (Min.) is the minimum power required at the receiver input. This is the signal level that must be available from the transmitted signal when fading corresponds to the set margin, and all other transmitter and propagation path characteristics are accounted for.

Rx power density (Min.) is the radio wave power density per unit area at minimum signal condition.

Rx field strength (Min.) is the radio wave electric field strength in Volts/m at minimum signal condition. This parameter is often used in a broadcasting context.

Rx pwr / noise density (Min) in dB-Hz is the ratio of minimum carrier power (W) to noise density (W/Hz), expressed in dB form. This parameter is used in satellite and space telemetry and other digital radio applications.

A table of propagation results is listed next for the signal strength and margin calculated at the specified nominal range, and also listing the maximum range obtained using the minimum receivable signal strength. The table lists cases for:
(1) no diffraction loss being included,
(2) diffraction loss being included for a smooth hill,
(3) diffraction loss being included for a rough hill.
The table lists columns for the height of the obstruction, which is the single value entered as a parameter, power density and field strength at the nominal range, maximum range obtainable at minimum receivable power, and the margin of received signal power over minimum required at the specified nominal range.

If the margin is, say, 10dB, that means at the specified nominal range, you have 10dB signal strength over the minimum needed for a feasible link taking into account all the model parameters. A margin is normally required to account for potential variations in estimated loss factors outside known limits, unknowns that might not be accounted for, ageing of equipment increasing cable losses, antenna losses etc., or changes in the environment (e.g. in an urban radio environment, there could be new building construction in the radio path).

For diffracted paths, the maximum range will be an under-estimate if the nominal range is less than the maximum range, because the diffraction angle will be reduced at the maximum range. Similarly if the nominal range is set higher than the maximum range, the maximum range will be an over-estimate. The diffraction loss is calculated only for the specified nominal range. Consequently, if you vary the nominal range or the transmitter/receiver to obstruction spacing, the maximum range will be seen to change. For a better estimate of maximum range you can adjust the nominal range and spacings until the nominal range is close to the maximum range. In normal radio systems however, it is not recommended to rely on operation at maximum range because, due to normal variations in environment and parameters, the signal may easily drop below that required for reliable communication. The preferred approach is to decide on a comfortable signal margin and ensure that it is obtained at the selected nominal range.

Params

Selecting Params/LOS allows you to change the Line of Sight parameters. This is simply an alternative method for entering the data instead of using the edit boxes on the main window.

Selecting Params/Diffraction selects the single diffraction model and allows you to change the single diffraction model parameters.

There is no support in this program for multiple diffraction models; please contact CRL if you have a need for such modelling.

Help

"Help/Contents" activates the Windows Help File with the Contents page displayed.

"Help/About" brings up an information box with version and licensing information, an email address for bug reports, and the amount of free virtual memory.

File (text window)

The menu options here are Export Ascii and Close. "Close" will close the text window; the main RFProp window will remain open and the program will continue to run. You can open up the text window again at any time.

The "Export Ascii" option prompts you for the name of a file, in which you can save the contents of the text output window.

Options

Selecting "Options/General" will bring up a Windows dialog box which allows you to change the column width for tabulated output. In addition to Cancel and OK buttons, there is a Recalculate button to allow you to view the effect of changing column widths on the text window without closing the dialog box.

System Requirements

The target platforms are Windows 3.1 or higher, Windows for Workgroups 3.1 or higher, and Windows 95. The program should also run on Windows NT although very limited testing has been done.

The program has been developed and tested on Windows for Workgroups 3.11.

Licence Conditions

LICENCE CONDITIONS AND AGREEMENT

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