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Technical Report

PowerLine Telecommunications (PLT); Hidden Node review and statistical analysis

Reference
DTR/PLT-00011

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee PowerLine Telecommunications (PLT).

Introduction

In order to study and compare characteristics of the LVDN network in different countries a STF (Special Task Force) was set-up. The present document is one of the four TRs which present the result of the work of the STF (TR 102 258 [5], TR 102 259 [6] and TR 102 270 [3]).

The present document takes into account matters like earthing variations, country variations, operator differences, phasing and distribution topologies, domestic, industrial housing types along with local network loading. The measurement set-up, the measurements as such, the used software the site reports and parts of the analysis are common for all the TRs and is collected in the TR 103 270 [3].

1 Scope

The present document shows results from Transverse Transfer Loss (TTL) measurements performed in Germany, The Netherlands and Spain. It investigates the distribution of the TTL-values in respect to the carrier-frequency, to the relative location of the sockets, to the phase conditions between the sockets and to the national LVDN-particularities (wiring technology, earthing etc).

These data are basic for the development of realistic hidden node models required for the development and/or the test of MAC-protocols as well as for the assessment of the performance in presence of hidden nodes.

2 References

For the purposes of this Technical Report (TR) the following references apply:

[1] ITU-T Recommendation G.117: "Transmission aspects of unbalance about earth".

[2] IEEE Transactions on Electromagnetic Compatibility (Vol 41, No. 1, pp 3-14): "A probe for the measurement of electrical unbalance of networks and devices", Ian P. Macfarlane.

[3] ETSI TR 102 270: "PowerLine Telecommunication (PLT); Basic LVDN measurement data".

[4] ETSI TR 102 175: "PowerLine Telecommunications (PLT); Channel characterization and measurement methods".

[5] ETSI TR 102 258: "PowerLine Telecommunications (PLT); LCL review and statistical analysis".

[6] ETSI TR 102 259: "PowerLine Telecommunications (PLT); EMI review and statistical analysis".

3 Abbreviations and symbols

3.1 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BALUN	BALanced to UNbalanced transformer
EDP	Electronic Data Processing
LCL	Longitudinal Conversion Loss
LVDN	Low Voltage Distribution Network
OFDM	Orthogonal Frequency Division Multiplexing
STF	Special Task Force
ToR	Terms of Reference (see note)
TTL	Transverse Transfer Loss

NOTE: For Specialist Task Force 222 (MB).

3.2 Symbols

For the purposes of the present document, the following symbols apply:

a	frequency space for which noise or TTL is below a specified value
k	specified threshold, frequencies are usable when the TTL or noise are below k

4 Measurement method and measurement locations

For the analysis of hidden node problems, the signal strengths and the noise levels of different connection points to the LVDN must be known. The noise levels were measured symmetrically with the LCL-measurement adapter according to Macfarlane [2]. The differential mode design impedance of the adapter is $Z = 100\ \Omega$.

Measurement locations were selected in order to get results from different countries, from different types of installations and from buildings of different use. All measurements were performed during day-time with household appliances, EDP-equipment and production machinery normally connected to the mains.

For the estimation of the signal strength available at a receiver location the output level of the transmitter and the attenuation of the network between transmitter and receiver location must be known. The output level is a specific modem design parameter and is therefore a priori unknown. The attenuation is a characteristic of the network and can be measured by Transverse Transfer Loss (TTL) according to ITU-T Recommendation G.711 [1]. Details of the measurement method and connection to the LVDN can be seen in TR 102 270 [3].

A modem designer will be able to determine the influence of hidden nodes by including the data presented in the present document into his system analysis, e.g. by calculating the data throughput both real and for the limit case of Shannon.

Since the present document must be independent of any specific modem design, further evaluation of the data cannot be provided. The present document is limited on the analysis of noise floor- and attenuation- measurements.

5 Example test results

In general, both noise floor and TTL are strongly dependent on frequency and measurement location. Therefore a statistical evaluation must be performed in order not to consider simply the absolute worst case or any other intuitively chosen conditions. The system parameters shall be chosen in such a way, that a defined percentage of the LVDN-sockets show equal or better results than the assumed limit case.

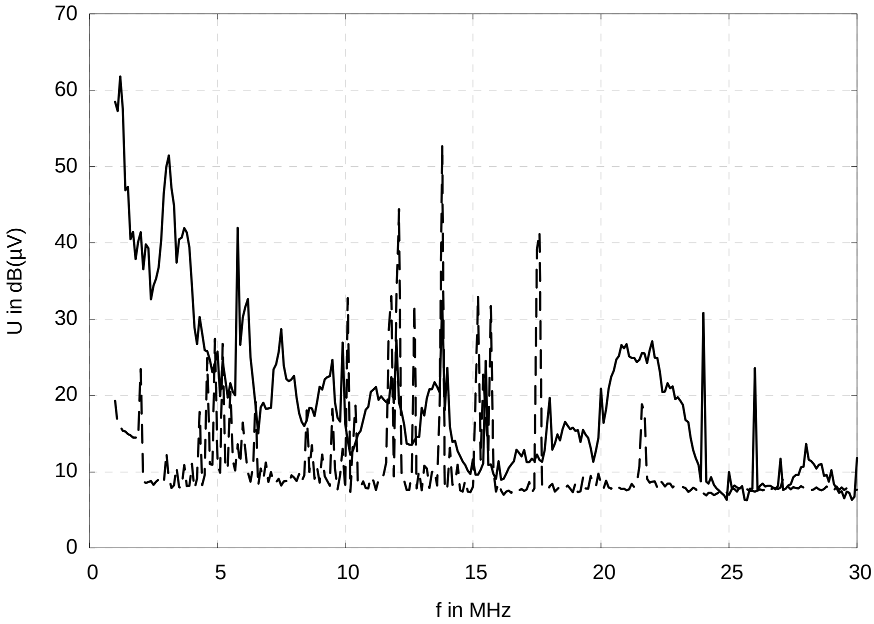
Figure 1 shows typical results of noise measurements at two plugs at different measurement locations (red: Germany, green: Spain). Figure 2 shows TTL at the same locations. Comparison of the different noise and TTL plots show that no specific behaviour can be observed regarding the country or the installation types (earthing variations). Therefore it is not necessary to distinguish between principle country- and installation-types for noise measurements. For the statistical evaluation of TTL two groups and two subgroups have been defined:

a) Transmitter and receiver located in the same flat or the same (small) house:

   1) Transmitter and receiver connected to same LVDN-phase.

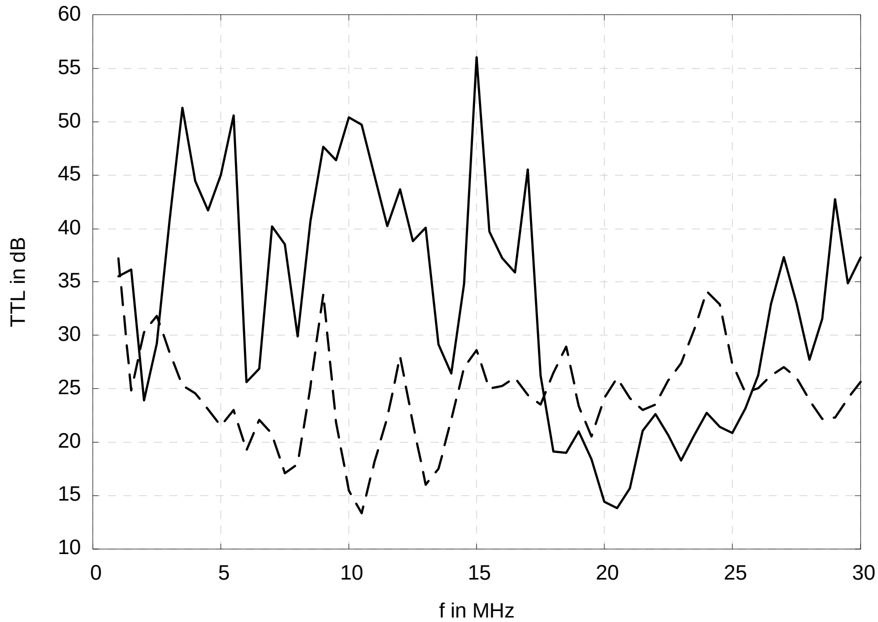
   2) Transmitter and receiver connected to different LVDN-phases.

b) Transmitter and receiver located in different flats or houses in the neighbourhood.



NOTE: --------: The Netherlands
_______: Spain

Figure 1: Example noise floor-measurements

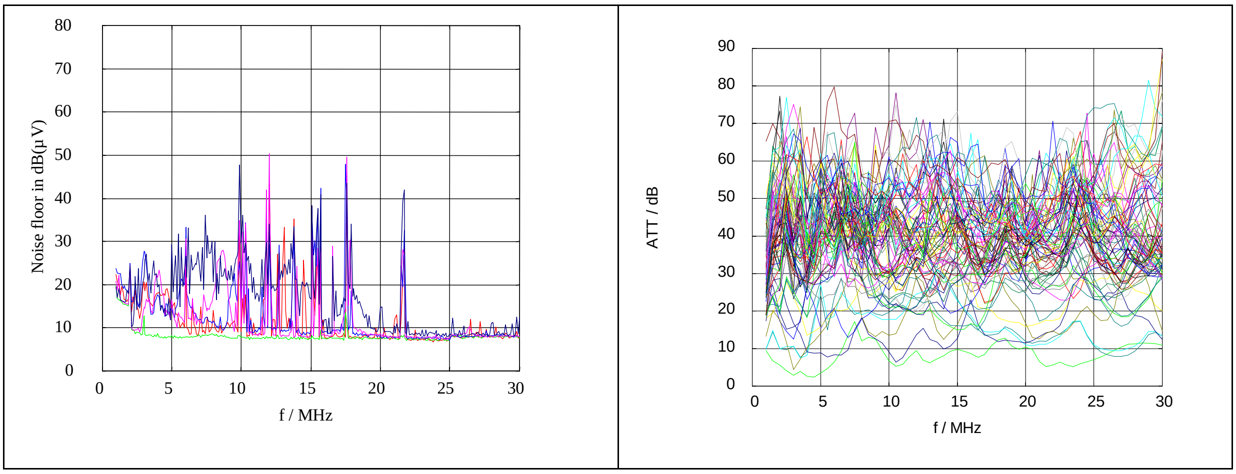


NOTE: --------: The Netherlands
_______: Spain

Figure 2: Example TTL-measurements

In total 69 noise floor measurements, 519 group A-TTL measurements and 124 group B-TTL measurements were performed. Each noise measurement consists of 291 single frequency points and each TTL measurement consists of 59 single frequency points.

Typical variations of the noise floor and TTL at a given measurement site are shown by figure 3, where all results measured in one flat are plotted in a single diagram.



NOTE: Gartenstrasse, Stuttgart, Germany.

Figure 3: Variation of noise floor and TTL at a single measurement site

6 Principles of statistical evaluation of noise- and TTL-data

For a general view all frequency plots were statistically evaluated. The empirical cumulative probability (using threshold k) was calculated and the contour lines for the probabilities of 20 %, 50 % and 80 % were chosen in figures 5 to 8.

From such plot it is difficult to derive hidden node criteria for a specific modem design, since these diagrams hide the spikes occurring on every measurement location. Therefore two other criteria were defined as shown in figure 4.

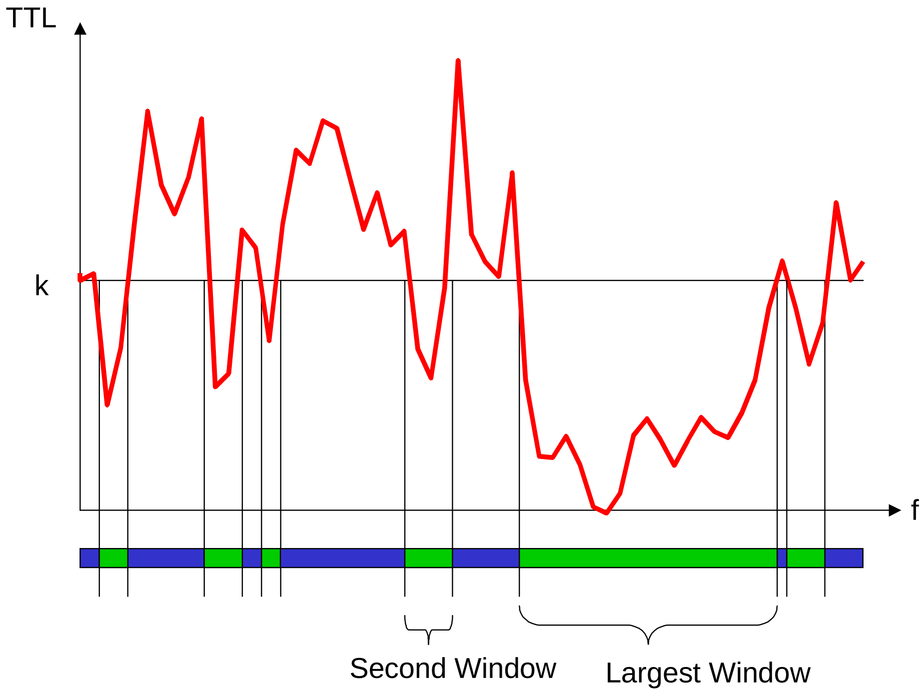


Figure 4: Definition of characteristic measures for hidden node analysis (TTL as example)

Criteria applicable for modems with OFDM and similar broadband modulation schemes are the part of the frequencies, for which noise and TTL are below specified threshold k. It is calculated as the ratio between the frequencies marked in green in figure 4 and the whole investigated frequency range (1 MHz to 30 MHz).

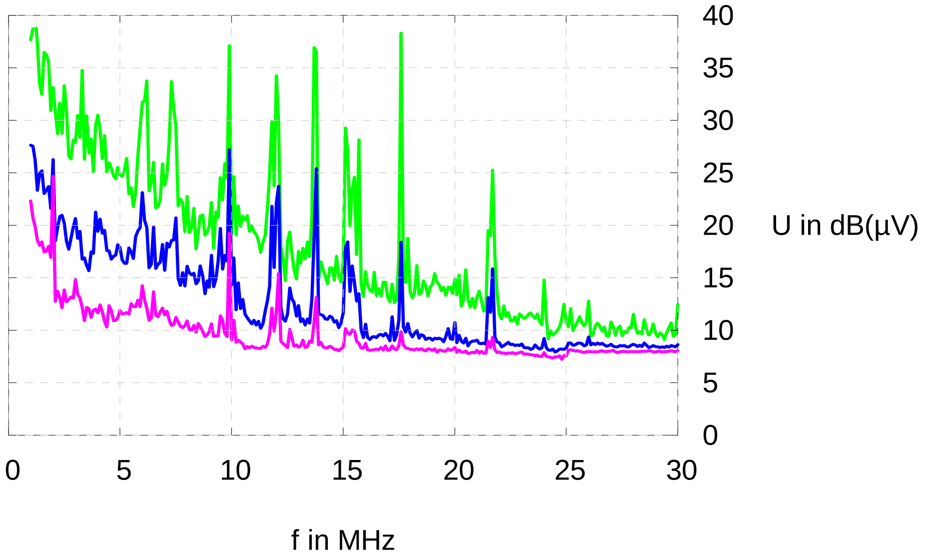
$$a = 100\% \times \frac{frequency\_space(Noise\_or\_TTL < k)}{whole\_frequency\_range}$$

Another criteria applicable for modems which need a continuous frequency band is the size of the largest window (referred to as "size of window"), where noise and TTL are below specified threshold k. To consider modems needing two channels (up and downstream) an additional quantity (referred to as "sum of window size"), the sum of the sizes of the two largest windows is defined.

Due to the fact that noise was measured in a frequency raster of 100 kHz and with a bandwidth of 10 kHz and that TTL was measured in a frequency raster of 500 kHz it is possible that very narrow spikes are missed.

7 Statistical evaluation of noise measurements

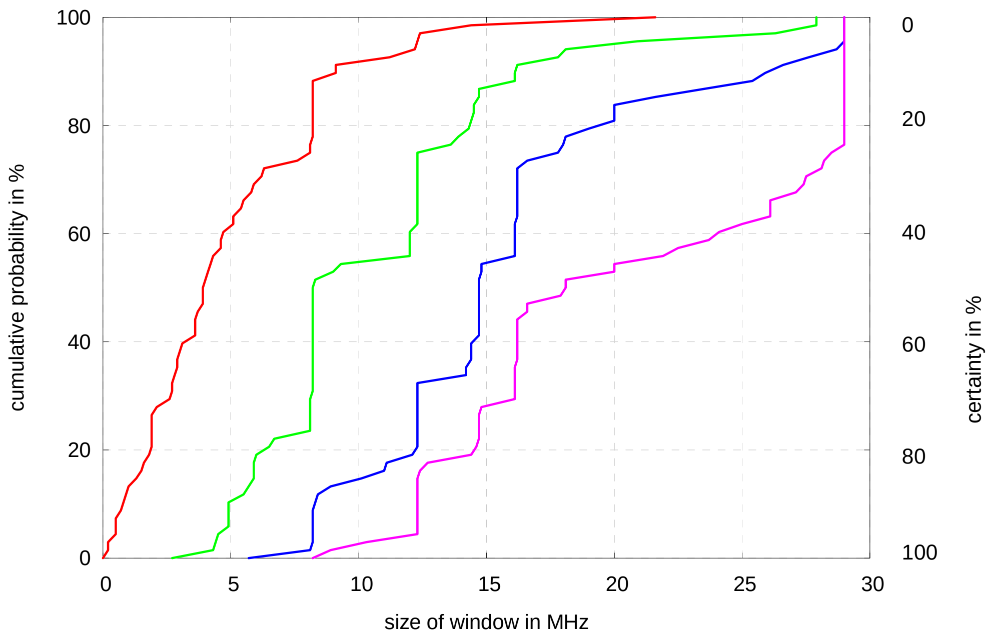
The general frequency-dependence of the noise floor can be seen in figure 5, where the cumulative probability is plotted on the noise-frequency plane as contour plot. The short wave broadcast-bands are well visible.



NOTE: from above: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

Figure 5: Noise floor in dependence of frequency for all sites

The largest continuous window is evaluated in figure 6.



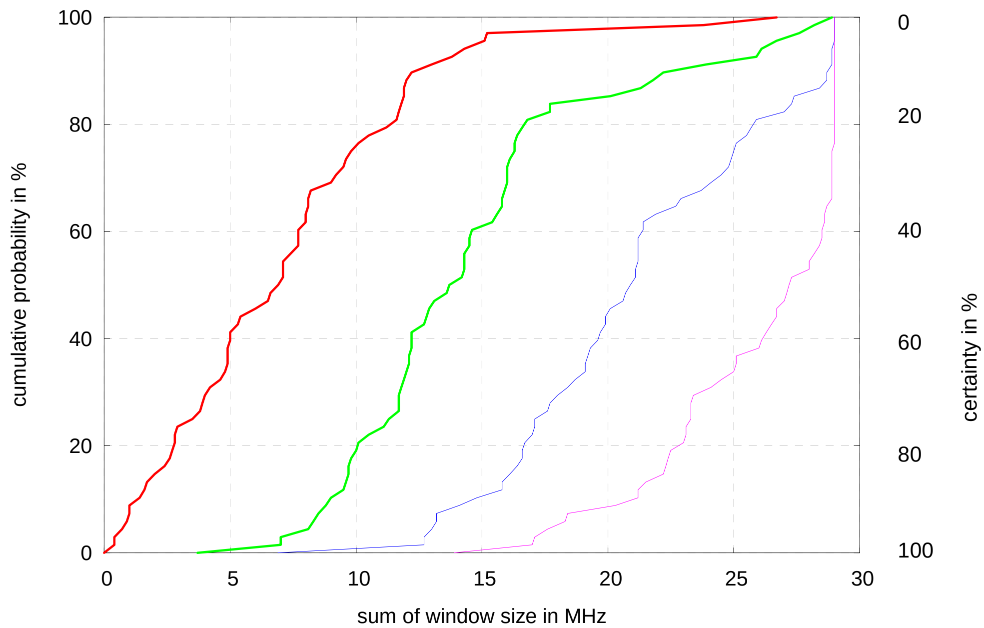
NOTE: from top to down: k = 10 dB(µV) (red), 20 dB(µV) (green), 30 dB(µV) (blue), 40 dB(µV) (violet).

Figure 6: Size of largest continuous window, for which noise < k

Figure 6 should be read in the following way:

- With a certainty of 0 % (never) a continuous frequency window of 29 MHz is available when a noise threshold k of 20 dB(µV) (green curve) is assumed. This also describes the top right corner in figure 6.
- With a certainty of 80 % a continuous frequency window of 12 MHz or more is available when a noise threshold k of 30 dB(µV) is assumed.

When a modem needs two channels and therefore requires two free frequency windows, figure 7 will give the analogous information.



NOTE: from top to down: k = 10 dB(µV) (red), 20 dB(µV) (green), 30 dB(µV) (blue), 40 dB(µV) (violet).

Figure 7: Sum of the size of largest two continuous windows, for which noise < k

Figure 7 shall be interpreted in the same way than figure 6.

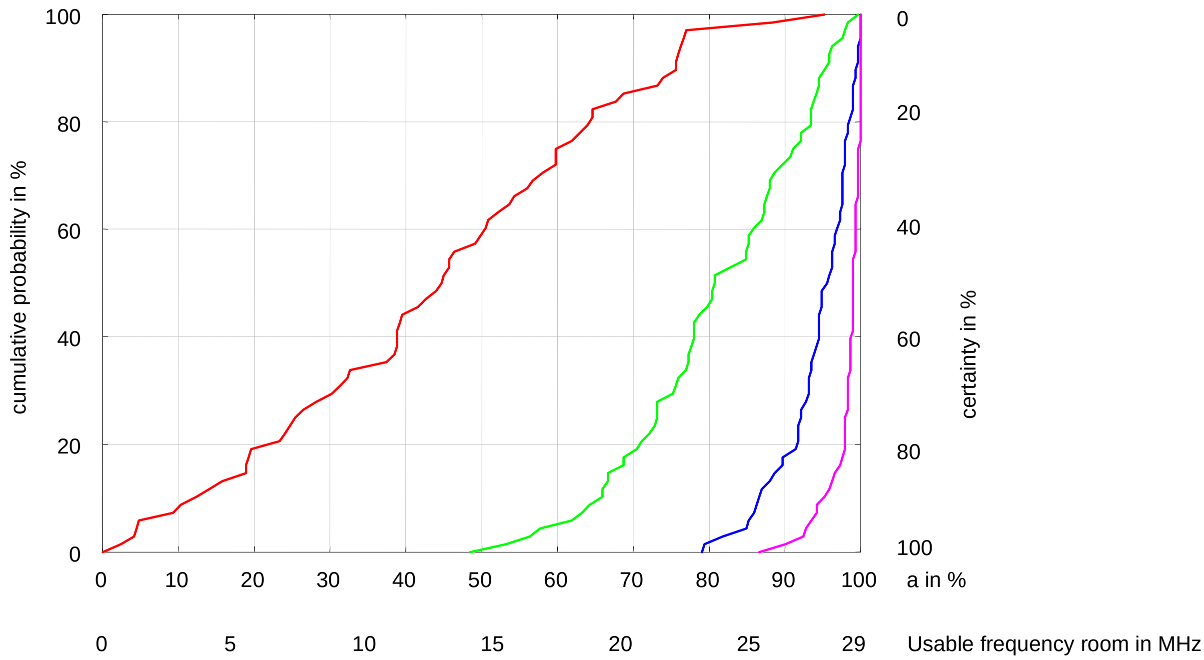
E.g. with a certainty of 80 % two continuous frequency windows with a total size of 17 MHz or more are available when a noise threshold k of 30 dB(µV) is permissible.

The probability distribution of the sum of frequencies, for which noise is below a specified value k, is shown in figure 8. Figure 8 can be interpreted in the following ways:

- In 50 % of all measurement locations 45 % of the frequency range (1 MHz to 30 MHz) have a noise below 10 dB(µV). If a higher degree of certainty is required (e.g. 80 %) we can read:
- In 20 % of all measurement locations 70 % of the frequency range (1 MHz to 30 MHz) have a noise below 20 dB(µV).

For a modem design the noise may be considered in the following way:

- If a modem design needs a noise, which is less than 10dB(µV), the maximum usable frequency range is 20 % (5,8 MHz) with a certainty of 80 %.

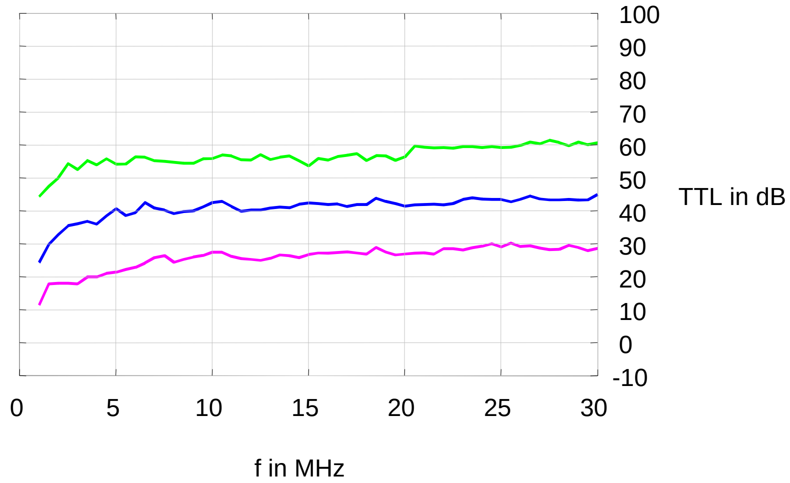


NOTE: from above: k = 10 dB(µV) (red), 20 dB(µV) (green), 30 dB(µV) (blue), 40 dB(µV) (violet).

Figure 8: Cumulative probability for the sum of frequencies with a noise below k

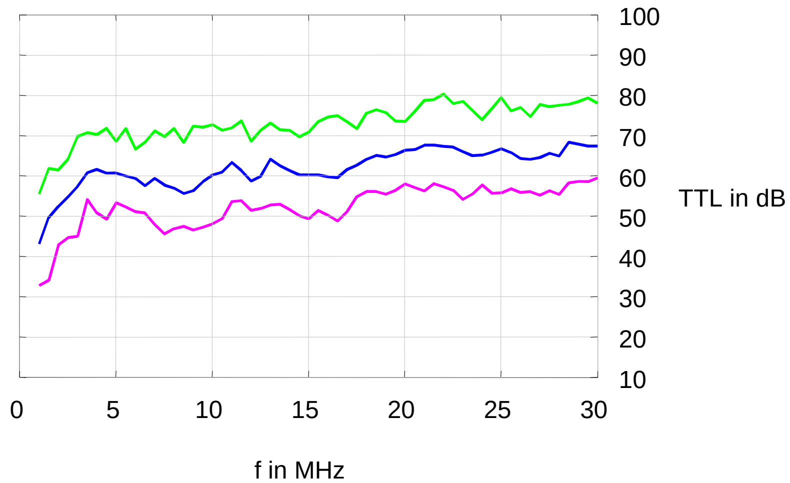
8 Statistical evaluation of measured TTL

The general dependence of TTL on frequency can be seen in figures 9 to 12, where the cumulative probabilities are plotted on the TTL-frequency plane as contour plot.



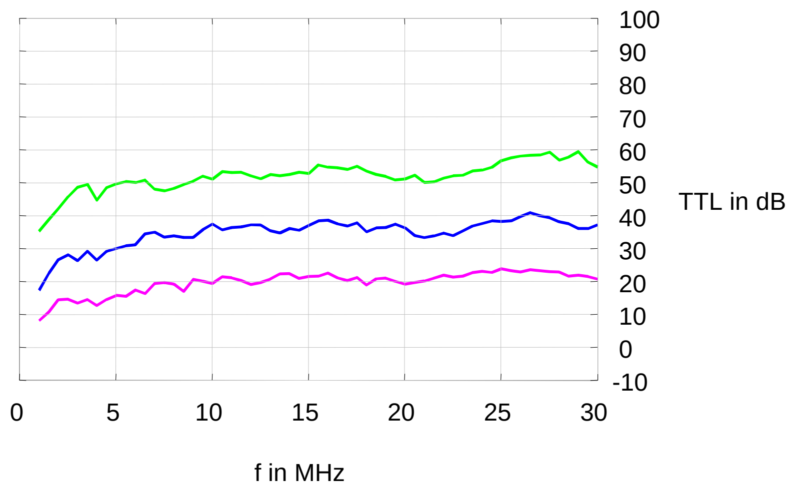
NOTE 1: Group A: same flat/house independent of phase.
NOTE 2: from above: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

Figure 9: TTL as a function of frequency for all sites



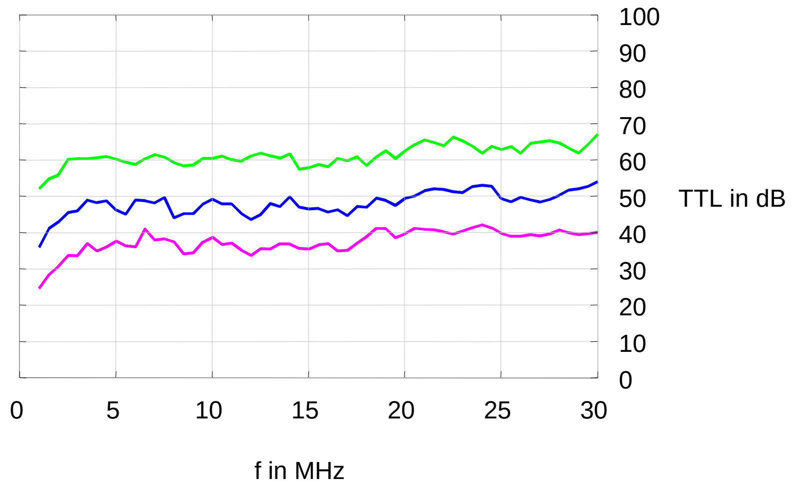
NOTE 1: Group B: different flat/house in neighbourhood independent of phase.
NOTE 2: from above: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

Figure 10: TTL as a function of frequency for all sites



NOTE 1: Group A1: same flat/house transmitter and receiver connected to same phase.
NOTE 2: from above: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

Figure 11: TTL as a function of frequency for all sites

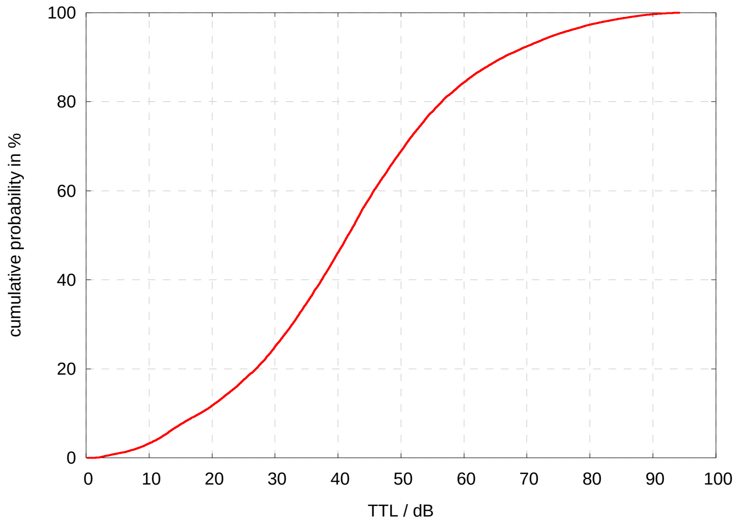


NOTE 1: Group A2: same flat/house transmitter and receiver connected to different phase.
NOTE 2: from above: 80 % (green), 50 % (blue), 20 % (violet) cumulative probability.

Figure 12: TTL as a function frequency for all sites

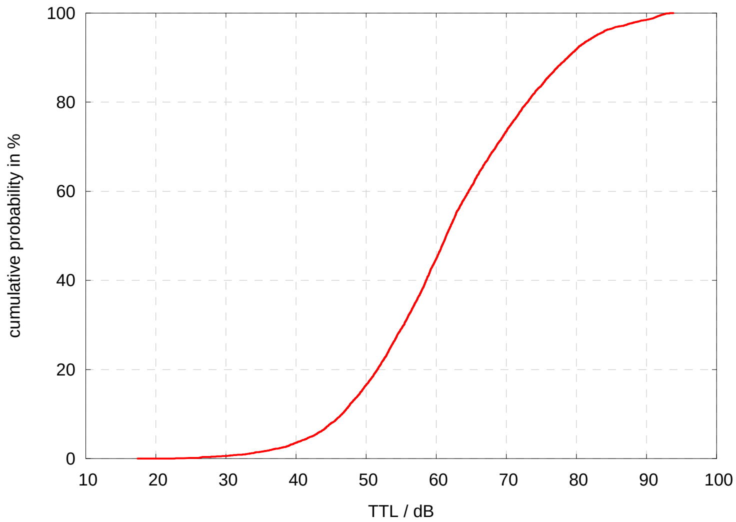
There is only a slight and therefore neglectable increase of attenuation with frequency.

By neglecting this frequency dependence, the diagrams of the cumulative probability of TTL may be drawn (figures 13 to 16).



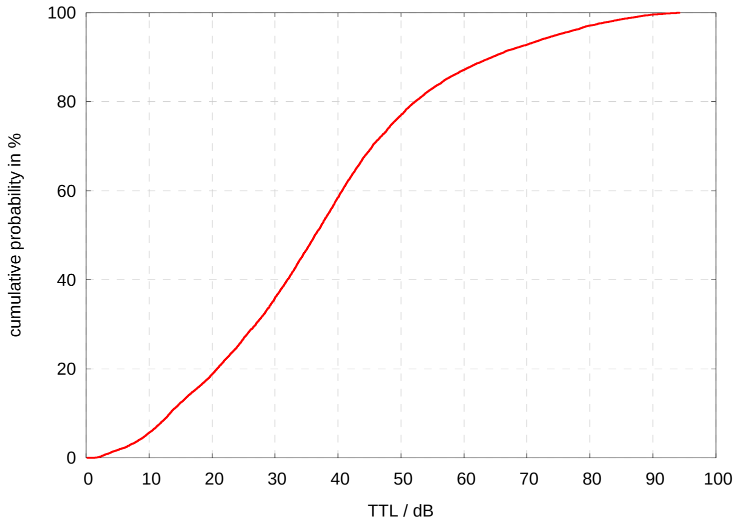
NOTE: Group A: same flat/house independent of phase.

Figure 13: Cumulative probability of TTL for all sites and frequencies



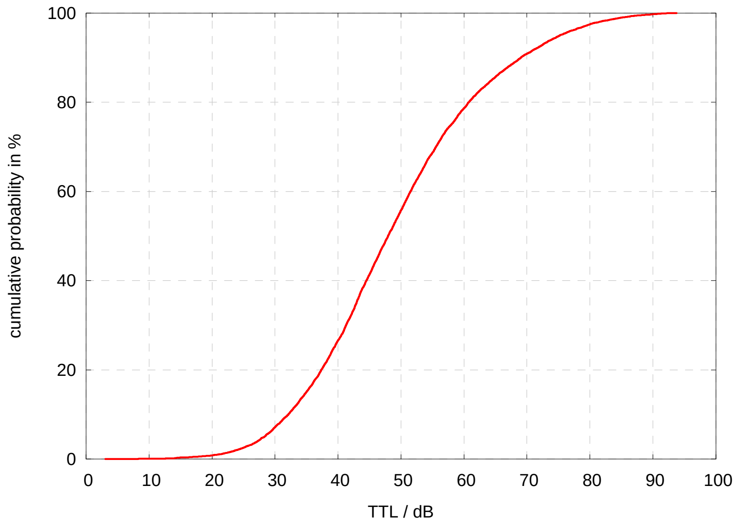
NOTE: Group B: different flat/house in neighbourhood independent of phase.

Figure 14: Cumulative probability of TTL for all sites and frequencies



NOTE: Group A1: same flat/house transmitter and receiver connected to same phase.

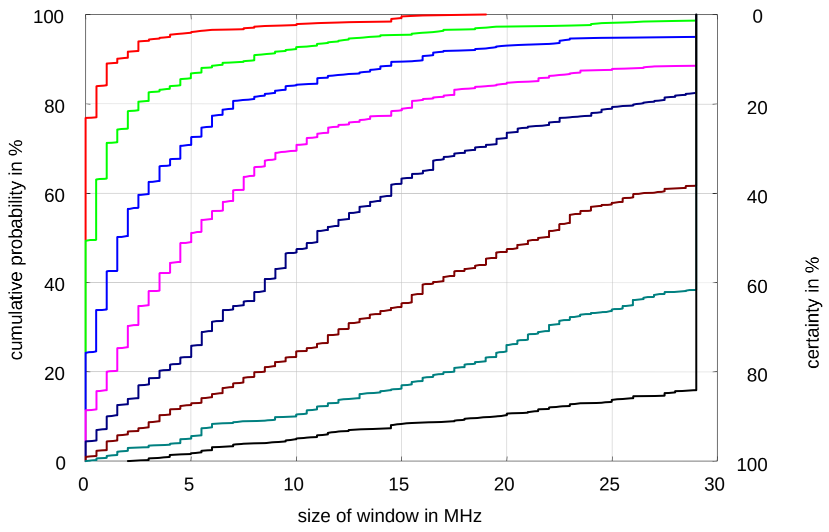
Figure 15: Cumulative probability of TTL for all sites and frequencies



NOTE: Group A2: same flat/house transmitter and receiver connected to different phase.

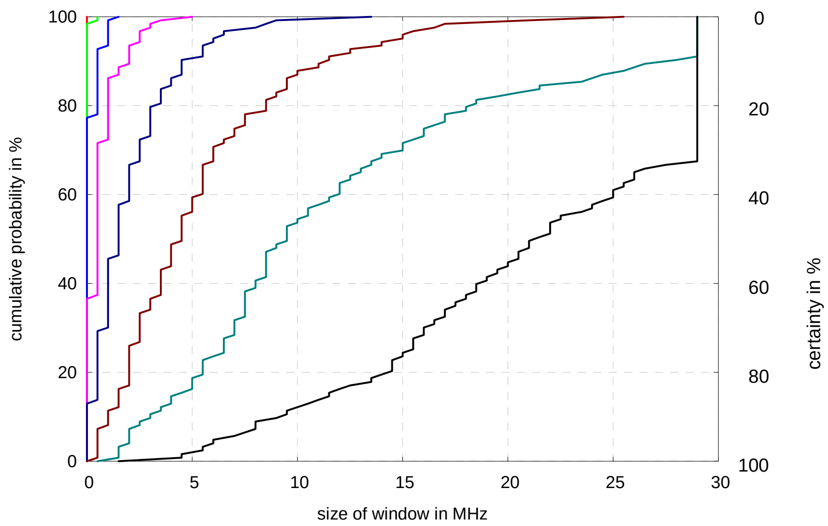
Figure 16: Cumulative probability of TTL for all sites and frequencies

The distribution of the largest continuous window, as defined in clause 6, is plotted in figures 17 and 18. From figure 17 it can be seen that for a certainty of 80 % the size of the largest continuous window is 17 MHz, if 70 dB attenuation threshold k is assumed.



NOTE: from above: k = 10 dB (red), 20d B (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

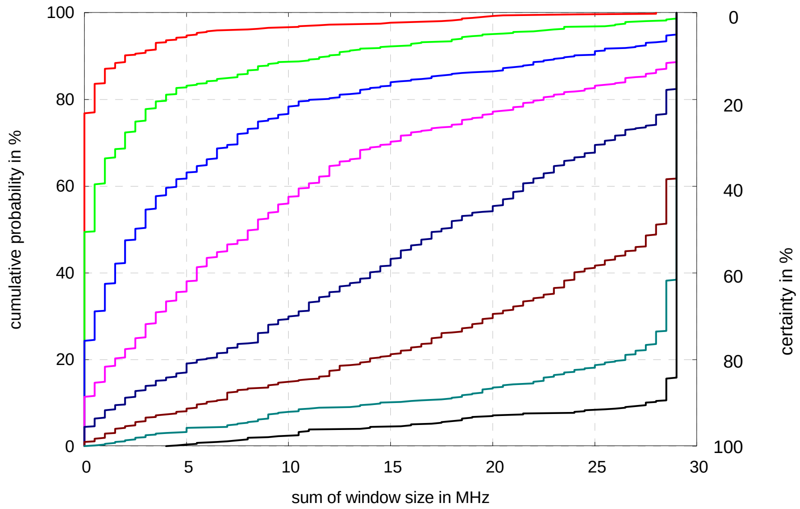
Figure 17: Cumulative probability for the largest continuous window with TTL below k same flat/house



NOTE: from above: k = 10 dB (difficult to see), 20 dB (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

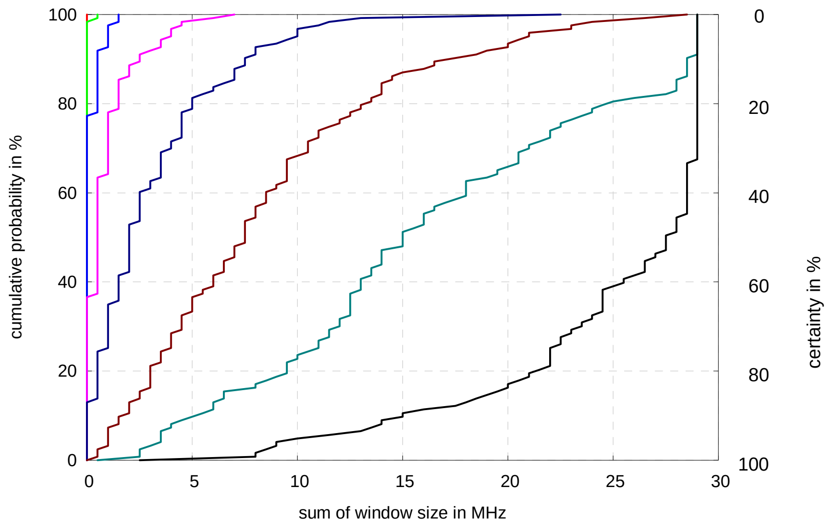
Figure 18: Cumulative probability for the largest continuous window with TTL below k different flat/house in neighbourhood

The distributions of the two largest continuous windows, as defined in clause 6, are plotted in figures 19 and 20. From figure 19 it can be seen, that for a certainty of 80 % the sum of the sizes of the two largest continuous windows is 14 MHz, if 60 dB attenuation threshold k is assumed.



NOTE: from above: k = 10 dB (red), 20 dB (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

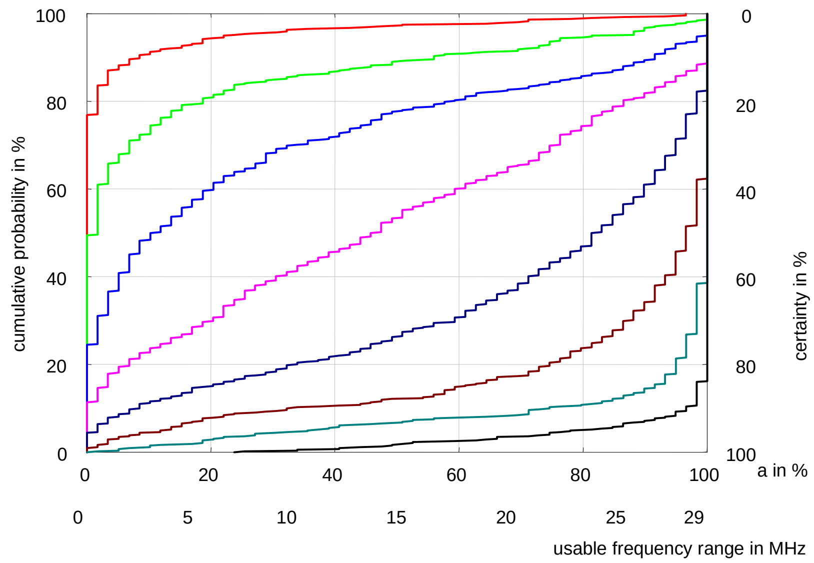
Figure 19: Cumulative probability for the two largest continuous windows with TTL below k same flat/house



NOTE: from above: k = 10 dB (difficult to see), 20 dB (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

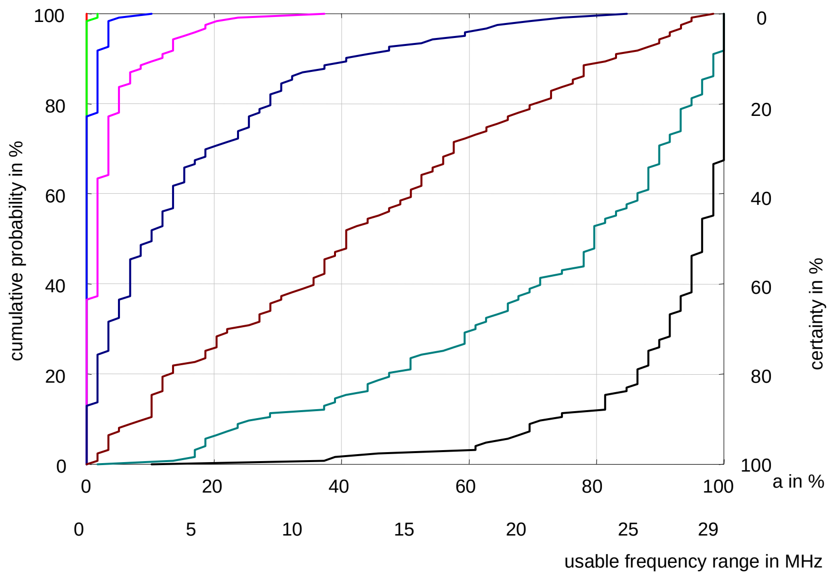
Figure 20: Cumulative probability for the two largest continuous windows with TTL below k different flat/house

The cumulative probability distributions of the sum of usable frequencies as defined in clause 6 are plotted in figures 21 and 22. From figure 21 it can be seen, that for a certainty of 80 %, 75 % of the frequency space can be used, if 60 dB attenuation threshold k is assumed.



NOTE: from above: k = 10dB (red), 20 dB (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

Figure 21: Cumulative probability for the part of frequencies with TTL below k same flat/house



NOTE: from above: k = 10 dB (difficult to see), 20 dB (green), 30 dB (blue), 40 dB (violet), 50 dB (dark blue), 60 dB (brown), 70 dB (grey), 80 dB (black).

Figure 22: Cumulative probability for the part of frequencies with TTL below k different flat/house

9 Dependencies from national particularities concerning installation- and earthing techniques in Germany, The Netherlands and Spain

The table below shows the median of all TTL-values measured in the three countries.

Table 1

Country	City	Median Noise floor (dB(µV))	Median TTL same flat/house (dB)	Median TTL different flat/house in the neighbourhood (dB)
Germany (DE)	Stuttgart	9,14	40,97	59,6
The Netherlands (NL)	Eindhoven	11,08	39,7	65,78
Spain (E)	Zaragoza	12,9	41,52	68,26

No significant difference can be detected for TTL measured within the same flat or house. The differences for transmitter and receiver in different flat/houses may reflect specific choice of measurement locations (Spain: including industrial sites, NL: Only houses, DE: flats and apartments in larger buildings, DE: 3 phase installations in all flats, NL, E: 1 phase installations in flats).

History

Document history		
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