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Technical Report

PowerLine Telecommunications (PLT); Basic data relating to LVDN measurements in the 3 MHz to 100 MHz frequency range

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DTR/PLT-00018

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Foreword

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

Introduction

In August 2002 ETSI PLT created a Special task Force (STF) to do in situ measurements in LVDN networks. It was necessary to define and implement a measurement set-up and to perform measurements in a number of countries in which various wiring and earthing techniques are used for LVDN.

The following documents produced as a result of the measurement campaign, describe measurements and analysis in the 1 MHz to 30 MHz frequency range:

- **TR 102 269,** PLT Hidden Node review and statistical analysis.
- **TR 102 258**, PLT LCL review and statistical analysis.
- **TR 102 259,** EMI review and statistical analysis.
- **TR 102 270,** Basic Low Voltage Distribution Network (LVDN) measurement data.

1 Scope

The present document describes the equipment and results of the measurement campaign in the 3 MHz to 100 MHz frequency range and is a supplement to TR 102 270 [2] and TR 102 269 [3].

2 References

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

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

[2] ETSI TR 102 270: "PowerLine Telecommunications (PLT); Basic Low Voltage Distribution Network (LVDN) measurement data".

[3] ETSI TR 102 269: "PowerLine Telecommunications (PLT); Hidden Node 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
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
LVDN	Low Voltage Distribution Network
OFDM	Orthogonal Frequency Division Multiplexing
PC	Personal Computer
STF	Special Task Force
sym	symmetrical
T	aTtenuator
TTL	Transverse Transfer Loss

3.2 Symbols

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

dB	deciBel
f	frequency
Hz	Hertz
Ω	Ohm
kHz	kiloHerz
m	meter
M	Mega
ms	millisecond
µ	micro
V	Volt
W	Watt

4 Major project phases

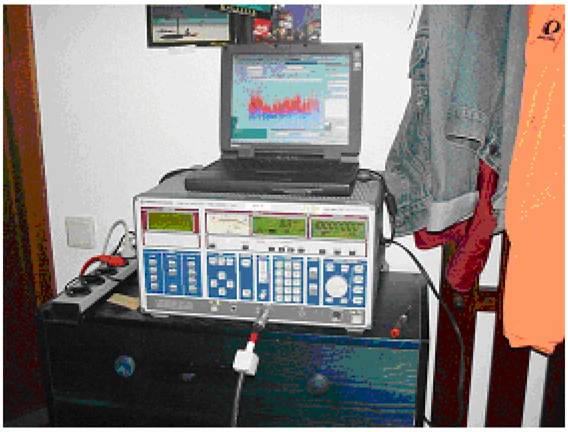
Table 4.1: Major project phases

No.	Period	Topic	Event
01	Sept. to Oct. 2002	Project organization Definition of characteristics Measurement set-up Planning	Task Force Meeting No. 1 and 2 Frankfurt
02	Nov. to Dec. 2002	Measurement set-up familiarisation, laboratory tests	Task Force Meeting No. 3 University Dortmund
03	Jan. 2003	Measurements in 3 single family houses	Measurement campaign Eindhoven, NL
04	February 2003	Measurements in 3 apartments and 1 office building	Measurement campaign Stuttgart, D
05	March 2003	Measurements in 4 apartments 2 single family houses 2 office buildings 2 factory buildings	Measurement campaign Zaragoza, E
06	May to July 2003	Data analysis Reports	Task Force meeting No.4 Frankfurt
07	July to August 2003	Measurements in higher frequency span in 3 apartments and 1 single family house	Measurement campaign Stuttgart, D
08	September 2003	Data analysis Reports	ETSI PLT Plenary Meetings

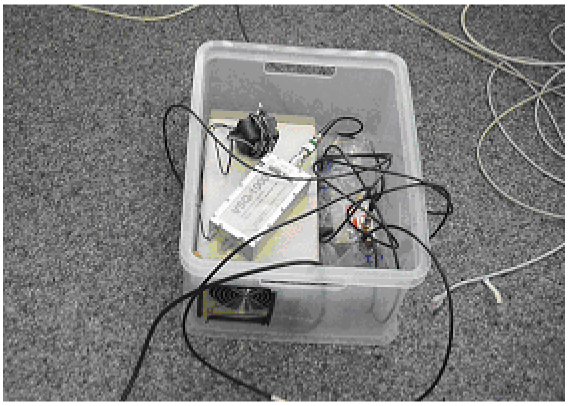
5 Measurement set-up description

5.1 Introduction

As a starting point the STF had to define the parameters to be measured and to build the corresponding measurement set-up. This clause shows the practical implementation, the various measurement set-ups and the instrumentation used. The definition of the parameters to be assessed can be found in [1]. Figure 5.1 shows the measurement-set-up.

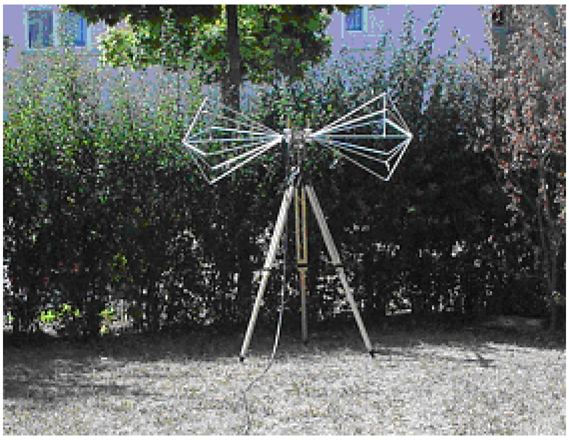


EMI Receiver and PC



Amplifier, Comb generator

Balun for Feeding or receiving



Biconal Antenna

Figure 5.1: Measurement equipment

5.2 Set-up for measurements of conducted signals between two LVDN-ports

The measurement set-up basically consists of a signal source connected via the 3 MHz to 100 MHz Balun to the mains.

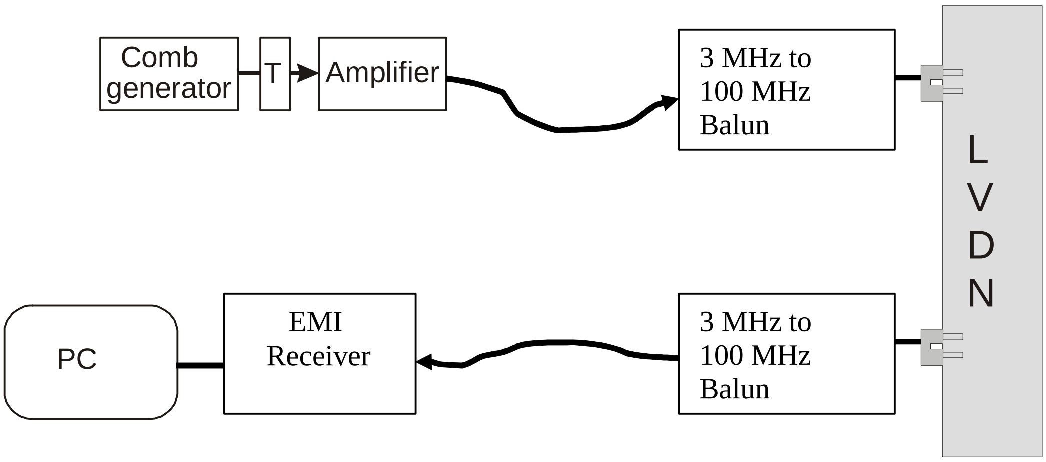


Figure 5.2: General measurement set-up for conducted signals with symmetrical injection

In comparison to the measurements described in [2] there are no common mode measurements done in the frequency range from 3 MHz to 100 MHz, so there is no ground plane needed. The 3 MHz to 100 MHz balun is inserted into the LVDN-socket with a ~15cm cable. Since no phase measurements should be performed, this cable has only a minimum effect on magnitude measurements. During calibration (i.e. direct connection of two baluns with this cable length) it was found that this short cable has almost no influence.

5.3 Set-up for measurements of radiated signals

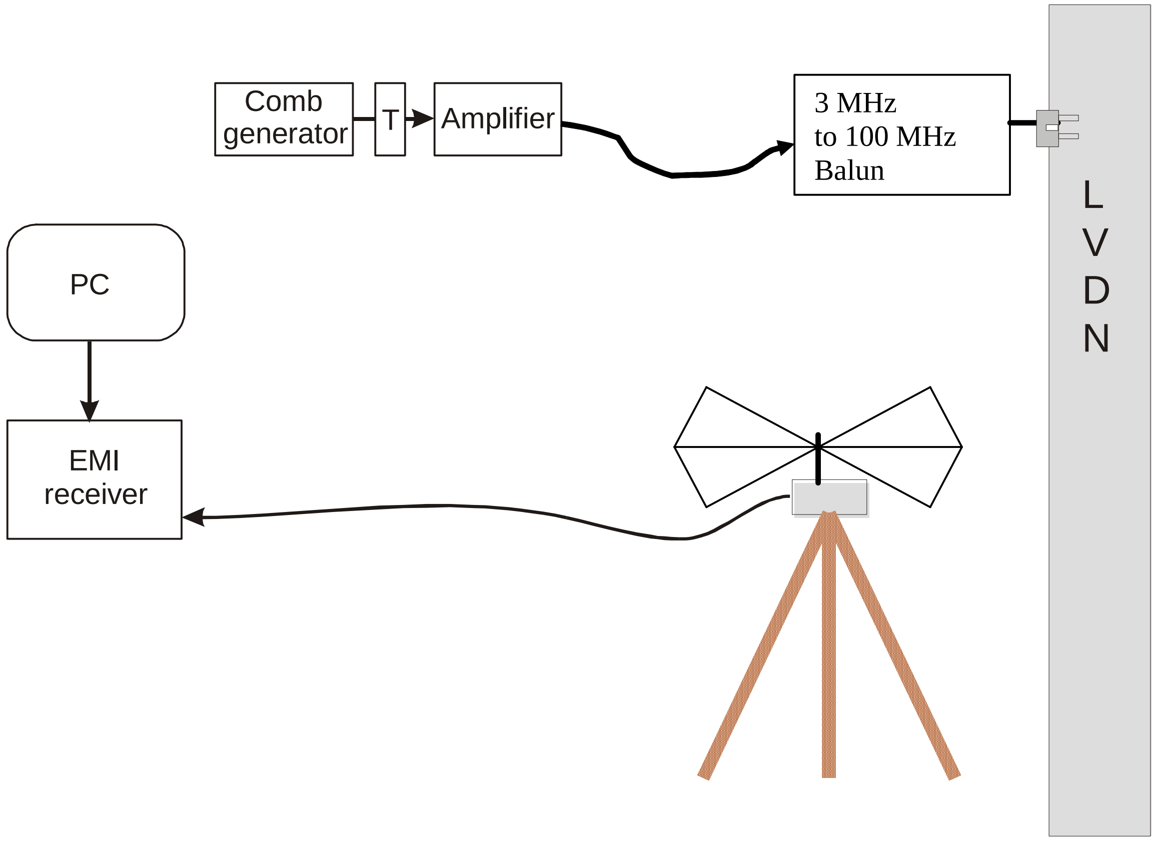


Figure 5.3: General measurement set-up for radiated signals with symmetrical injection

NOTE: The distance of the phase centre of the antenna to power line network is about 10 m.

5.4 General equipment list

5.4.1 Comb generator

The published specifications of this commercially available comb generator are not very tight. The unit used for the STF measurements however shows a flat spectrum in the range of interest between 3 MHz and 100 MHz and a very good stability of the output level.

Table 5.1

Property	Value	Comment
Type	VSQ 1000	
Manufacturer	Bogerfunk (see note)	
Output level	78 dBμV	in the frequency domain; into 50 Ω
Output impedance	50 Ω	
Frequency range	> 100 MHz	
Repetition frequency	1 MHz	(also adjustable in 5 steps)
NOTE: Bogerfunk is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.		

Figure 5.4: Comb generator

5.4.2 Amplifier

The specifications of the amplifier generator are not very tight; but the gain was found to be very stable.

Table 5.2

Property	Value	Comment
Type	102LC	10 Hz to 100 MHz
Manufacturer	Kalmus (see note)	
Output level	2 W	into 50 Ω
Output impedance	50 Ω	
Input impedance	50 Ω	
Gain	36 dB	100 kHz to 100 MHz
NOTE: Kalmus is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.		

The amplifier is sufficiently linear for 1 MHz-spaced spectrum lines up to 96 dBμV. For an output level of 96 dBμV a 23 dB attenuator must be inserted between the comb generator and the amplifier.

Figure 5.5: Amplifier

5.4.3 EMI receiver

Table 5.3

Property	Value	Comment
Type	ESPC	
Manufacturer	Rohde & Schwarz (see note)	
Detector	Peak and Average	Note: Peak- or Average value of the measured RMS voltage (for the evaluation, only the average value has been taken into account)
Frequency range	0.009 MHz to 2 400 MHz	
Frequency steps	100 kHz	4 noise readings between Comb generator peaks
Dwell time	20 ms default	
Resolution bandwidth	10 kHz	
Receiver noise	< -5 dBµV	up to 30 MHz
NOTE: Rohde & Schwarz is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.		

Figure 5.6: EMI receiver

5.4.4 Biconal antenna

Table 5.4

Property	Value	Comment
Type: Antenna Balun	VHBA 9123	
Type: Biconal Element	BBA 9106	
Manufacturer	Schwarzbeck (see note)	
Antenna factor	Varies between 12,2 dB and 7,9 dB (1/m)	The antenna factor was measured individually for the used antenna in an EMC lab. This data was used for calibration of the Antenna Measurements.
Antenna tripod	Wooden tripod, always at 1 m above floor.	
NOTE: Schwarzbeck is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.		

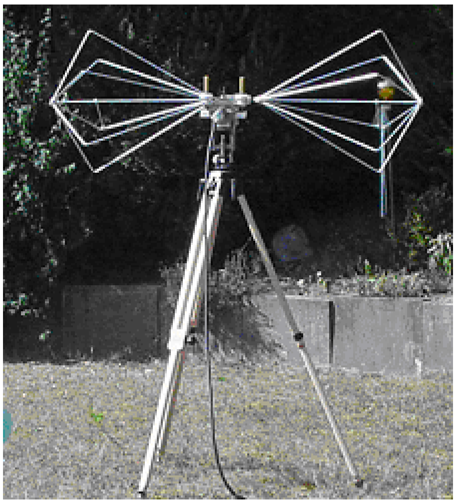


Figure 5.7: Biconal antenna

5.4.5 3 MHz to 100 MHz Balun

This balun transforms 100 Ω symmetrical to 50 Ω asymmetrical. It was designed for low power loss within the frequency spectrum from 3 MHz to 100 MHz with the aim to maximize the injected signal.

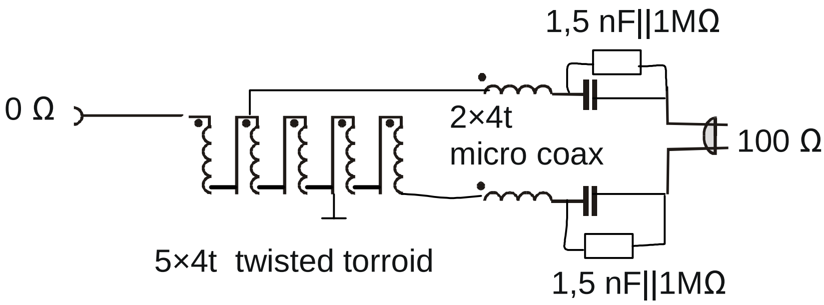


Figure 5.8: Schematic of the "3 MHz to 100 MHz balun"

6 Measurement software

6.1 Description of software

The software used for the measurements from 3 MHz to 100 MHz is almost identical to the software described in [2] (measurements 1 MHz to 30 MHz).

Following changes had been performed:

- Start Frequency: 3 MHz.
- Stop Frequency: 100 MHz.
- Frequency step size: 500 kHz. Every 2nd value is ground noise, the other 2nd value is the spike from the comb generator.
- Evaluation of the antenna measurements: use the max measurement out of 2 measurements at different polarisations.
- Considering the frequency dependent antenna factor.

- Instead of fixed transducer settings it is possible to reference a file with frequency dependent transducer settings.
- Charts in the analysis section show the measurement in the span from 3 MHz to 100 MHz respective 30 MHz to 100 MHz for radiation measurements.

6.2 Evaluation of the results

For precise evaluation of the Attenuation measurements the two 100 MHz Baluns need to be calibrated. This was done by connecting both baluns. From that the transducer factor was derived and used as reference for attenuation measurements.

Attenuation = [Feeding sym. Signal (measured at second balun) + Correction Factor file from Transducer Settings] - [Received sym. Signal + Correction Factor file from Transducer]

k-Factor = max measurement out of 2 measurement orientations (x,y) + Antenna Factor file from Transducer Settings - [Feed sym Signal + Correction factor file from transducer settings]

Noise = Received sym. Signal + Correction Factor file from Transducer Settings

6.2.1 Principle of evaluation of Noise Floor and TTL

As overview the empirical cumulative probability (probability that Noise or TTL is below a certain value) is plotted as contour plot in the Noise/TTL - Frequency plane. As contour lines the probabilities 20 %, 50 % and 80 % have been chosen in the following diagrams.

From that plot it may be difficult to derive hidden node criteria for any modem design, since these diagrams hide spikes occurring on every measurement location. Therefore two other criteria have been defined as shown in figure 6.1.

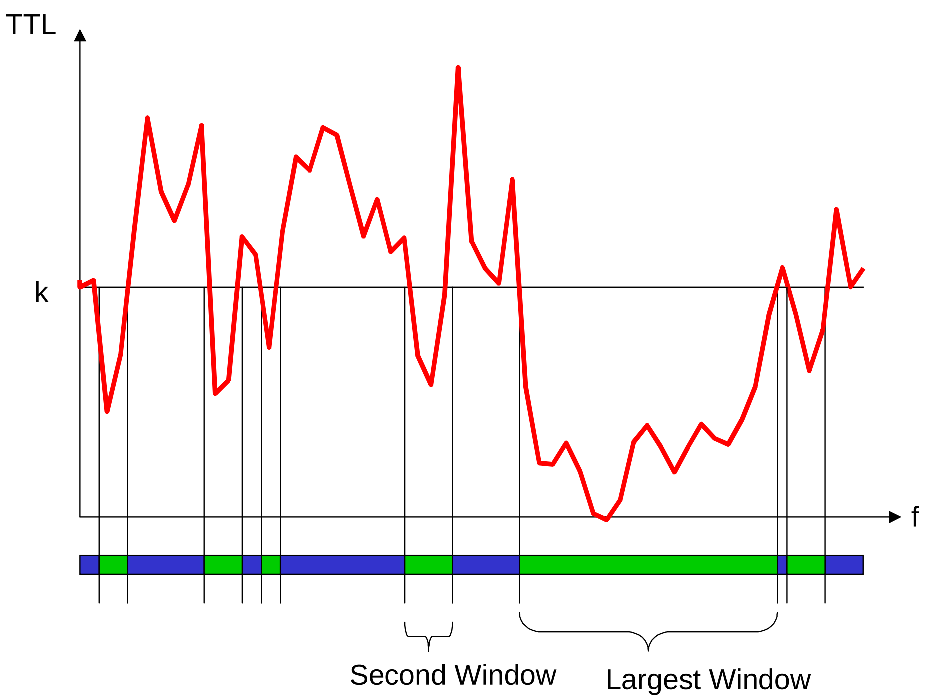


Figure 6.1: Definition of characteristic quantities for hidden node analysis (TTL as example)

A criteria applicable for modems with OFDM and similar broadband modulation scheme is the part of the frequencies, where noise or TTL is below a specified value k. It is calculated as quotient of the frequencies marked in green in figure 4 and the whole investigated frequency room.

$$a = 100\ \% \cdot \frac{frequency\_room(Noise\_or\_TTL < k)}{whole\_frequency\_room}$$

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 or TTL is below a specified value 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 can be defined.

Due to the fact that noise was measured in a frequency raster of 500 kHz with a bandwidth of 10 kHz and that TTL was measured in a frequency raster of 1 MHz it is possible that narrow spikes will occur which have not been measured.

7 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 7.1 shows typical results of noise measurements at two plugs at different measurement locations. Figure 7.2 shows TTL at the same locations. Comparison of the different noise and TTL plots show that no specific behavior can be observed regarding the installation or building types (earthing variations). Therefore it is not necessary to distinguish between principle 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.

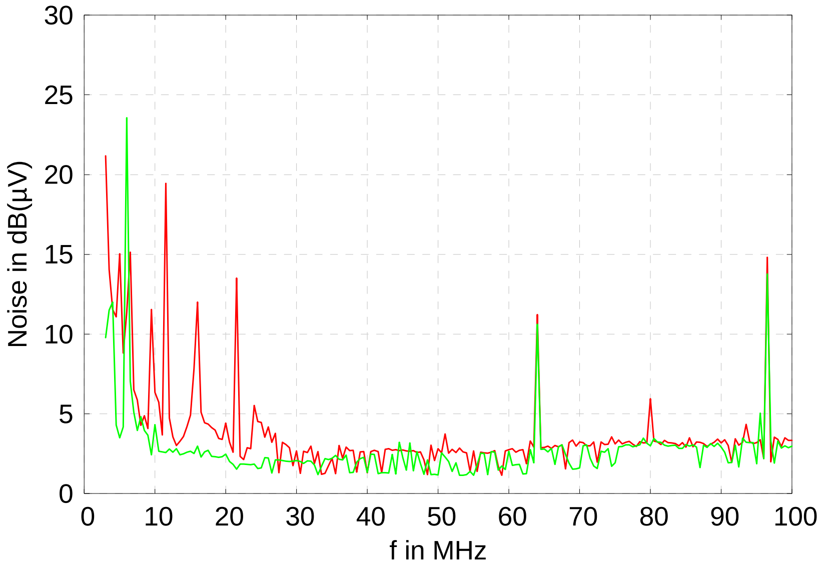


Figure 7.1: Example noise floor-measurements

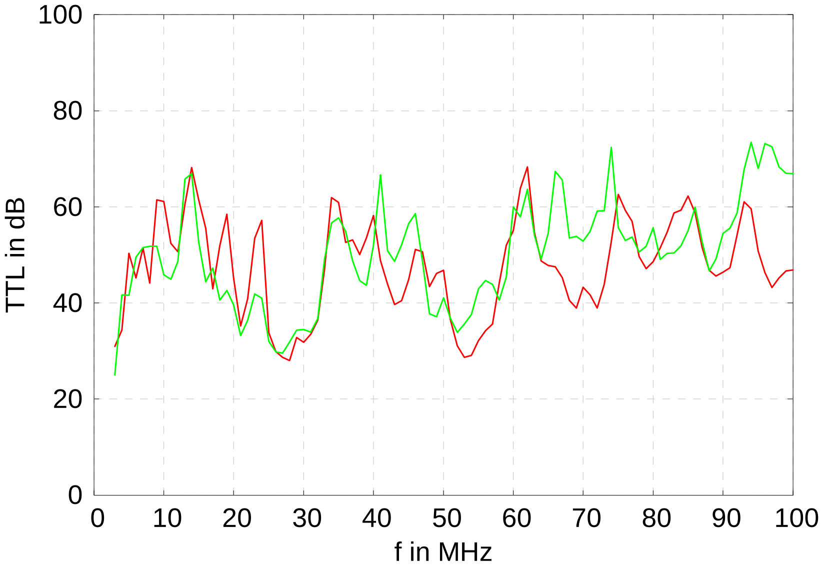
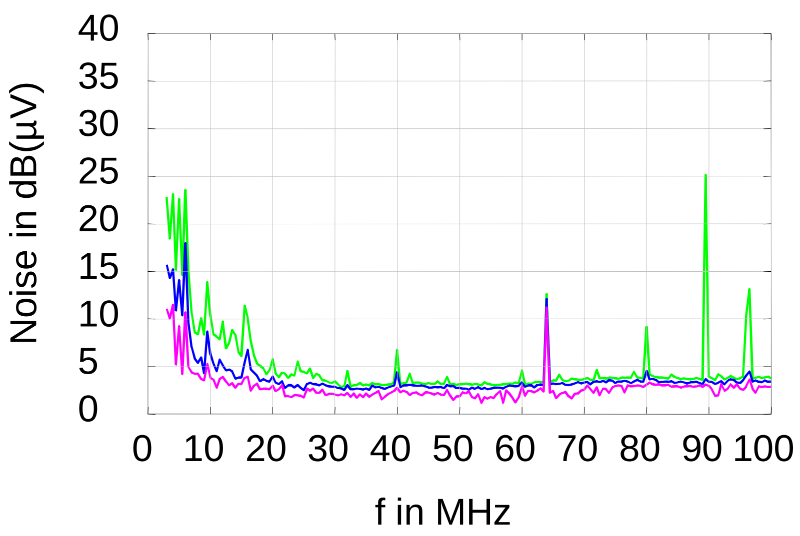


Figure 7.2: Example TTL-measurements

In total 26 noise floor measurements, 87 group A-TTL measurements and 33 group B-TTL measurements were performed. Each noise measurement consists of 195 single frequency points and each TTL measurement consists of 98 single frequency points.

8 Statistical evaluation of Noise Measurements

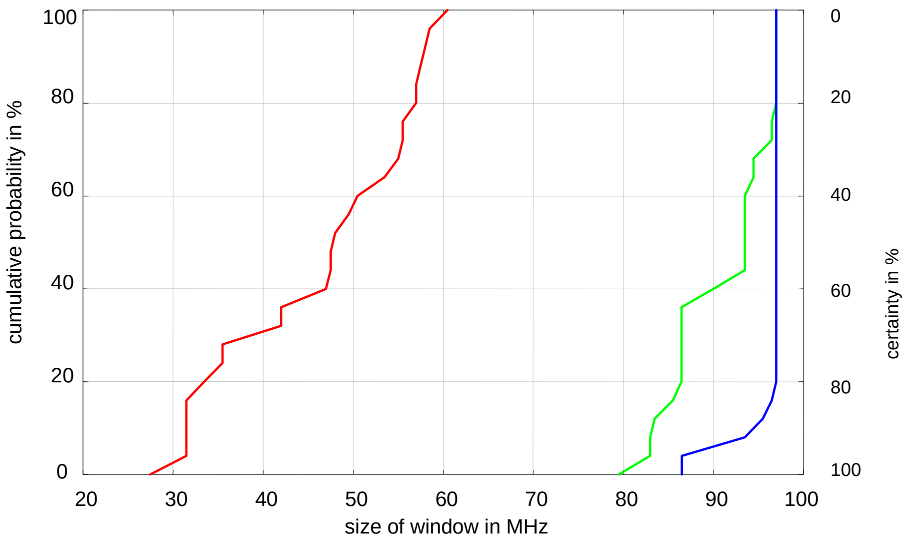
The frequency-dependence of the noise floor can be seen in figure 8.1, where the cumulative probability is plotted on the noise-frequency plane as contour plot. Some ultra short wave broadcast-transmitters are well visible.



Line colour	Cumulative probability
Green	80 %
Blue	50 %
Violet	20 %

Figure 8.1: Noise floor in dependence of frequency for all sites

The largest continuous window is evaluated in figure 8.2.



Line colour	k [dB(µV)]
Red	10
Green	20
Blue	30

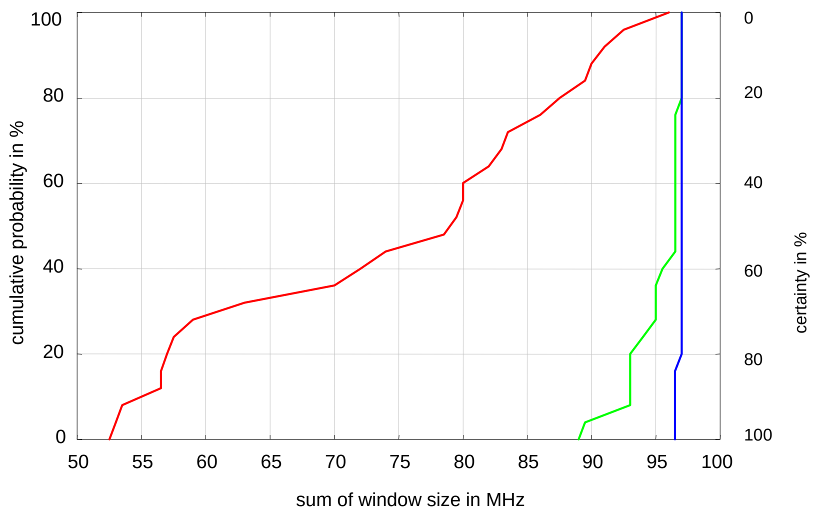
Figure 8.2: Size of largest continuous window, for which Noise floor ≤ k (from top to down:)

The reader of the present document shall interpret figure 8.2 in the following way:

- With a certainty of 0% (definitely never) a continuous frequency window of 97 MHz or more is available when a noise floor of 30dB(µV) (blue curve) is permissible. This sentence describes the top right corner in figure 8.2.
- With a certainty of 100% (always) a continuous frequency window of 28 MHz or more is available when a noise floor of 10 dB(µV) (red curve) is permissible. This sentence describes the lower left corner in figure 8.2.

So from this diagram it can be seen that with a certainty of 80% a continuous frequency window of 86 MHz or more is available when a noise floor of 20 dB(µV) is permissible.

When a modem needs two channels and therefore two free frequency windows figure 8.3 will give the necessary information.



Line colour	k [dB(µV)]
Red	10
Green	20
Blue	30

Figure 8.3: Sum of the size of largest two continuous windows, for which Noise floor ≤ k

Figure 8.3 shall be interpreted in the same way as figure 8.2. E.g. with a certainty of 80 % two continuous frequency windows with a total size of 93 MHz or more are available when a noise floor of 20 dB(µV) is permissible.

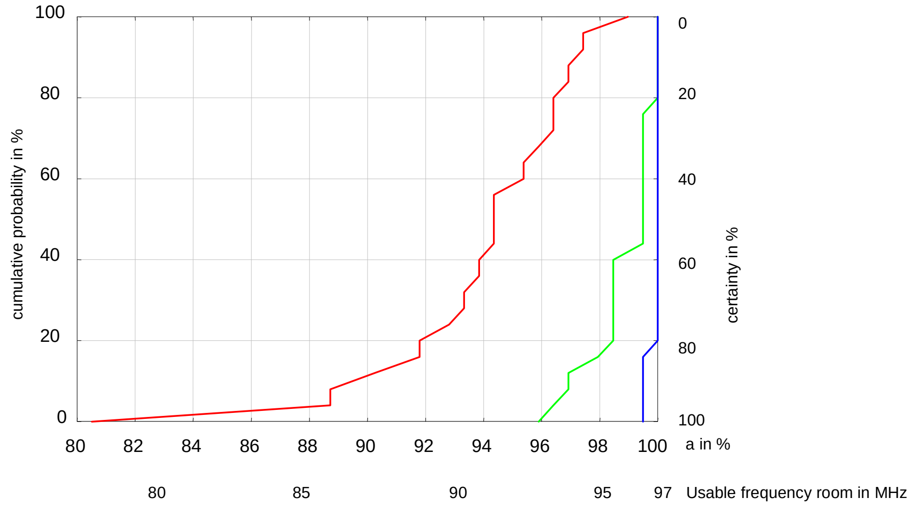
The distribution of the part of frequencies, for which noise floor is below a specified value k is shown in figure 8.4. This diagram can be interpreted in the following ways:

In 50 % of all measurement locations 94,3 % of the frequency room (3 MHz to 100 MHz) have a noise floor below 10 dB(µV). If a higher degree of certainty is required (e.g. 80 %) we can read:

In 20% of all measurement locations 98% of the frequency room (3 MHz to 100 MHz) have a noise floor below 20 dB(µV).

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

If a special modem design needs a noise floor, which is less than 10 dB(µV), the maximum usable frequency range is 92 % (89,2 MHz) with a certainty of 80 %.

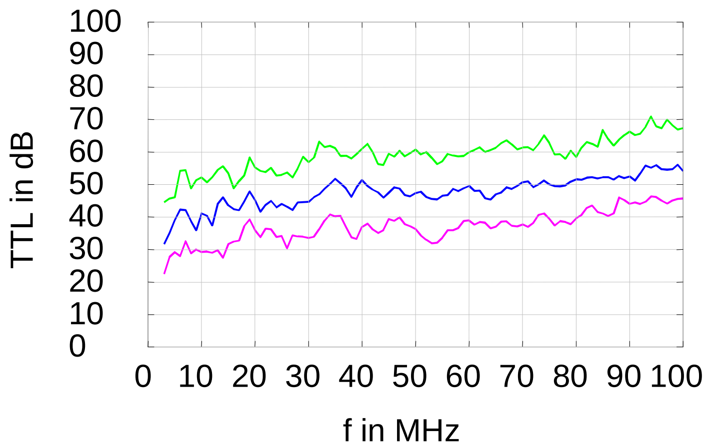


Line colour	k [dB(µV)]
Red	10
Green	20
Blue	30

Figure 8.4: Cumulative probability for the part of frequencies with a noise floor below k

9 Statistical evaluation of measured TTL

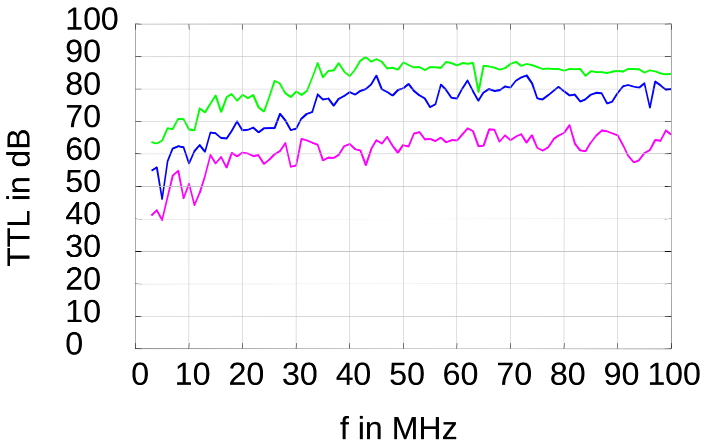
The general dependence of TTL on frequency can be seen in figures 9.1 to 9.4, where the cumulative probabilities are plotted on the TTL-frequency plane as contour plot.



Line colour	Cumulative probability
Green	80 %
Blue	50 %
Violet	20 %

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

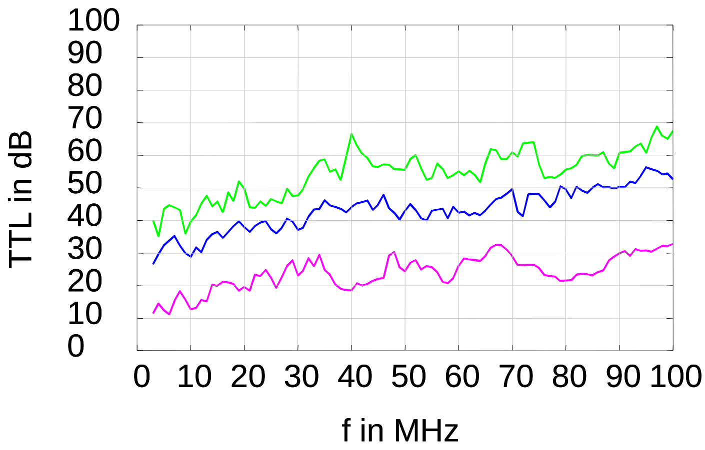
Figure 9.1: TTL as a function of frequency for all sites



Line colour	Cumulative probability
Green	80 %
Blue	50 %
Violet	20 %

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

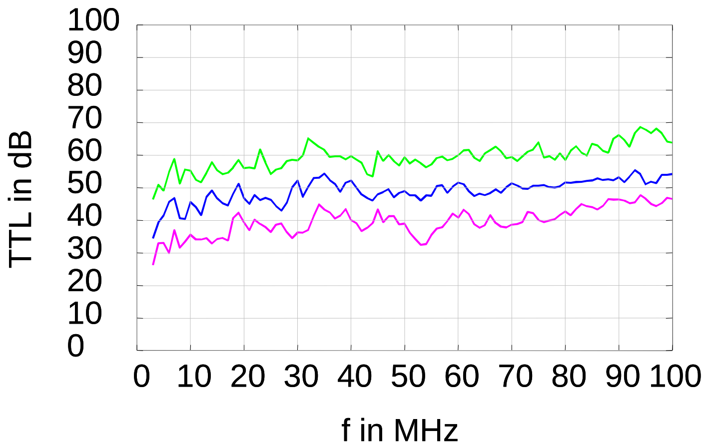
Figure 9.2: TTL as a function of frequency for all sites



Line colour	Cumulative probability
Green	80 %
Blue	50 %
Violet	20 %

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

Figure 9.3: TTL as a function of frequency for all sites

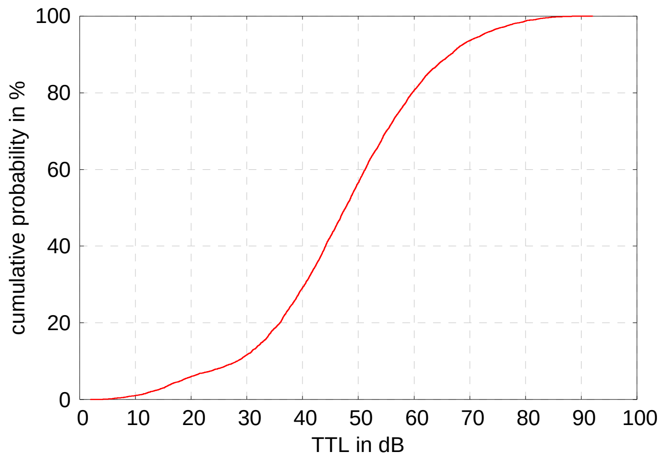


Line colour	Cumulative probability
Green	80 %
Blue	50 %
Violet	20 %

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

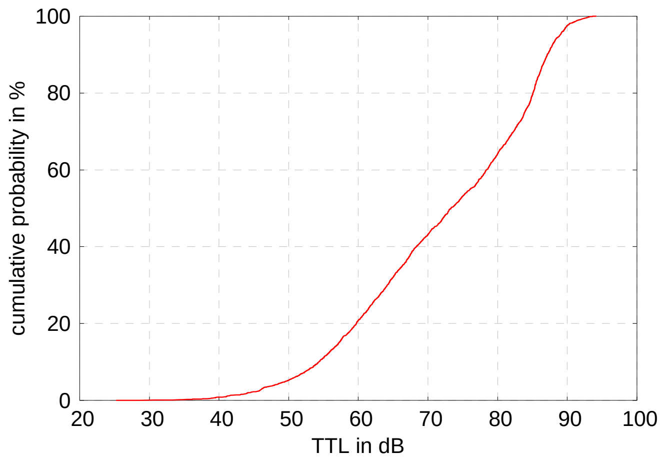
Figure 9.4: TTL as a function frequency for all sites

There is a slight increase of attenuation with frequency. By neglecting this frequency dependence, the diagrams of the cumulative probability of TTL may be drawn (see figures 9.5 to 9.8).



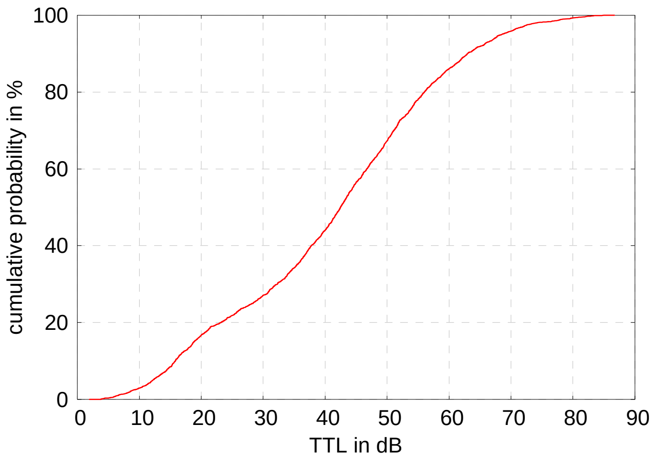
NOTE: Group A: same flat/house independent of phase

Figure 9.5: Cumulative probability of TTL for all sites and frequencies



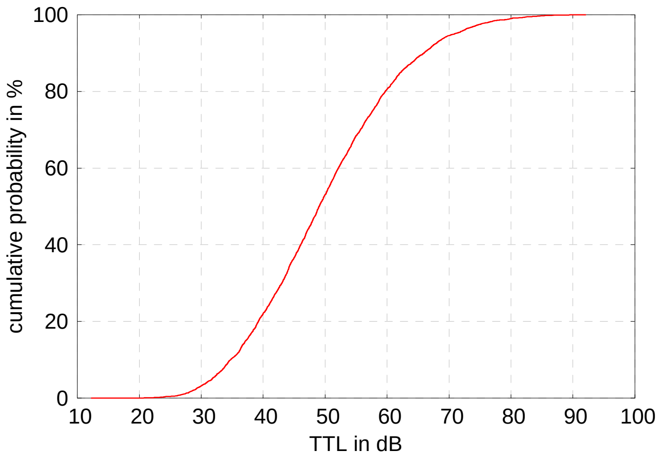
NOTE: Group B: different flat/house in neighbourhood independent of phase.

Figure 9.6: Cumulative probability of TTL for all sites and frequencies



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

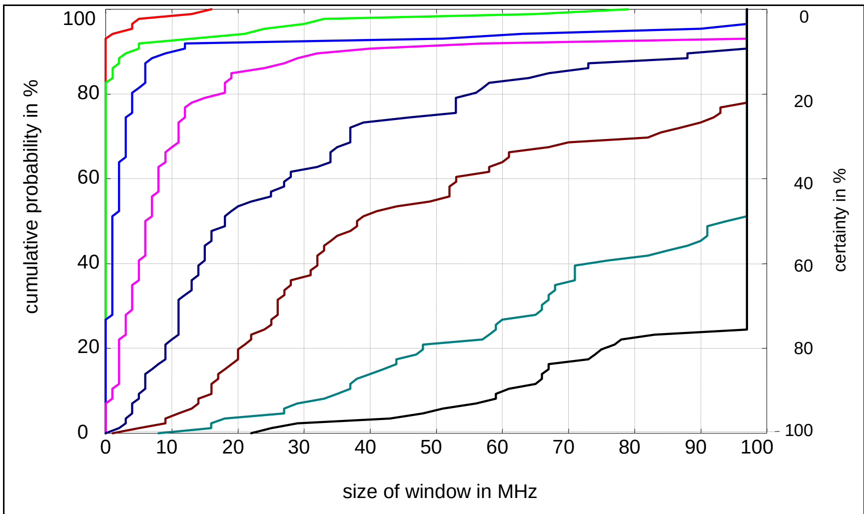
Figure 9.7: Cumulative probability of TTL for all sites and frequencies



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

Figure 9.8: Cumulative probability of TTL for all sites and frequencies

The distribution of the largest continuous window as defined in clause 6.2 is plotted in figures 9.10. From these figures it can be seen that e.g. for a certainty of 80 % the size of the largest continuous window is 48 MHz, if 70 dB attenuation is permissible for the channel.

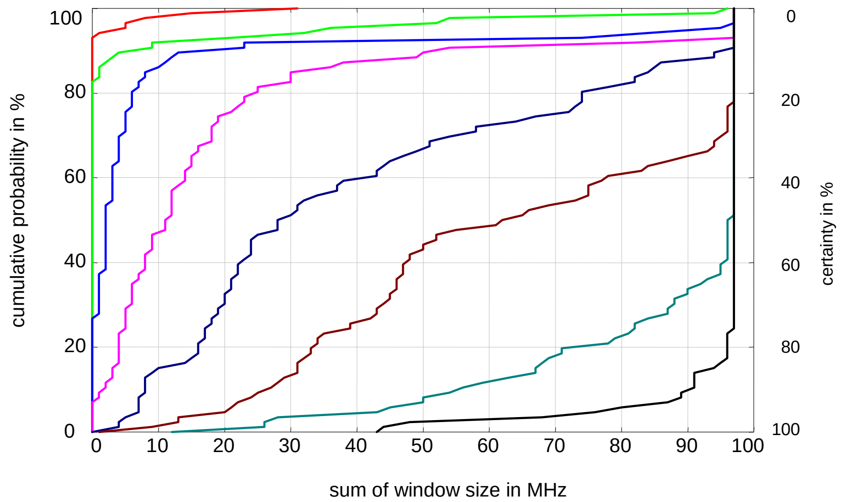


Line colour	k [dB]
Red	10
Green	20
Blue	30
Violet	40
Dark blue	50
Brown	60
Grey	70
Black	80

NOTE: Group A same flat/house

Figure 9.10: Cumulative probability for the largest continuous window with TTL below k

The distribution of the two largest continuous window as defined in clause 6.2 is plotted in figure 9.11. From these figures it can be seen that e.g. for a certainty of 80 % (20 % line) the sum of the sizes of the two largest continuous windows is 33 MHz, if 60 dB attenuation is permissible for the channel.

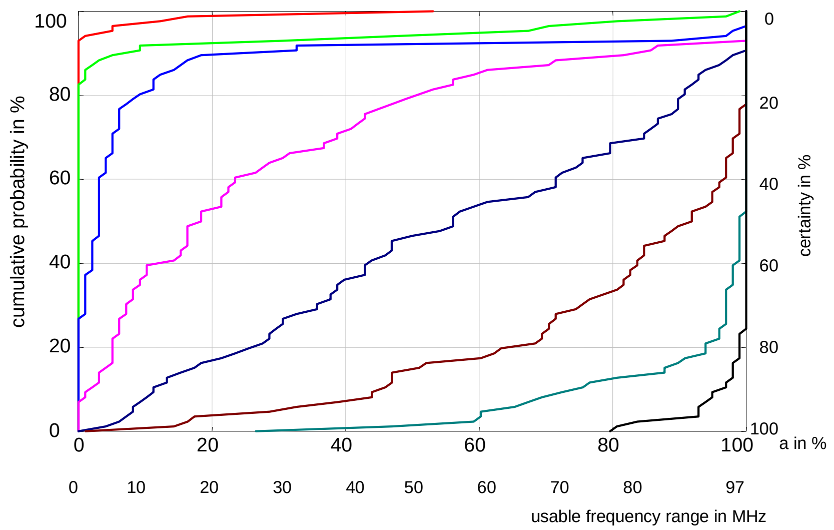


Line colour	k [dB]
Red	10
Green	20
Blue	30
Violet	40
Dark blue	50
Brown	60
Grey	70
Black	80

NOTE: Group A same flat/house.

Figure 9.11: Cumulative probability for the two largest continuous windows with TTL below k

The cumulative probability distribution of the part of usable frequencies as defined in clause 6.2 is plotted in figure 9.12. From these figures it can be seen that e.g. for a certainty of 80 %, 63 % of the frequency room can be used, if 60 dB attenuation is permissible for the channel.



Line colour	k [dB]
Red	10
Green	20
Blue	30
Violet	40
Dark blue	50
Brown	60
Grey	70
Black	80

NOTE: Group A same flat/house.

Figure 9.12: Cumulative probability for the part of frequencies with TTL below k

10 Statistical evaluation of Coupling Factor

10.1 Frequency Dependency

If the coupling factor behaviour shows no general tendency with frequency, all measurement points regardless of frequency can be used for statistical evaluation. A general frequency dependence can be established by calculating the regression line (especially its slope) with the least squares method for each coupling factor measurement. From all slopes the cumulative probability can be obtained in dependence of the slope. This function is plotted in figure 10.1. It can seen that there is a slight frequency dependence of about -0,03 (dB(µV/m)-dBm) / MHz. Obviously the LVDN is an effective radiator even for low frequencies. The decrease of coupling factor with increasing frequency can be explained by the attenuation of the lines, which also increases with frequency.

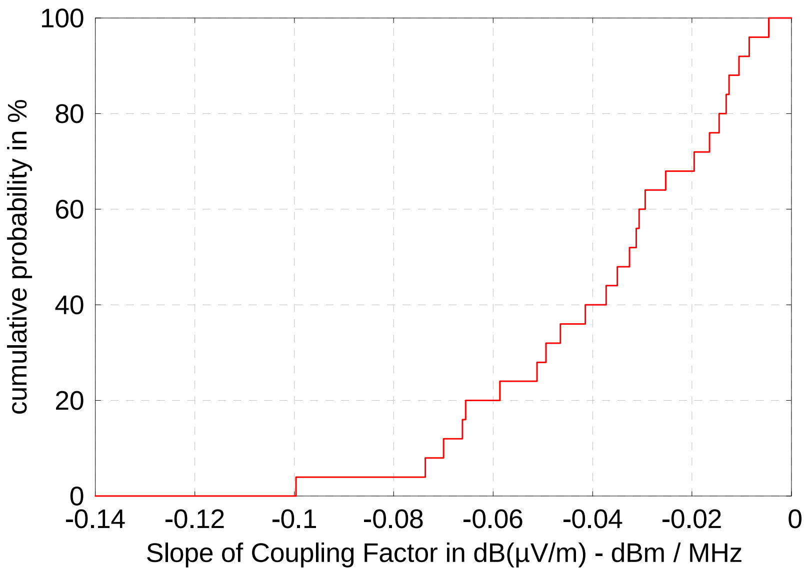


Figure 10.1: Cumulative probability of the slope of the regression line for the coupling factor

10.2 Cumulative Probability of Coupling Factor

Taking into account all frequencies and locations the cumulative probability in dependence of coupling factor is plotted in figure 10.2. As it can seen from this curve, the median coupling factor (50 %-value) is 45,3 dB(µV/m)-dBm. 80 % of all measurement points have a coupling factor of less than 53,8 dB(µV/m)-dBm.

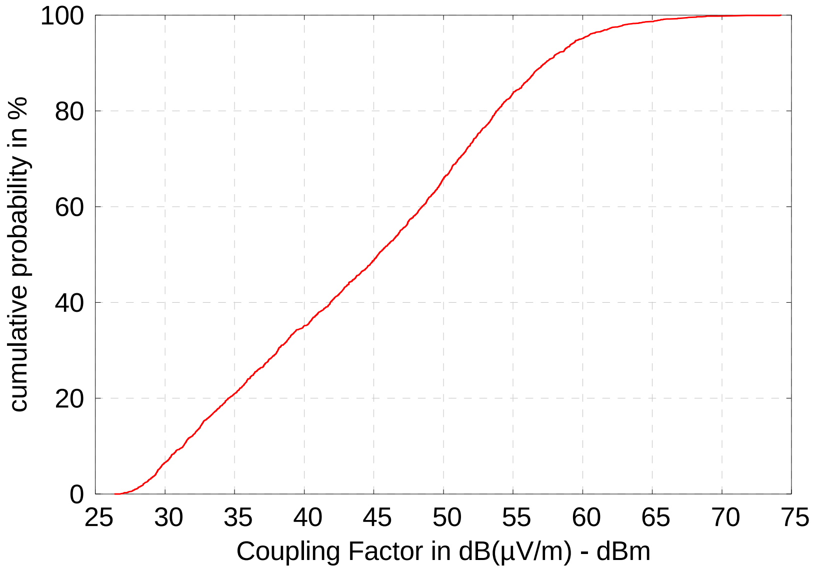


Figure 10.2: Cumulative probability in dependence of the coupling factor for all measurement frequencies and locations

History

Document history		
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