ETSI WG TM6

(ACCESS TRANSMISSION SYSTEMS ON METALLIC CABLES)

Permanent Document

TM6(06)05 – rev 5

Living List for Spectral Management
SpM - part 2
revision of TR 101 830-2

This document is the living list of current issues connected with ETSI's spectral management report TR 101 830, part 2 (*Technical methods for performance evaluations*). This work item is focussed on the revision of "Part 2", dedicated to calculation and measurement methods for evaluating what the performance of xDSL systems will be for various scenarios. The target date for achieving "working group approval" from ETSI-TM6 is scheduled for **November 2007**. (See minutes 071w14, delayed compared to the orginal work item sheet in 061w23.pdf)

Scope: The present document gives guidance on a common methodology for studying the impact of noise on xDSL performance (maximum reach, noise margin, maximum bitrate) when changing parameters within various Spectral Management scenarios. These methods enable reproducible results and a consistent presentation of the assumed conditions (characteristics of cables and xDSL equipment) and configuration (chosen technology mixture and cable fill) of each scenario. The revision could add to this:

- receiver performance models for all variants of VDSL, ADSL2plus, enhanced-SDSL and ADSL2.
- transmitter models for the same modems (PSD templates in stead of PSD masks, PSD shaping parameters
- models for crosstalk from multiple locations, such as topologies with customers distributed along the line (relevant for VDSL simulations) or branched topologies.
- additional example scenarios
- refining the generic DMT model by accounting for side-lobe pick-up
- etc.

The issues related to "Part 1" are beyond the scope of this living list.

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2. STUDY POINTS PART 2 (TECHNICAL METHODS FOR PERFORMANCE EVALUATIONS)

SP	Title	Owner	Status
2-1	Performance model for ADSL2	Bernd Heise (Infineon)	prov delete
2-2	Performance model for ADSL2plus	Bernd Heise (Infineon)	prov delete
2-3	Modelling sidelobe pick-up in DMT Receivers	Olivier van de Wiel (Broadcom	deleted
2-4	Multi node crosstalk models, restricted to the case that all LT nodes are co-located, and NT distributed	Czech Telecom (Milan Meninger)	Agreed
2-5	Multi node crosstalk models, with both LT nodes and NT nodes distributed	Czech Telecom (Milan Meninger)	Agreed
2-6	Basic transmitter/disturber model for VDSL2	Swisscom (Andreas Thöny)	US
2-7	Model for VDSL2 PSD template variations	Swisscom (Andreas Thöny)	US
2-8	Model for VDSL2 PSD shaping for remote deployment	Swisscom (Andreas Thöny)	US
2-9			
2-10			
2-11			
2-12			

The current agreed procedure for changing the status of living list items is in Annex A of TM6 working methods.

Part 2 study points

SP 2-1 Performance model for ADSL2

The performance of ADSL2 is different from the performance of ADSL, and a dedicated calculation model is desired. A useful performance benchmark for ADSL2 is unfortunately lacking, since there are currently no reach requirements in a standard that pushes these modem with extend spectrum to their true performance limits. Therefore this study point has also to address the way of preventing the inclusion of models in the SpM-2 standard that are predicting overoptimistic results

Related Contributions:

- *034t33, Sophia 2003 - Receiver models for G.992.3@A and G.992.5@A - TI*

SP 2-2 Performance model for ADSL2plus

The performance of ADSL2plus is different from the performance of ADSL, and a dedicated calculation model is desired. A useful performance benchmark for ADSL2plus is unfortunately lacking, since there are currently no reach requirements in a standard that pushes these modem with extend spectrum to their true performance limits. Therefore this study point has also to address the way of preventing the inclusion of models in the SpM-2 standard that are predicting overoptimistic results

Related Contributions:

- *034t33, Sophia 2003 - Receiver models for G.992.3@A and G.992.5@A - TI*

SP 2-3 Modelling sidelobe pick-up in DMT Receivers

In order to improve the validity of performance models for DMT receivers, the impact of sidelobe pick-up in DMT receivers may be a useful addition to the model, including a model for input filtering that reduces the impact of sidelobe pick-up. The main issues are detailed in 041t22, and this study point is to develop the text that should be added to the description of the DMT performance model.

Related Contributions:

- *991t30, Villach 1999 - Adopting HDSL2 components in SDSL (Fig 1 & table 1)*
- *034w13, Sophia 2003 - Sidelobe pick-up in DMT receivers - Alcatel, Conexant*
- *041t22, Sophia 2004 - Sidelobe pick-up in ADSL DMT receivers - Alcatel*
- *041t23, Sophia 2004 - Modeling filtering in ADSL receivers - Alcatel*

SP 2-4 Multi node crosstalk models, restricted to the case that all LT nodes are co-located, and NT distributed (*for VDSL from the exchange*)

A commonly used simplification of modeling crosstalk coupling in a loop assumes a two-node topology, as if all disturbers are co-located at the NT side as well as the LT side. In some cases, more advanced models for crosstalk coupling are required, accounting for the fact that NT modems are not co-located but "scattered" along the loop, and connected with branches. These models (without branching) have been used in various "VDSL from the exchange" studies, but a *punctual* description of that approach is lacking.

This study point is to develop a literal text proposal on a mathematical description to specify such a multi-node crosstalk model.

- *033w07, Sophia 2003 – Method on Xtalk Calculations in a Distributed Environment*
- *051t21, Sophia, feb 2005 – Distributed cable tree installation scenario – Czech Telecom*
- *052t06, Sophia, june 2005 –Generic crosstalk model, for one/multi node collocation – Czech Telecom*
- *052t07, Sophia, june 2005 –Crosstalk model, based on distribution of coupling – Czech Telecom*
- *053t22, Ghent, sept 2005 –Editorial changes for draft text of SP 2-44 (see LL used for creating SpM-2) – Czech Telecom*
- *054t17, Vienna, nov 2005 – US and DS equivalent crosstalk powers at one node/multi-node collocation - Czech Tel.*
- *054w20, Vienna, nov 2005 – WD20 Problems with proposed models for crosstalk from multiple locations -TNO*
- *061t06, Zurich, jan 2006 – Crosstalk One-node/Multi-node co-location model- Czech Telecom*
- *061w21, Zurich, jan 2006 – Examples of One-node/Multi-node co-location model- Czech Telecom*
- *061w25, Zurich, jan 2006 – Evaluating the crosstalk for a multi-node topology – TNO*
- *062t03, Sophia, may 2006 – Crosstalk One/Multi-node co-location model - Czech Telecom*
- *062w23, Sophia, may 2006 – Crosstalk One/Multi-node co-location model - Czech Telecom*
- *063t12r2, Sophia, sept 2006 – Evaluating crosstalk for multi-node topologies - TNO*
- *063t22, Sophia, sept 2006 – Comments to TD12 - Telefónica O2 Czech Republic*
- *064t24, Sophia, nov 2006 – Evaluating crosstalk for multi-node topologies (update) - TNO*
- *064w23, Sophia, nov 2006 – Editorial comments to TD24 - Telefónica O2 Czech Republic*
- *071t30, Sophia, feb 2007 - Clarifications to Text Proposal on Crosstalk Models - Swisscom*
- *072t09, Sophia, april 2007 – Refinements in Text Proposal on Crosstalk Models – Swisscom+TNO*

SP 2-5 Multi node crosstalk models, with both LT nodes and NT nodes distributed (*for VDSL from the cabinet*)

Somewhat similar to SP2-4, but now to model the crosstalk in case VDSL is deployed from the cabinet and other xDSL modems from the local exchange.

- *061t07, Zurich, jan 2006 – Crosstalk Multi-node/Multi-node co-location model- Czech Telecom*
- *063t12r2, Sophia, sept 2006 – Evaluating crosstalk for multi-node topologies - TNO*
- *063t22, Sophia, sept 2006 – Comments to TD12 - Telefónica O2 Czech Republic*

SP2-6: Basic transmitter/disturber model for VDSL2

è *To define a fixed PSD template (e.g. for VDSL2/Ex from the exchange) up to a certain loop length,*

It is the intention to elaborate a description of the PSD templates of several VDSL2 options (depending on bandplan, profile, deployment topology, …)

Related Contributions:

- *061t20, Zurich, jan 2006 - Issues concerning the description of VDSL2 PSD templates - Swisscom*
- *063t11, Sophia, sept 2006 – Text proposal on 998 VDSL2 PSD template for profiles 8b, 12a and 17a - Swisscom*
- *064t27, Sophia, nov 2006 – Text proposal on 998 VDSL2 PSD template for profiles 8b, 12a and 17a (update) - Swisscom*
- *064t22, Sophia, nov 2006 – Algorithmic approach for defining VDSL2 PSD templates for simulation purposes - TNO*
- *072t10, Sophia, april 2007 – Algorithmic model for VDSL2 transmitters - TNO*

SP2-7: Model for VDSL2 PSD Template Variations

è *To define a length-dependent PSD template (e.g. for VDSL2/Ex beyond that loop length)*
The VDSL2 Limit PSD Mask as described in European Annex B of G.993.2 allows to allocate the transmitting power to different frequency ranges taking into account the bit loading in order to get the best possible performance. The result of this SP shall be a description of the VDSL2 PSD Template for up- and downstream taking such variations into account.
Related Contributions:

- *061t20, Zurich, jan 2006 - Issues concerning the description of VDSL2 PSD templates – Swisscom*
- *See also contributions to studypoint SP2-6*

SP2-8: Model for VDSL2 PSD Shaping for remote deployment

è *To define a set that address PSD shaping (e.g for VDSL2/Cab from the cabinet, at specified distance between exchange and cabinet).*
The VDSL2 offers the flexibility to perform in a remote deployment a PSD shaping in order to reduce the disturbance on the DSLs deployed from e.g. the CO. The result of this SP shall be a description of the VDSL2 PSD shaping mechanism for simulations. Items to be considered are: • Distance between CO and cabinet • kind of protection (non protection, full protection, equal pain, …) • the type of DSL to protect (ADSL, ADSL2+, …) • shaping floor (e.g. -80 dBm/Hz) • fstart incl. MUF concept
Related Contributions:

- *061t20, Zurich, jan 2006 - Issues concerning the description of VDSL2 PSD templates - Swisscom*
- *See also contributions to studypoint SP2-6*

Text proposals, for inclusion in the revised SpM-2.

The text fragments below have been proposed for inclusion in the draft version of SpM part 2, but are still in the "under study" status. If agreement is achieved, they will be moved into the Draft

All references to a "part 3" of spectral management are to be removed, since this project has been discontinued

2 References

[1] ETSI TS 101 270-1 (V1.3.1): "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements".

[2] ITU-T Recommendation G993.2: "Very High Speed Digital Subscriber Line 2 (VDSL2)", March 2006.

[3] ITU-T Recommendation G997.1: "Physical layer management for digital subscriber line (DSL) receivers", june 2006.

Text portions, proposed for inclusion in clause 4

EDITORIAL NOTE. All values highlighted in blue are modifications compared to the originating text, contributed by TNO in 072t10. Please double-check all numbers, to ensure it is compliant with the ITU text and the latest views on VDSL2 modelling

4 Transmitter signal models for xDSL

4.17 Transmitter signal models for "VDSL1"

Same text as currently in clause 4.17, but replace "VSDL" by "VDSL1" to avoid confusion with the "VDSL2" models

4.18 Transmitter signal models for "VDSL2"

EDITORIAL NOTE. Al text fragments that are highlighted in blue have been updated to reflect the recent changes, found in the ITU amendment from February 2007, literal 2, and to assist the reader with additional clarity

The PSD templates for VDSL2 are to model the VDSL variants being defined in ITU specification G993.2 [2].

The complexity of VDSL2 (many flavours many kinds of PSD shaping/PBO in downstream and upstream, power restrictions) requires a break-down of the specification of a PSD template for a particular scenario. Figure 1 illustrates how the VDSL2 transmitter model is broken down into four individual building blocks. Each block has its own set of controlling parameters, to control one or more aspects of the output spectrum of VDSL2.

- A "PSD band constructor" that enables the bands requested by the user above a "*noise floor*" being defined for all frequency of interest.
- A "PSD shaper" that modifies the shape of an intermediate template PSD by a parametric formula, guided by the victim spectrum to be protected in the downstream and by the desired received signal in the upstream.
- A "PSD Notcher" that can "punch" notches in a shaped PSD, to prevent egress levels being too high in radio bands of interest.
- A "PSD power restrictor" that can modify a PSD (template) in such a way that the aggregate power of the PSD does not exceed some pre-defined upper limit.

In addition, pre-defined tables are provided for the "PSD band constructor" to generate spectra that are compliant with those being defined in the ITU specification G993.2 [2].

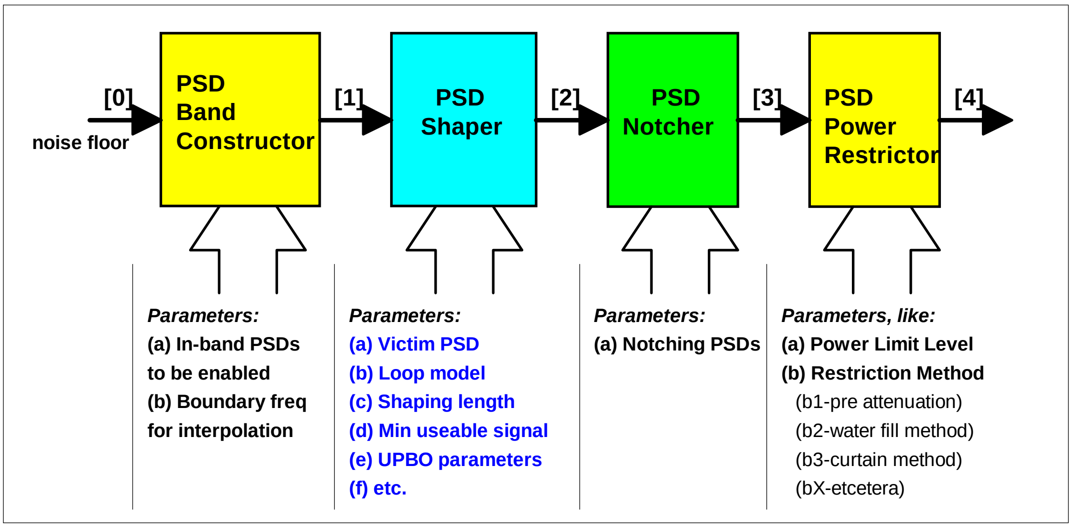


Figure 1: Building blocks of a VDSL2 transmitter model, for defining a wide range of PSD templates with only a few PSD tables and formulas.

4.18.1 Building block #1 for "PSD Band Constructor"

Building block #1 for the "PSD band constructor" generates a static PSD template, selected from a set of spectra (in-band PSDs). Pre-defined spectra are provided by means of break point tables, up to 30 MHz, but the use of the algorithmic model is not restricted to these tables.

The model in figure 2 starts from a PSD, representing a *noise floor*, and combines it subsequently with as many in-band PSDs as required. A pre-defined noise floor is provided as well.

Combining means within this context: taking the *maximum* of two PSD levels, where one PSD is the selected in-band PSD, and the other is a PSD being built-up in previous steps (starting with the noise floor). This maximum is to be evaluated for all frequencies within the band of the selected in-band PSD. Outside that band, the PSD will remain unchanged.

Figure 3 visualizes such a step in reconstructing a resulting PSD from these two "input" PSDs.

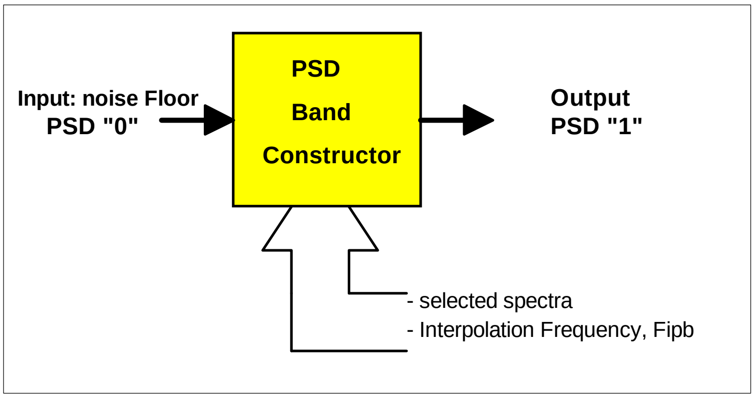


Figure 2: Conceptual description of the "PSD Band Constructor" block

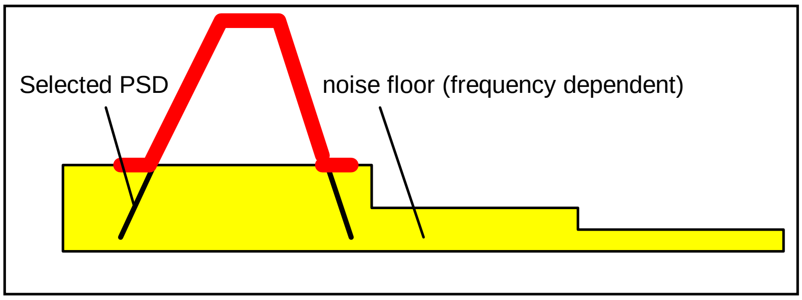


Figure 3: Illustration on how building block #1 combines two PSDs into a third.

The in-band PSDs can have arbitrary spectra and can be defined in many ways. A commonly used approach is a PSD definition by means of break-point tables. Such a PSD is derived via interpolation, by interconnecting the breakpoints via a straight line when plotted on a linear dB scale. This is called “linear” interpolation, when plotted on a linear frequency axis, “logarithmic” interpolation, when plotted on a logarithmic axis, and “mixed” interpolation when both methods are applied in different frequency bands. When mixed interpolation applies, the boundary frequencies are to be specified as well.

For the purpose of VDSL2 modelling pre-defined in-band spectra are provided by means of breakpoint tables, and specified in table 3 to 13 for all band plans and profiles being identified in G993.2 [2]. For all cases only one boundary frequency applies (f_{ipb}), based on the following convention:

- if $f \le f_{ipb}$ do logarithmic interpolation
- if $f > f_{ipb}$ do linear interpolation

Suitable noise floors are pre-defined in table 1, but the model is not restricted to any of these pre-defined PSDs.

Table 1: Pre-defined noise floors, derived from clause B4.1 in G993.2 [2], as starting PSD for building block #1 (NF2 is intended for transmissions above 12 MHz)

	NF1_998	NF1_997	NF2
f [MHz]	**P [dBm/Hz]**	**P [dBm/Hz]**	**P [dBm/Hz]**
0	–100	–100	–100
4M	–100	–100	–100
4M	–110	–110	–110
5.1M	interp	–110	interp
5.1M	interp	–112	interp
5.2M	–110	interp	interp
5.2M	–112	interp	interp
7.05M	interp	interp	–110
7.05M	interp	interp	–112
30M	–112	–112	–112

4.18.2 Building block #2 for “PSD Shaper”

Building block #2 is typically algorithmic in nature, roughly following the way it is formulated in G997.1 [3]. A difference is that shaping is to be applied in this building block to PSD *templates* and not to PSD *masks*. The model in figure 4 provides the generic idea, but details are currently left for further study. The algorithm is expected to be rather complicated.

NOTE The details of specifying block#2 is for further study. Below are some initial thoughts on how to implement this building block

To model DPBO aspects in downstream signals, the following parameters may apply:

- The PSD template of a victim signal (level at central office) that is to be protected by proper shaping is typically an ADSL2plus downstream signal. This signal may distinct between the “annex-A” and “annex-B” variants for both the overlapping and non-overlapping spectra. This template is related to DPBO_EPSD specified in G997.1.
- A pair of (f_{min}, f_{max}) to indicate the band in which shaping is applied to the VDSL spectrum. These are typically the **DPBO_FMIN** and **DPBO_FMAX**

parameters specified in G997.1.

- The loop model is another "parameter", such as for instance a polynomial curve (like the e-side cable model "**DPBO_ESCM**" used in G997.1, using parameters like A,B,C), or even more advanced models like "TP100" or "TP150" specified by ETSI as VDSL test loop.
- The shaping length can be another parameter, which can be the actual loop-length between central office and cabinet, or something shorter. This is typically the **DPBO_ESEL** parameter specified in G997.1, representing the so called "E-Side Electrical Length" (in dB).
- The minimum useable victim signal can be a fifth parameter, which can even change with the shaping length. Its value is essential to determine up to what frequency the VDSL2 PSD has to be shaped to protect the victim PSD. This is typically the **DPBO_MUS** parameter specified in G.997.1, and is called "Minimum Useable Signal".
- More parameters can be applied, when appropriate.

To model UPBO aspects in upstream signals, several methods can be used. Currently, only one method is defined in the standard, the *reference length*. However, in the future, new methods can be included and supported.
Considering the *reference length* method only, he following parameters may apply:

- The PSD template desired at the receiver side (cabinet), defined by [a,b] per band parameters.
- The frequency at which kl_0 will be evaluated (e.g. 1 MHz, 3.75 MHz, etc).
- More parameters can be applied, when appropriate.

All details are left for further study, but the concept remains the same as for downstream and its implementation is straightforward

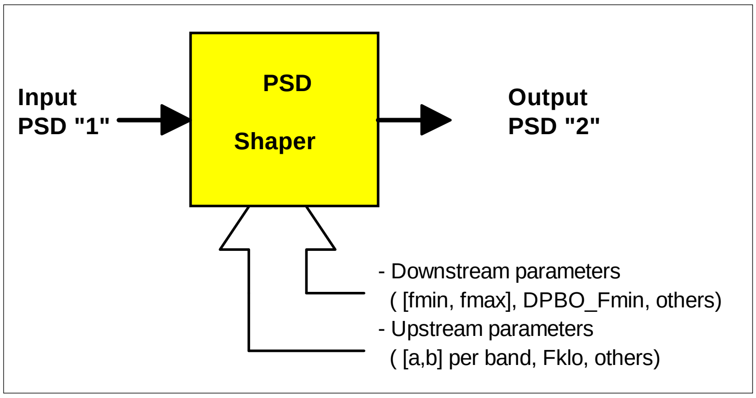


Figure 4: Conceptual description of the "PSD Shaper" block

4.18.3 Building block #3 for "PSD notcher"

Building block #3 enables to punch notches in the spectrum, to reduce the effect of unwanted radiated emissions from VDSL2 causing undue interference to existing licensed users of that part of the spectrum. The description of this building block is roughly the same as for building block #2 ("PSD band constructor"), but its influence on the overall PSD will be different when shaping (in block #3) has been applied. The model in figure 5 starts from an input PSD and combines it subsequently with as many notching PSDs as required.
Combining means within this context: taking the *minimum* of two PSD levels, where one PSD is the selected notching PSD, and the other is a PSD being built-up in previous steps. This minimum is to be evaluated for all frequencies within the band of the selected notching PSD. Outside that band, the PSD will remain unchanged.

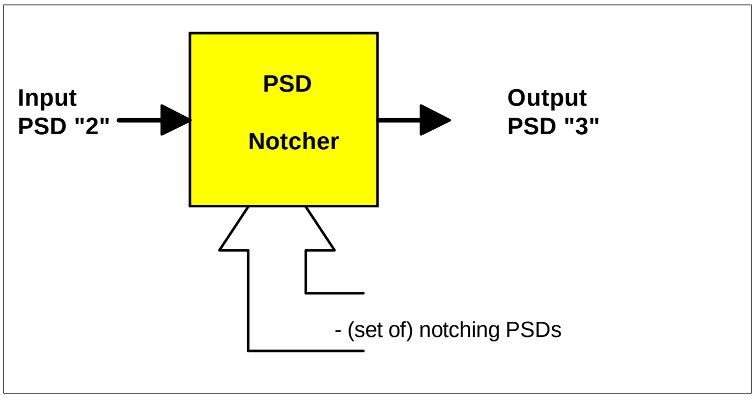


Figure 5: Conceptual description of the "PSD Notcher" block

Table 2 summarizes a set of pre-defined notching PSDs, suitable for reducing egress into internationally standardized amateur radio bands. The model is not restricted to these pre-defined notching PSDs. The numbers are taken from the ETSI VDSL1 standard [1]. If required, this notching can be repeated for multiple frequency intervals when more bands are to be notched. In that case the controlling parameter of this model is a *set* of notching PSDs.

Table 2: Break point tables of several pre-defined notching PSDs

Band to be notched	f [MHz]	P [dBm/Hz]
'NB1'	1.81 2.00	-80 -80
'NB2'	3.50 3.80	-80 -80
'NB3'	7.00 7.10	-80 -80
'NB4'	10.10 10.15	-80 -80
'NB5'	14.00 14.35	-80 -80
'NB6'	18.068 18.168	-80 -80
'NB7'	21.000 21.450	-80 -80
'NB8'	24.890 24.990	-80 -80
'NB9'	28.000 29.100	-80 -80

4.18.4 Building block #4 for "PSD Power Restrictor"

Building block #4 enables to cut-back the overall PSD when its aggregate power appears to be above a certain power limit. Such a cut-back is to be applied when for instance a modem implementation is unable to generate powers beyond that limit, or when the output PSD has to be compliant with maximum values specified by the profiles from G993.2 [2].

Different modem implementations may follow different strategies to cope with power limitations, and therefore different restriction methods can be applied to this model. A few restriction methods that can ensure that the aggregate power of a modified PSD does not exceed a certain maximum value are pre-defined below, but other methods are not excluded:

- ***Attenuator method***. This power restriction requires an algorithm that causes a (frequency *in*dependent) attenuation of the full PSD. When the aggregate power of the PSD exceeds a specified limit, the algorithm is to increase this attenuation until a value that makes the aggregate power of the PSD equal to the specified limit. This method is very simple, and is often inadequate to approximate the power restriction in a real modem implementation.
- ***Water-filling method***. This power restriction requires an algorithm that clips all PSD values above a certain (frequency independent) “ceiling PSD value”. When the aggregate power of the PSD exceeds a specified limit, the algorithm is to lower this ”ceiling” down to a value that makes the aggregate power of the PSD equal to the specified limit. This method is typically iterative in nature but rather straightforward.
- ***Curtain method***. This power restriction requires an algorithm that replaces all PSD values up to a certain “curtain” frequency by a pre-defined (frequency independent) “floor PSD value”. When the aggregate power of the PSD exceeds a specified limit, the algorithm is to raise this ”curtain” frequency up to a value that makes the aggregate power of the PSD equal to the specified limit. This method is also typically iterative in nature and rather straightforward as well.

Other methods may be applied too, but have not been described here.

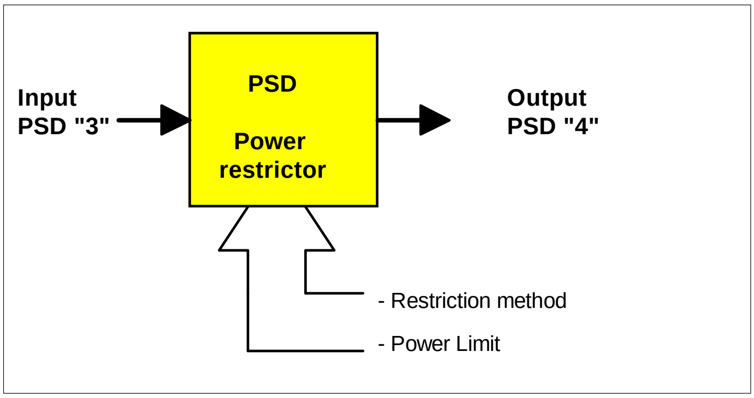


Figure 6: Input/Output Baseline PSD Power Restrictor

4.18.5 Pre-defined downstream tables for “PSD Band Constructor”

The PSD band constructor in building block #1 can be controlled via an arbitrary number of in-band PSDs. Pre-defined in-band PSDs for downstream transmission are summarized in table 4 to 8 and specified by means of breakpoints. Each in-band spectrum has its own (unique) identifier (summarized in table 3), for convenient referencing. A full VDSL2 transmit signal can be built-up from a proper selection of these in-band spectra. Example of meaningful combinations can be found in table [14].

The values are constructed from the breakpoints of G993.2 masks [2], roughly by correcting 3.5dB difference between mask and template for in-band frequencies, and roughly by corrected the PSD according to the constraints in 1 MHz resolution bands for out-of-band frequencies. In addition, some of the pre-defined values are adjusted via a pragmatic compromise between simplicity and ITU details.

Table 3: Summary of pre-defined in-band spectra, for downstream

downstream identifiers for in-band spectra	**downstream identifiers for in-band spectra**
DS.1L.a_998	Tables defining in-band spectra suitable for band plan 997 are left for further study
DS.1L.b_998	
DS.1X.r_998	
DS.1X.b_998	
DS.2.r_998	
DS.2.b_998	
DS.3.p1_998	
DS.3.p2_998	
DS.3.p3_998	
DS.3.p4_998	
DS.4.p1_998	

NOTE The identifiers in table 3 enable the recognition of some of the characteristics of the in-band spectra:

The band suffix 1L refers to the *Legacy* frequencies (below 2.2 MHz) of the first band, and 1X to the *eXtended* frequencies (above 2.2MHz) of the first band.

The PSD suffices *a* and *b* (in DS.1L.a and DS.1L.b) refer to the "over POTS" or the "over ISDN" variants, specified in "annex A" and "annex B" of ADSL2/ADSL2plus.

The PSD suffices *r* and *b* (in DS.1X.r and DS.1X.b) indicate if the power levels are derived from *regular* or *boosted* masks.

The PSD suffices *p#* (like in DS.3.p4 and in DS.4.p1) have no special meaning and are only to distinguish between different PSD variants.

The extensions "997" and '998" refer to the different band plans of VDSL2.

Table 4: Pre-defined in-band spectra for DS.1-legacy

f **[Hz]**	**DS.1L.a_998**	**DS.1L.b_998**
	P **[dBm/Hz]**	***P*** **[dBm/Hz]**
0	-100	-100
3999	-100	-100
4000	-96	-96
80000	-76	interp
101200	interp	-96
137999	-47.7	interp
138000	-40	interp
227110	interp	-65.5
275999	interp	-52
276000	interp	-40
1104000	-40	-40
1622000	-50	-50
2208000	-51.5	-51.5

Table 5: Pre-defined in-band spectra for DS.1-extended

f **[Hz]**	**DS.1X.r_998**	**DS.1X.b_998**
	P **[dBm/Hz]**	***P*** **[dBm/Hz]**
2208001	-51.5	-51.5
2249000	-53	interp
2500000	-60	interp
3749999	-60	-54.7
3750000	-83.5	-83.5
3894760	-100	-100
3999999	-100	-100
4000000	-110	-110

Table 6: Pre-defined in-band spectra for DS.2

	DS.2.r_998	**DS.2.b_998**
f [Hz]	***P*** [dBm/Hz]	***P*** [dBm/Hz]
4999999	-110	-110
5000000	-112	-112
5055624	-112	-112
5055625	-100	-100
5199999	-83.5	-83.5
5200000	-60	-56.2
8499999	-60	-58.3
8500000	-83.5	-83.5
8644566	-100	-100
8644567	-112	-112

Table 7: Pre-defined in-band spectra for DS.3

	DS.3.p1_998	**DS.3.p2_998**	**DS.3.p3_998**	**DS.3.p4_998**
f **[Hz]**	***P*** **[dBm/Hz]**	***P*** **[dBm/Hz]**	***P*** **[dBm/Hz]**	***P*** **[dBm/Hz]**
11825000	-112	-112	-112	-112
11855638	interp	-112	interp	-112
11855639	interp	-100	interp	-100
11999999	interp	-83.5	interp	-83.5
12000000	interp	-60	interp	-60
13855658	-112	interp	-112	interp
13855659	-100	interp	-100	interp
13999999	-83.5	interp	-83.5	interp
14000000	-60	interp	-60	interp
17664000	-60	-60	interp	interp
21000000	-83.5	-83.5	interp	interp
21372373	-100	-100	interp	interp
21372374	-112	-112	interp	interp
21449999	interp	interp	-60	interp
21450000	interp	interp	-83.5	interp
21594776	interp	interp	-100	interp
21594777	interp	interp	-112	interp
24889999	interp	interp	interp	-60
24890000	interp	interp	interp	-83.5
25034810	interp	interp	interp	-100
25034811	interp	interp	interp	-112
30000000	-112	-112	-112	-112

Table 8: Pre-defined in-band spectra for DS.4

	DS.4.p1_998
f **[Hz]**	***P*** **[dBm/Hz]**
12000000	-112
24745527	-112
24745528	-100
24889999	-83.5
24890000	-60
29999999	-60
30000000	-83.5
30096499	-100
30096500	-112
31000000	-112

4.18.6 Pre-defined upstream tables for “PSD Band Constructor”

The PSD band constructor in building block #1 can be controlled via an arbitrary number of in-band spectra. Pre-defined in-band spectra for upstream transmission are summarized in table 10 to 13 and specified by means of breakpoints. Each in-band spectrum has its own (unique) identifier (summarized in table 9), for convenient referencing. A full VDSL2 transmit signal can be built-up from a proper selection of these in-band spectra. Example of meaningful combinations can be found in table 14.

The values are constructed from the breakpoints of G993.2 masks [2], roughly by correcting 3.5dB difference between mask and template for in-band frequencies, and roughly by corrected the PSD according to the constraints in 1 MHz resolution bands for out-of-band frequencies. In addition, some of the pre-defined values are adjusted via a pragmatic compromise between simplicity and ITU details.

Table 9: Overview of pre-defined in-band spectra for upstream

Upstream identifiers for in-band spectra	**Upstream identifiers for in-band spectra**
US.0.p1_998	Tables defining in-band spectra suitable for band plan 997 are left for further study
US.0.p2_998	
US.0.p3_998	
US.0.p4_998	
US.1.r_998	
US.1.b_998	
US.2.r_998	
US.2.b_998	
US.2.bx_998	
US.3.p1_998	
US.3.p2_998	

NOTE The identifiers in table 9 enable the recognition of some of the characteristics of the in-band spectra:
The PSD suffices *p#* (like in US.0.p2 and US.3.p1) have no special meaning and are just to distinguish between different PSD variants.
The PSD suffices *r* and *b* (like in US.1.r and US.1.b) indicate if the power levels are derived from *regular* or *boosted* masks.
The PSD suffix *bx* (used in US.2.bx) indicates that the power level is not only derived from the “boosted” mask but that is has been *expanded* with frequencies above 12 MHz.

Table 10: Pre-defined in-band spectra for US.0

f **[Hz]**	**US.0.p1_998**	**US.0.p2_998**	**US.0.p3_998**	**US.0.p4_998**
	P **[dBm/Hz]**	***P*** **[dBm/Hz]**	***P*** **[dBm/Hz]**	***P*** **[dBm/Hz]**
0	-100	-100	-100	-100
3999	-100	-100	-100	-100
4000	-96	-96	-96	-96
25875	-38	interp	-41	-96
50000	interp	-93.5	interp	-93.5
80000	interp	-85.3	interp	-85.3
120000	interp	-38	interp	-38
138000	-38	interp	interp	interp
243000	-96.7	interp	interp	interp
276000	interp	-38	-41	-38
405125	-100	interp	interp	interp
486810	interp	interp	-100	interp
501500	interp	-100	interp	-100
686000	-100	-100	-100	-100

Table 11: Pre-defined in-band spectra for US.1

	US.1.r_998	US.1.b_998
f [Hz]	*P* [dBm/Hz]	*P* [dBm/Hz]
3575001	-100	-100
3605175	-100	-100
3749999	-83.5	-83.5
3750000	-60	-54.7
5199999	-60	-56.2
5200000	-83.5	-83.5
5344693	-100	-100
5344694	-112	-112

Table 12: Pre-defined in-band spectra for US.2

	US.2.r_998	US.2.b_998	US.2.bx_998
f [Hz]	*P* [dBm/Hz]	*P* [dBm/Hz]	*P* [dBm/Hz]
8355624	-112	-112	-112
8355625	-100	-100	-100
8499999	-83.5	-83.5	-83.5
8500000	-60	-58.3	-58.3
10000000	interp	-59	-59
11999999	-60	-59	-59
12000000	-83.5	-83.5	-60
12144761	-100	-100	interp
12144762	-112	-112	interp
13999999	interp	interp	-60
14000000	interp	interp	-83.5
14144781	interp	interp	-100
14144782	interp	interp	-112
15000000	-112	-112	-112

Table 13: Pre-defined in-band spectra for US.3

	US.3.p1_998	US.3.p2_998
f [Hz]	*P* [dBm/Hz]	*P* [dBm/Hz]
21275000	-112	-112
21305249	-112	interp
21305250	-110	interp
21449999	-83.5	interp
21450000	-60	interp
24745847	interp	-112
24745848	interp	-100
24889999	-60	-83.5
24890000	-83.5	-60
25034810	-100	interp
25034811	-112	interp
29999999	interp	-60
30000000	interp	-83.5
30096499	interp	-100
30096500	interp	-112
31000000	-112	-112

4.18.7 Example definitions of VDSL2 transmitters

The above pre-defined break point tables enable the construction of all PSD combinations (profiles and band plans) being identified in G993.2 [2]. For example, table 14 shows a full elaboration for several ITU profiles within limiting mask “B8-4”, also known as “998-M2x-A”. In this example, shaping and notching is disabled. The profiles differ in their combination of allocated bands (within the limiting mask) and maximum power. When a VDSL2 transmitter is specified in this way, its output signal is fully defined.

Table 15 shows for each limiting masks being defined in G993.2 [2] what break-point tables can be considered when constructing the PSD for a specific profiles. A full elaboration for all possible combinations has been omitted here for sake of brevity.

Table 14: Full elaboration of the VDSL2 transmit PSD for a few profiles within limiting mask “B8-4”.

ITU profile + limiting mask	PSD Band constructor		PSD Shaper	PSD Notcher	PSD Power restrictor
8a, B8-4 (8a, 998-M2x-A)	**NF1 f_{ipb} = 138 kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.0.p1_998 US.1.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
8b, B8-4 (8b, 998-M2x-A)	**NF1 f_{ipb} = 138 kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**20.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.0.p1_998 US.1.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
8c, B8-4 (8c, 998-M2x-A)	**NF1 f_{ipb} = 138 kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**11.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.0.p1_998 US.1.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
8d, B8-4 (8d, 998-M2x-A)	**NF1 f_{ipb} = 138kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**17.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.0.p1_998 US.1.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
12a, B8-4 (12a, 998-M2x-A)	**NF1 f_{ipb} = 138kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.0.p1_998 US.1.b_998 US.2.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
12b, B8-4 (12b, 998-M2x-A)	**NF1 f_{ipb} = 138kHz**	**DS.1L.a_998 DS.1X.b_998 DS.2.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**
	NF1 f_{ipb} = 3575 kHz	**US.1.b_998 US.2.b_998**	**<none>**	**<none>**	**14.5 dBm Water-fill**

Table 15: Summary of the set of break-point tables that may play a role within each limiting mask being defined in G993.2 [2].

Mask name	DS.1L.a	DS.1L.b	DS.1X.r	DS.1X.b	DS.2.r	DS.2.b	DS.3.p1	DS.3.p2	DS.3.p3	DS.3.p4	DS.4.p1		US.0.p1	US.0.p2	US.0.p3	US.0.p4	US.1.r	US.1.b	US.2.r	US.2.b	US.2.bx	US.3.p1	US.3.p2
B8-1	×		×		×								×				×		×				
B8-2		×	×		×									×			×		×				
B8-3	×		×		×												×		×				
B8-4	×			×		×							×					×		×			
B8-5		×		×		×									×			×		×			
B8-6		×		×		×										×		×		×			
B8-7	×			×		×												×		×			
B8-8	×			×		×	×											×			×		
B8-9		×		×		×	×											×			×		
B8-10		×		×		×		×										×		×			
B8-11	×			×		×		×					×					×		×			
B8-12		×		×		×		×								×		×		×			
B8-13	×			×		×			×		×							×			×	×	
B8-14		×		×		×			×		×							×			×	×	
B8-15		×		×		×				×								×		×			×
B8-16	×			×		×				×								×		×			×
B7-xx	under study																						

Text portions, proposed for inclusion in clause 8

8 Crosstalk models

Crosstalk is commonly a dominant contributor to the overall disturbance that impairs a transmission. Crosstalk models are to evaluate how much crosstalk originate from various disturbers that are distributed over the local loop wiring. In practice this is not restricted to a one-dimensional cable topology, since wires may fan out into different directions to connect for instance different customers to a central office.

This clause summarizes basic models for evaluating crosstalk in various scenarios. The models are presented here as individual building blocks, but a full analysis requires the use of a combination of these blocks.

8.1 Basic models for crosstalk cumulation

Cumulation models relate the crosstalk powers generated by multiple disturbers with the *number* and *type* of these disturbers.

The meaning of *the* crosstalk power is not obvious. When a cable with N wire pairs is filled-up completely with similar disturbers, the resulting crosstalk power in each wire-pair (from N-1 disturbers connected to the other wire-pairs) is maximal and therefore unambiguous. This upper limit is the saturated crosstalk power for that type of disturber, for that particular wire-pair.

However if the number M of disturbers is lower ($M<N$-1), this crosstalk power will commonly change when another combination of M wire-pairs will be chosen. So an exact expression for the resulting crosstalk, as function of the *number* and *type* of disturbers, does not exist if it remains unknown to which wire-pairs they are connected.

What does exist are crosstalk powers that occur with a certain probability. To illustrate that, consider an experiment that connects 30 disturbers to a cable with 100 wire pairs in 100.000 different ways. If the resulting noise is observed in one particular wire-pair, it is most likely that 100.000 different crosstalk noise powers will be observed. The result of such a “probability experiment” is therefore not a single power, but a (wide) range of powers with a certain probability distribution.

Within this range, a certain crosstalk noise power can be found that is not exceeded in 99% of the cases (or 80% or 65% or whatsoever). That power level is named a *probability limit* for a particular wire pair.

A cumulation model predicts how such a *limit* (at given probability) behaves as a function of number and type of disturbers. The use of 99% worst case limits is commonly used. When a study evaluates the performance under a noise power that equals such a probability limit, then the actual performance will in “most cases” be better then predicted in this way. The use of 100% worst case limits is commonly avoided, to prevent for over-pessimistic analyses.

8.1.1. Uniform cumulation model

The uniform cumulation model is restricted to the special case that all disturbers are from the same type. It assumes that the probability limit from M disturbers is proportional with M^{1/K_n}, where K_n is an empirical parameter (values like K_n=1/0,6 are commonly used for 99% worst case analyses).

Expression 1 shows this uniform cumulation model. It uses a frequency dependent quantity P_{Xd} (the *normalized crosstalk power*) as intermediate result, that has been derived from the saturated crosstalk power (maximum cross talk power at 100% cable fill), for that particular type of disturber. This saturated crosstalk power will most likely be different for each individual wire-pair, but a worst case value of all wire-pairs could be selected if a cable is to be modelled as a whole. Hence Expression 1 can be applied to predict probability limits in either a single wire-pair or in a cable as a whole. The difference is that in the latter case $P_X(N\text{-}1, f)$ is the saturated crosstalk power in the worst-case wire-pair (having the highest saturated value) and that $P_X(M,f)$ represents a statistical value (e.g. a 99% worst case value) taken from much more values then in the single wire-pair case.

The reliability of the model improves when M>>1. By definition, the model provides an exact value for the crosstalk power experienced within a specific victim wire-pair when M=(N-1).

$$P_X(M,f) = M^{1/K_n} \times P_{Xd}(f) \qquad \text{with } P_{Xd}(f) \overset{def}{=} \frac{P_X(N-1,f)}{(N-1)^{1/Kn}}$$

N = number of wire pairs in the cable
M = number of similar disturbers (1 ≤ M ≤ N-1)
$P_X(M, f)$ = probability limit of crosstalk from M similar disturbers
$P_X(N\text{-}1, f)$ = saturated crosstalk power (at a complete cable fill)
$P_{Xd}(f)$ = normalized crosstalk power, for that particular disturber type
K_n = empirical constant (K_n=1/0,6 is commonly used)
f = frequency

Expression 1: Definition of the uniform cumulation model

NOTE: For some cables used in the Netherlands, it has been observed that a slightly different value for K_n provides a better fit with measurements on these cables. For instance, values between 1/0,6 and 1/0,8 have been observed. For those cables, these values for K_n may be more appropriate for use in expression 1 and associated expresions.

8.1.2. FSAN sum for crosstalk cumulation

The FSAN sum is a cumulation model that is also applicable when different disturbers are involved. It is a generalization of the uniform cumulation model, and is specified in expression 2. The (frequency dependent) probability limit of the crosstalk, caused by M individual disturbers, is expressed below.

$$P_X(M,f) = \left(P_{Xd,1}(f)^{K_n} + P_{Xd,2}(f)^{K_n} + P_{Xd,3}(f)^{K_n} + \ldots + P_{Xd,M}(f)^{K_n}\right)^{1/K_n}, \quad with\ K_n = \frac{1}{0{,}6}$$

M = number of involved disturbers
$P_X(M,f)$ = probability limit of crosstalk from those M disturbers
$P_{Xd,k}(f)$ = normalized crosstalk power, for disturber k, as defined in expression 1.
K_n = empirical constant (K_n=1/0,6 is used for the FSAN sum)
f = frequency

Expression 2: FSAN sum for cumulating the power levels of *M* individual disturbers into the power level of an equivalent disturber

Factor K_n is assumed to be frequency independent. In the special case that all M disturbers generates equal power levels (P_{Xd}) at all frequencies of interest, the FSAN sum simplifies into $P_X(M, f) = P_{Xd}(f) \times M^{1/Kn}$. This demonstrates consistency with the uniform cumulation model. The FSAN sum operates directly on powers, and ignores the existence of source and termination impedances. If different impedances are involved (due to different disturber and victim types), their *available* power levels are to be combined according to the FSAN sum. Available power of a source is the power dissipated in a load resistance, equal to its source impedance.

8.2 Basic models for NEXT and FEXT coupling

These sub-models for crosstalk coupling are to evaluate the normalized crosstalk power, as defined before in expression1, that a *single* disturbing modem pair couples into a specific (other) wire-pair in the cable. However, it should be noted that the models in this clause are restricted to *normalized* crosstalk coupling only, and are not intended for evaluating the *actual* crosstalk coupling between two individual wire-pairs. The actual coupling fluctuates rapidly with the frequency and changes significantly per wire-pair combination. Therefore the ratio between *normalized* crosstalk amplitude

(measured at 100% cable fill, and subsequently normalized to a single disturber) and the disturber amplitude is being modeled.
The models for topologies with multiple disturber pairs are derived from these basic models.

- NEXT-coupling refers to the transfer function between ends of different pairs at the same cable section side (“near-end”).
- FEXT-coupling refers to the transfer function between ends of different pairs at the opposite cable section sides (“far-end”).

When P_d represents the (frequency dependent) transmit power of the involved disturber, and P_{Xd} represents the (frequency dependent) normalized crosstalk power (scaled down from the saturated crosstalk power at 100% cable fill), then this ratio becomes as shown below in expression 3:

$$H(f) = normalized\ crosstalk\ coupling = \sqrt{\frac{normalized\ crosstalk\ power}{disturber\ power}} = \sqrt{\frac{P_{Xd}(f)}{P_d(f)}}$$

Expression 3: Definition of normalized crosstalk coupling function.

The normalized crosstalk coupling is dependent from the wire-pair being connected to the victim modem pair. A possible approach for modeling coupling in cables as a *whole*, is to find the normalized crosstalk power (for a chosen disturber type) in each of the *N* wire pairs of the cable, and then to find (for each frequency) the 99% worst case value of those *N* powers.

8.2.1 Normalized NEXT and FEXT coupling at an elementary cable section

The normalized coupling models for co-located NEXT and FEXT are restricted to the special case of an elementary cable section topology, as illustrated in figure 7. The LT side of a disturbing modem pair is in such a topology co-located with the LT-side of a victim modem, and the same applies to the NT side. It means that the two involved wire-pairs are coupled over the full length of that (elementary) cable or cable section.

Figure 7: Example of a two-node cable section topology

Expression 4 specifies the transfer functions of this normalized NEXT and FEXT coupling model. The termination impedances of the wire-pairs are fully ignored in this model, and all wire-pairs are assumed to be terminated by the *characteristic* impedance Z_0 of the cable. By doing so, a cascade of two loops can easily be evaluated by multiplying their respective characteristic transmissions, without bothering impedances.

$$\begin{aligned} H_{next}(f,L) &= K_{xn} \times \left({f}/{f_0} \right)^{0,75} \times \sqrt{1-\left|s_T(f,L)\right|^4} \\ H_{fext}(f,L) &= K_{xf} \times \left({f}/{f_0} \right) \times \sqrt{L/L_0} \times \left|s_T(f,L)\right| \end{aligned}$$

NOTE 1: Parameter ***f*** refers to the frequency. Constant f_0 identifies a chosen reference frequency, commonly set to f_0 = 1 MHz.

NOTE 2: Parameter ***L*** refers to the coupling length of the wirepairs. Constant L_0 identifies a chosen reference length, commonly set to L_0 = 1 km.

NOTE 3: Values for K_{xn} and K_{xf} are cable specific, and are to be specified for each scenario being studied. Commonly used values (in dB) for generic European studies, not dedicated to any particular cable or region, are: K_{xn}_dB = –50 dB and K_{xf}_dB = –45 dB for f_0 = 1 MHz and L_0 = 1 km.

NOTE 4: Function $s_T(f, L)$ represents the frequency and length dependent characteristic transmission of the wire pairs. This equals the insertion loss when the cable is terminated at both ends with its characteristic impedance.

Expression 4: Transfer functions of co-located normalized NEXT and FEXT coupling

8.2.2 Normalized NEXT and FEXT coupling at distributed or branched cables

When crosstalk from a disturbing modem pair originates from locations that are not co-located with the victim modem pair, the two involved wire-pairs are not coupled over the full length. An example topology occurs when a victim modem-pair operates between cabinet and customer premises while a disturbing modem pair operates between central office and customer premises. Another example topology occurs when a cable is branched to different (customer) locations, from a certain point in the loop. Both examples are illustrated in figure 8.

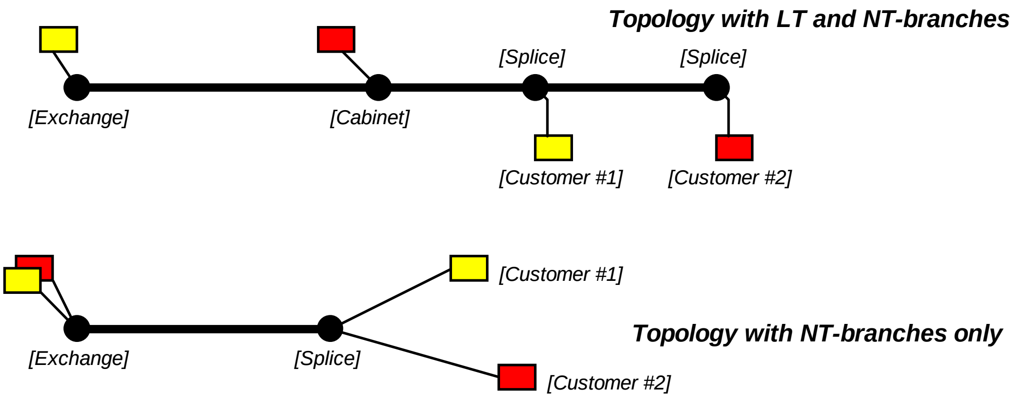
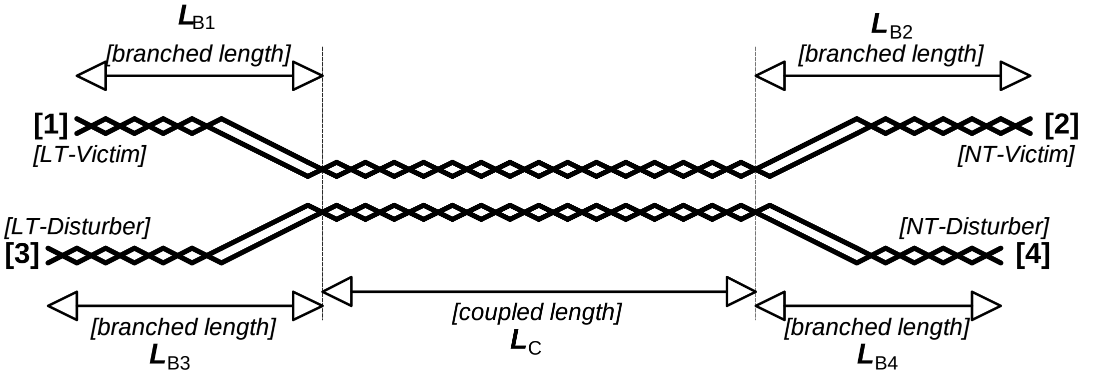


Figure 8: Two example topologies with branching

In all these distributed or branched examples, the interaction between disturbers and victims can be characterized by a common section that couples signals, and four independent sections (branches) that are attenuating signals only. This is illustrated in figure 9. Branches may have zero length in special topologies.



Victim modem pair, between port [1] and [2]
Disturbing modem pair, between port [3] and [4]

Transfer function	Involved ports	Coupling length L_C	Branch length L_B
LT-NEXT coupling: $H_{next,LT}(f, L_C, L_B)$	[3] → [1]	L_C	$L_{B3} + L_{B1}$
NT-NEXT coupling: $H_{next,NT}(f, L_C, L_B)$	[4] → [2]	L_C	$L_{B4} + L_{B2}$
LT-FEXT coupling: $H_{fext,LT}(f, L_C, L_B)$	[4] → [1]	L_C	$L_{B4} + L_{B1}$
NT-FEXT coupling: $H_{fext,NT}(f, L_C, L_B)$	[3] → [2]	L_C	$L_{B3} + L_{B2}$

Figure 9: Example of the lengths that are to be used for evaluating branched normalized NEXT and FEXT

The expressions for branched normalized crosstalk coupling are not so different from the co-located case. They mainly differ by the fact that *two* length values are involved instead of one: the coupling length L_C and the total branch length L_B. The branched model is simply derived from the co-located model, by incorporating the additional attenuation of these branches.

The table in figure 9 summarizes what the total branch length is for each combination of ports. The associated transfer functions from a disturbing transmitter to a victim modem are shown in expression 5. If L_B=0, the expressions simplify in those for the co-located case, and this demonstrates consistency between the two models.

This model assumes a single cable type, so that branch length could be added to the coupling length to account for its insertion loss. If this is not the case, the insertion losses of the branches have to be evaluated individually.

$$H_{next}(f, L_C, L_B) = K_{xn} \times \left(\frac{f}{f_0} \right)^{0,75} \times \sqrt{1 - |s_T(f, L_C)|^4} \times |s_T(f, L_B)|$$

$$H_{fext}(f, L_C, L_B) = K_{xf} \times \left(\frac{f}{f_0} \right) \times \sqrt{L_C / L_0} \times |s_T(f, L_C + L_B)|$$

NOTE 1: Parameter ***f*** refers to the frequency.
Constant $\boldsymbol{f_0}$ identifies a chosen reference frequency, commonly set to f_0 = 1 MHz.

NOTE 2: Parameter $\boldsymbol{L_C}$ refers to the coupling length between the wire pair connected to the disturbing transmitter and the wire pair connected to the victim receiver. It represents the length they share in the same cable.
Constant $\boldsymbol{L_0}$ identifies a chosen reference length, commonly set to L_0 = 1 km.

NOTE 3: Parameter $\boldsymbol{L_B}$ refers to the respective branching length (for adding signal attenuation only) from a disturbing transmitter to a victim receiver.

NOTE 4: Values for $\boldsymbol{K_{xn}}$ and $\boldsymbol{K_{xf}}$ are cable specific, and are to be specified for each scenario being studied. Commonly used values (in dB) for generic European studies, not dedicated to any particular cable or region, are: K_{xn}_dB = –50 dB and K_{xf}_dB = –45 dB for f_0 = 1 MHz and L_0 = 1 km.

NOTE 5: Function $\boldsymbol{s_T(f, L)}$ represents the frequency and length dependent characteristic transmission of the wire pairs. This would be the insertion loss when the cable is terminated at both ends with its characteristic impedance.

Expression 5: Transfer functions of branched normalized NEXT and FEXT coupling

8.3 Basic models for crosstalk injection

same text as current clause 8.3

8.4 Overview of different network topologies

same text as current clause 8.4

8.5 Crosstalk evaluation for multi-node topologies

If a victim modem pair is impaired by disturbers from all kinds of locations, the evaluation of the crosstalk probability limits may be rather complex. Figure 10 shows an example of the wiring in a multi-node topology.

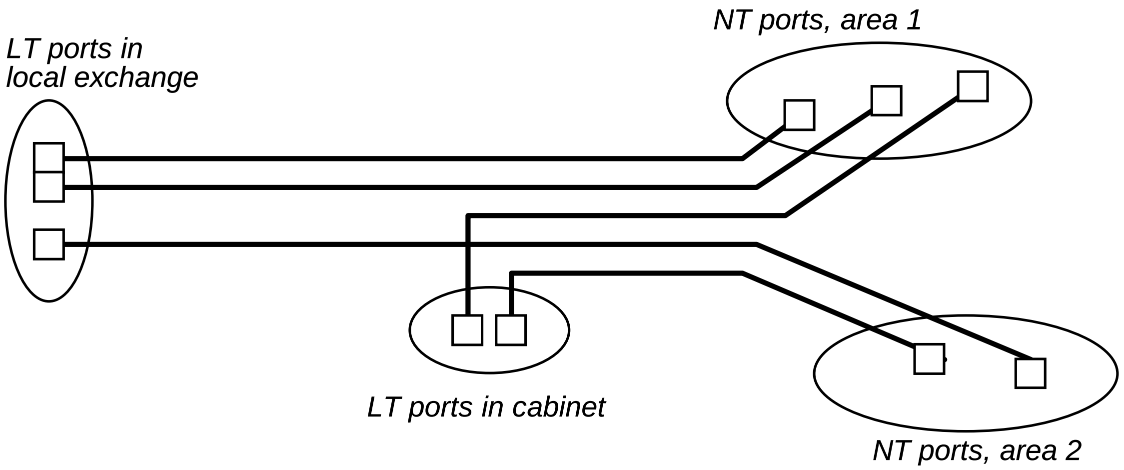


Figure 10: Example of the wiring in a multi-node topology.

Essentially, this example with five wire pairs is a combination of four individual couplings between a disturbing modem pair and the victim modem pair. Each coupling function can be different (in coupling length, in branching length, etc). By evaluating these individual coupling functions one by one, the probability limits of the crosstalk from all involved disturbers can be derived.

The probability limit $P_{XN,NT}$ of the crosstalk power at the NT side of a victim modem pair, and the associated probability limit $P_{XN,LT}$ at the other side, can be evaluated as follows:

- First, evaluate for each individual disturber pair {k}, the four normalized crosstalk coupling functions between the two disturbers and the two victims. Appropriated models are provided in expression 5. When disturbers are not co-located with other disturbers, the coupling and branching lengths may be different for each disturber pair.
- Then, evaluate for each individual disturber pair {k} the normalized crosstalk power $P_{Xd\{k\}}$ from the transmit power $P_{d\{k\}}$ of the involved disturber. This is formulated below at both victim modems:
  Normalized NEXT at NT-side: $P_{XNd\{k\},NT} = P_{d\{k\},NT} \times |H_{next\{k\},NT}|^2$
  Normalized NEXT at LT-side: $P_{XNd\{k\},LT} = P_{d\{k\},LT} \times |H_{next\{k\},LT}|^2$
  Normalized FEXT at NT-side: $P_{XFd\{k\},NT} = P_{d\{k\},LT} \times |H_{fext\{k\},NT}|^2$
  Normalized FEXT at LT-side: $P_{XFd\{k\},LT} = P_{d\{k\},NT} \times |H_{fext\{k\},LT}|^2$
- Next, cumulate all these normalized individual NEXT powers with an appropriated cumulation model (for instance the FSAN sum in expression 2) into a probability limit of the NEXT.
- Do the same for normalized FEXT powers.
- Finally add both powers. If direct disturbers ($P_{bn,NT}$ and $P_{bn,LT}$) are also involved (like systems sharing the same wire pair in another frequency band), then they can be added here as well.

Expression 6 evaluates the probability limit of the crosstalk at each receiver as explained above, in the case that FSAN summing is applied for the cumulation, and direct disturbers are involved at both sides.

$$P_{XN,NT} = \left(\sum_{k=1}^{M}\left(P_{d\{k\},NT}\times\left|H_{next\{k\},NT}\right|^2\right)^{Kn}\right)^{1/Kn} + \left(\sum_{k=1}^{M}\left(P_{d\{k\},LT}\times\left|H_{fext\{k\},LT}\right|^2\right)^{Kn}\right)^{1/Kn} + P_{bn,NT}$$

$$P_{XN,LT} = \left(\sum_{k=1}^{M}\left(P_{d\{k\},LT}\times\left|H_{next\{k\},LT}\right|^2\right)^{Kn}\right)^{1/Kn} + \left(\sum_{k=1}^{M}\left(P_{d\{k\},NT}\times\left|H_{fext\{k\},NT}\right|^2\right)^{Kn}\right)^{1/Kn} + P_{bn,LT}$$

NOTE1: Power $P_{d\{k\}}$ represents the transmit power of an involved disturber k, and M represents the total number of involved disturbers in the cable.

NOTE2: All involved powers P and coupling functions H are assumed to be frequency dependent, but this has been omitted to simplify the above expressions.

Expression 6: Evaluation of the probability limit of the crosstalk at each receiver

8.6 Crosstalk evaluation for two-node topologies

In the special (simplified) case that all disturbers are co-located with one of the two victim modems, the generalized approach in expression 6 can be simplified significantly. Such an approach can be applicable to scenarios with long distribution cables in which all customers can be regarded are virtually co-located (compared to the length of the distribution cable). Since they are all served from the same central office, the topology requires only two nodes (one on the LT side, and another one on the "common" NT side).

Figure 11 shows an example of the wiring in such a two-node topology.

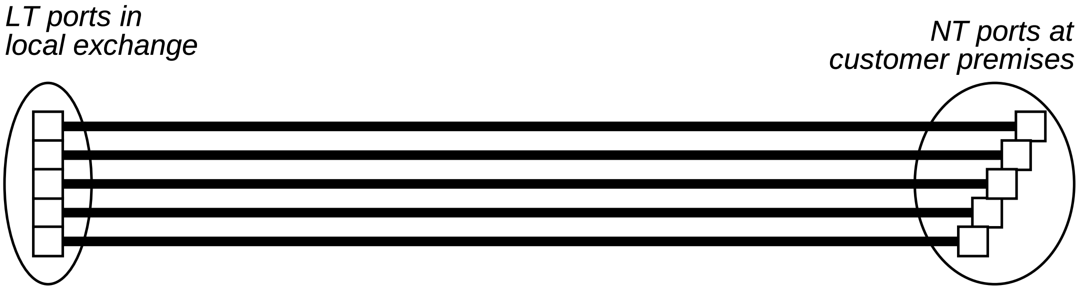


Figure 11: Example of the wiring in a two-node topology, where all wire-pairs are assumed to be of equal length.

An additional characteristic of two-node topologies is that all the NEXT coupling functions in expression 6 are assumed equal, and that the same applies for the FEXT coupling functions. The result is that the previous expression 6 for crosstalk simplifies into expression 7. By combining the powers $P_{d\{k\}}$ from all co-located disturbers into a single equivalent disturber $P_{d.eq}$ at that location, the crosstalk expression simplifies even further as shown in expression 8.

$$
\begin{aligned}
P_{XN,NT} &= \left(\sum_k \left(P_{d\{k\},NT}\right)^{Kn}\right)^{1/Kn} \times \left|H_{next}\right|^2 + \left(\sum_k \left(P_{d\{k\},LT}\right)^{Kn}\right)^{1/Kn} \times \left|H_{fext}\right|^2 + P_{bn,NT} \\
P_{XN,LT} &= \left(\sum_k \left(P_{d\{k\},LT}\right)^{Kn}\right)^{1/Kn} \times \left|H_{next}\right|^2 + \left(\sum_k \left(P_{d\{k\},NT}\right)^{Kn}\right)^{1/Kn} \times \left|H_{fext}\right|^2 + P_{bn,LT}
\end{aligned}
$$

Expression 7 Simplified version of expression 6, for the special case that all NEXT and all FEXT couplings are the same

$$P_{d.eq} \overset{def}{=} \left(\sum_k \left(P_{d\{k\}}\right)^{Kn}\right)^{1/Kn} \quad \text{(for each end of the cable)}$$

$$
\begin{aligned}
P_{XN,NT} &= P_{d.eq,NT} \times \left|H_{next}\right|^2 + P_{d.eq,LT} \times \left|H_{fext}\right|^2 + P_{bn,NT} \\
P_{XN,LT} &= P_{d.eq,LT} \times \left|H_{next}\right|^2 + P_{d.eq,NT} \times \left|H_{fext}\right|^2 + P_{bn,LT}
\end{aligned}
$$

NOTE All involved powers *P* and coupling functions *H* are assumed to be frequency dependent, but this has been omitted for simplifying the above expressions.

Expression 8: Evaluation of the crosstalk from two locations.

A convenient way of presenting the evaluation of the various crosstalk powers is the use of a flow diagram. This is shown in figure 12 (for downstream) and 13 (for upstream) for the two-node topology. It illustrates how the various building blocks of expression 8 work together when deriving the probability limits of the crosstalk.
The flow diagram illustrates that the crosstalk can be evaluated in steps.

- The diagram combines for each end of the cable the disturber output powers (P_{d1}, P_{d2}, …) into a single equivalent disturber ($P_{d.eq}$), as if the cumulation operates directly on these disturber powers. This has been illustrated in figures 12 and 13 by a box drawn around the involved building blocks.
  Using the equivalent disturber concept as intermediate result yields an elegant concept to break down the complexity of a full noise scenario into smaller pieces, but works only for two-node topologies.
- Next, the diagram evaluates the probability limit of the crosstalk noise (P_{XN}), that is coupled into the wire pair of the victim modem being studied. Figures 12 and 13 illustrate what

portion of the equivalent disturbance is coupled into that wire pair by using models for (co-located) normalized *NEXT* and *FEXT*.

- If direct disturbers are involved, their power (P_{bn}) can be added to the probability limit of the crosstalk noise. Such a direct disturber can be used to represent for instance (a) line shared noise (from POTS/ISDN to ADSL), (b) all kinds of unidentified ("background") noise sources or (c) anything else not being incorporated in the NEXT and FEXT coupling models.
  Since it is a generic diagram, the power of this direct noise is left undefined here. Commonly used values are zero, or powers as low as P_{bn} = -140 dBm/Hz.

Mark that the impedance of each disturber is fully ignored in this evaluation of the crosstalk. In practice however, the impedance of a victim modem may be different for different types of victim modems. This is not as unrealistic as it may look at a first glance. When the received noise power is assumed to remain at constant level, and when the impedance of the victim modem drops, then the received noise voltage drops too. The same applies for the received signal, and this causes that the resulting changes in received signal-to-noise ratio are significantly lower. The noise injection model can be used to improve this even further, by introducing an additional impedance-dependency.

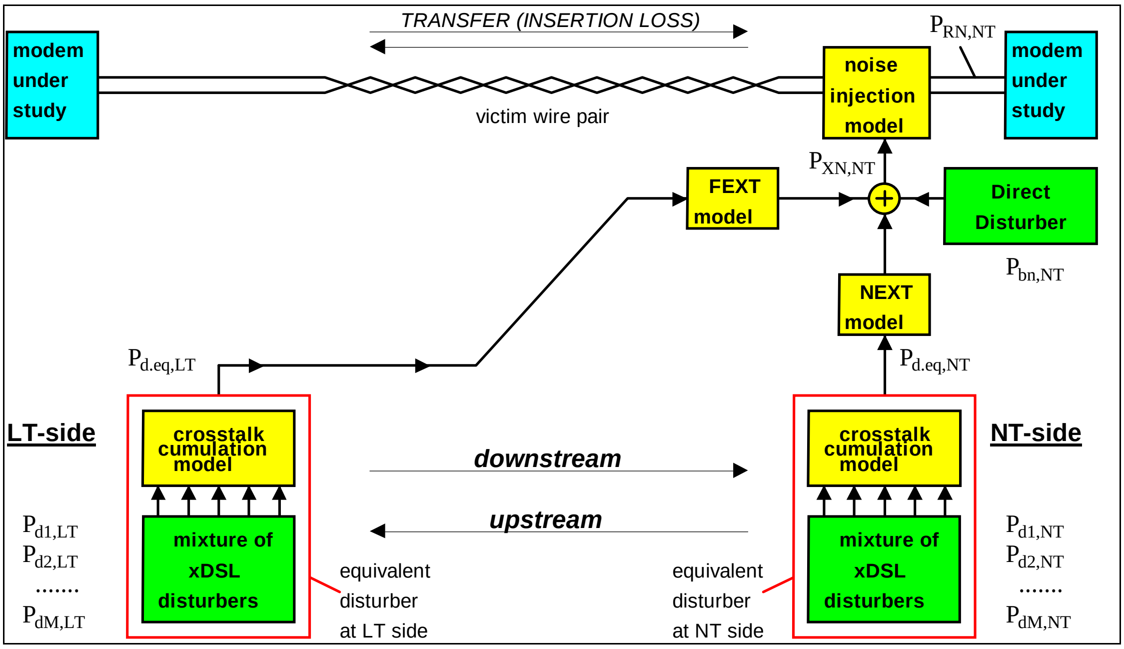


Figure 12: Flow diagram to evaluate crosstalk probability limits for two-node topologies, at the NT side (for evaluating downstream performance)

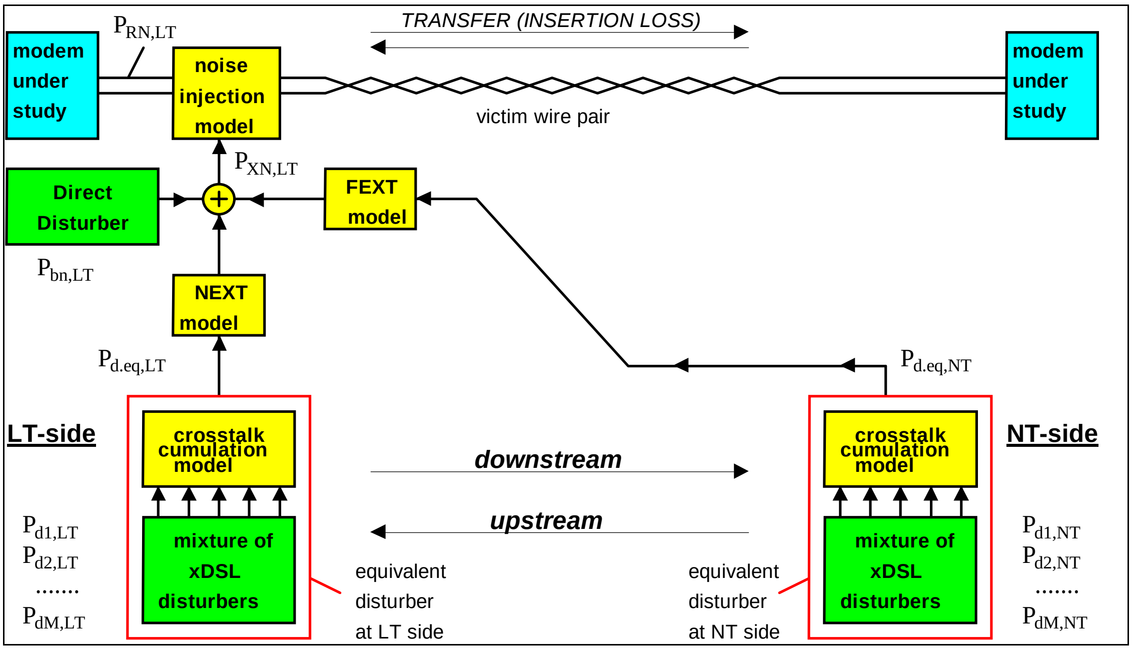


Figure 13: Flow diagram to evaluate the crosstalk probability limits for two-node topologies, at the LT side (for evaluating upstream performance)

End of literal text proposals