TITLE **Receiver performance model for ETSI compliant SDSL**

PROJECT Spectral Management - part 2

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STATUS for Decision

ABSTRACT Part 2 of SpM requires many different calculation models, including models for predicting noise margin at given bitrate under given stress conditions (noise, loss, etc). Generic performance models for PAM encoded signals have been proposed in a previous meeting of ETSI-TM6, but a *specific* performance model for ETSI compliant SDSL is currently lacking. This contribution proposes such a model and demonstrates how close the match is between predicted performance and ETSI reach/bitrate requirements for SDSL.

1. Objectives

To enable spectral management studies, it is required to predict the reach of an xDSL transmission system under a variety of noisy conditions. Part 2 of the Spectral Management project is dedicated to provide the technical means to enable these studies, covering calculation models for loss and crosstalk coupling in cables, models for signal generation in xDSL transmitter and models for performance prediction in xDSL receivers. So far, a variety of calculation models have been contributed, all covering different building blocks for a full performance simulation.
One of the many calculation models that are required for Part 2 is a specific model for receiver performance prediction of SDSL. The difference between such a *specific* model and each of the *generic* performance models that have been contributed in [5] is that a specific model provides values for the parameters of a generic model. This contribution proposes a first receiver performance model for ETSI compliant SDSL, for inclusion in "Part 2" of SpM.

To find parameter values for receiver performance models for xDSL it is quite common to estimate these values on the basis of detailed theoretical analyses. New in this contribution is that these theoretic values have been taken as starting values of an iterative fit, using the ETSI reach requirements for SDSL as target (under ETSI stress conditions).

> Using ***ETSI requirements as reference*** for performance modelling, is seen as the key to enable realistic performance assumptions in spectral management studies. This ensures that performance assumptions on xDSL modems are not too optimistic, nor too pessimistic, because xDSL vendors have verified that this performance is feasible in practice and can be guaranteed.

This contribution shows how close the match can be made between predicted performance, using the proposed model, and the ETSI reach requirements for SDSL. This match demonstrates how usable the proposed model is in practice. The evaluated model is a significant step forward for the creation of "Part 2", and we propose to have this model included in the document as a first "reference" model for ETSI compliant SDSL.

2. Receiver performance model

A generic performance model can be made specific by defining all involved parameter values. When that model predicts a well-defined (reference) performance requirement under well defined (reference) stress conditions, the model can be seen as valid for that range of stress conditions.
This section summarizes in short the ETSI (reference) stress conditions being used, and the extracted parameter values for modems that are compliant to the ETSI standard for SDSL [1].
Section 3 demonstrates that the match between prediction and ETSI requirements is close enough to identify this model as valid for predicting ETSI reach under ETSI stress conditions.

2.1. ETSI stress conditions in short

The ETSI reach requirements hold under ETSI stress conditions (see clause 12 of [1]), based on the setup shown in figure 1. For each combination of noise model and test loop, a reach requirement is specified.

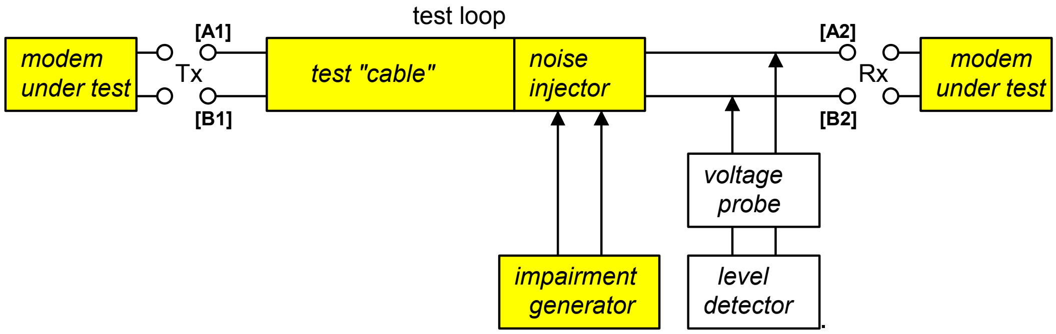

Figure 1. *The ETSI setup that facilitates the reference tests conditions, to stress an SDSL modem into one transmission direction.*

ETSI Noise injection

The noise levels specified by ETSI hold under calibration conditions, and may (a slightly) change in practice when injected into the loop using the specified injection method. The noise is injected at the receiver side of the victim SDSL modem, while the transmission in opposite direction operates at the same bitrate. The injection of this noise is *forced* in such a way that the specified noise power is facilitated for all testloops terminated with the SDSL impedances.

ETSI Noise models ("impairment generator")

Several noise models have been defined by ETSI, representing the crosstalk from a mixture of disturbers, and they are identified as:

Noise Model A, "high penetration scenario" (up to hundreds of wire pairs)
Noise Model B, "medium penetration scenario" (up to tens of wire pairs)
Noise Model C, "legacy scenario", somewhat similar to model B.

All noise models are a combination of alien noise (of non-SDSL origin) and self noise (of SDSL origin with the same bitrate as the SDSL modem under test), and operators have indicated in the past that the above set of noise models are seen as a usable simplification of realistic operational conditions. See the ETSI SDSL standard for details [1]).

ETSI Testloops

The performance predicted by the proposed model for SDSL holds under the stress condition that the received signal is attenuated by the insertion loss of testloops. These testloops are specified by ETSI in Clause 12.4.2 of [1], and shown in figure 2. Different loop lengths are used for different noise models, and they are specified as electrical length (insertion loss at specified frequency) when the loop is terminated at 135 Ω.
The process of modeling has been focussed on test loop 2, but other loops have shown similar results due to the fact that different loops have similar electrical length when the same noise model is used. The loop with bridge taps has been ignored here.

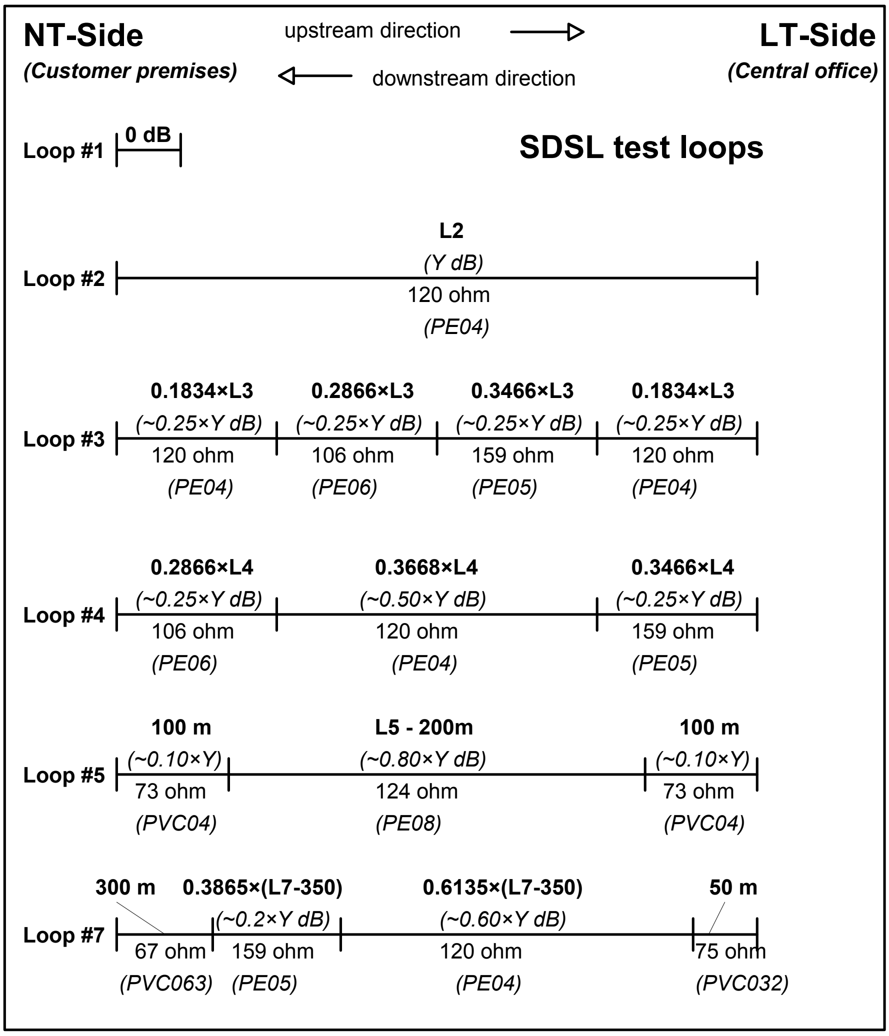

Figure 2. *Configuration of SDSL testloops.*

2.2. ETSI reach requirements in short

The ETSI reach requirements, under ETSI stress conditions, specify that the required reach is to be met under the following quality criteria:

noise margin: at least 6 dB for all reference stress conditions;
bit-error rate: better then 10^{-7};
duration: at least 10^{+9} bits.

In practice, it is not the noise margin that is verified, but the BER when the crosstalk noise is increased by 6 dB. If some BER<10^{-7} is observed with noise increased by 6 dB, the modem has passed the test. No matter if the modem performs better then required.

During the process of modelling the same approach has been followed. The noise, specified by ETSI, has been increased by 6 dB and an iterative fit forces the parameters of the model to predict operation at 0 dB noise margin. In other words, in expression 3 of clause 5.2.2 (see living list [3] of SpM-2) a value of 6 dB is used for parameter "m" in the "noise offset format" of the effective SNR. The resulting required SNR_{req} (or the SNR-gap Γ if preferred) is found by evaluating that expression 3.

These minimum performance requirements hold for a variety of reference stress conditions. Different loop lengths are used in combination with each noise model. Loop 1 (zero length) and 6 (with bridge taps) are not used for modelling purposes.

The length of each loop and for each bitrate is specified in table 1a and 1b in terms of *electrical* length (insertion loss at specified test frequency). The associated physical length is given for information only.

SDSL, Noise model A

Payload Bitrate [kb/s]		f_T [kHz]	Y [dB] @f_T, @135Ω	L2 [m]	L3 [m]	L4 [m]	L5 [m]	L7 [m]
384		**150**	**43.0**	4106	5563	5568	11064	4698
512		**150**	**37.0**	3535	4787	4789	9387	3996
768		**150**	**29.0**	2773	3747	3753	7153	3062
1024		**150**	**25.5**	2439	3285	3291	6174	2668
1280		**150**	**22.0**	2105	2829	2837	5193	2266
1536		**150**	**19.0**	1820	2453	2455	4357	1900
2048 (s)		**200**	**17.5**	1558	2046	2052	3285	1550
2304 (s)		**200**	**15.5**	1381	1815	1820	2789	1331
2048 (a)		**250**	**21.0**	1743	2264	2272	3618	1726
2304 (a)		**250**	**18.0**	1494	1927	1937	2915	1402

Table 1a. *ETSI reach requirements (in terms of electrical length) for SDSL systems, under ETSI stress conditions.Bitrate requirements marked by "(s)" apply to the symmetric PSD and "(a)" to the asymmetric PSD.*

SDSL, Noise model B, C, D

Payload Bitrate [kb/s]		f_T [kHz]	Y [dB] @f_T, @135Ω	L2 [m]	L3 [m]	L4 [m]	L5 [m]	L7 [m]
384		**150**	**50.0**	4773	6471	6477	13021	5508
512		**150**	**44.0**	4202	5692	5698	11344	4814
768		**150**	**35.5**	3392	4592	4596	8970	3815
1024		**150**	**32.0**	3058	4135	4141	7990	3403
1280		**150**	**28.5**	2725	3678	3684	7011	3006
1536		**150**	**25.5**	2439	3285	3291	6174	2673
2048 (s)		**200**	**24.0**	2135	2812	2820	4886	2271
2304 (s)		**200**	**21.5**	1913	2509	2518	4257	2010
2048 (a)		**250**	**28.0**	2323	3030	3034	5189	2389
2304 (a)		**250**	**25.0**	2075	2699	2705	4514	2102

Table 1b. *ETSI reach requirements (in terms of electrical length) for SDSL systems, under ETSI stress conditions. Bitrate requirements marked by "(s)" apply to the symmetric PSD and "(a)" to the asymmetric PSD.*

2.3. Building blocks of the proposed model

The proposed receiver performance model for ETSI compliant SDSL is build-up from the following building blocks (see the current version of the living list]3] for the referred clauses):

- The echo-loss model, specified in clause 7.2
- The basic model for the input block, specified in clause 5.1
- The generic PAM detection model, specified in clause 5.2.2.
- The parameter values specified in the succeeding clause 6.3.2 and 6.3.3.

These models have been contributed before to ETSI-TM6 [4,5] and currently captured in the living list [3] of Spectral Management project, part 2.

2.4. Parameters of the proposed model

The parameter values, that make the generic model specific are summarized in table 2 and 3.

- Part of them are directly based on the SDSL specification, as explained below.
- The summation range $N_L \ldots N_H$, as used in the expression of the PAM-detection model (see expression 3, in clause 5.2.2, currently captured in the Living list of SpM part 2 [3]), has been set to the theoretical values used in the ANSI spectral management report.
- The remaining values are based on an iterative fit of the model to the ETSI reach requirements for SDSL under the associated stress conditions. The starting values of these parameters were based on the values expected from theory.

Various parameters are derived directly from the above mentioned parameters. Their purpose is to simplify the required expression of the used PAM-detection model.
The predicted performance has assumed that the transmit spectrum of SDSL equals the PSD-template summarized in clause 4.3.6, as currently captured in the Living list of SpM part 2 [3]).

2.4.1. Parameters, obtained from ETSI specifications.

The model proposed here is based on a generic performance model, dedicated to PAM linecoding, as specified in clause 5.2.2 (see living list [3]). Some of the parameter values of that generic model are clearly specified by the SDSL standard [1]. They are summarized in table 2, and explained below. The summation bounds ($N_L \ldots N_H$) of the PAM model are chosen from theory, and do not find their origin in any SDSL specification.

Bitrate overhead parameters, according to the standard
To enable signalling, error correction and synchronisation, the actual LineRate on the copper wires of SDSL is higher than the DataRate (payload bitrate). This overhead is 8 kb/s for all SDSL bitrates.
The performance model for SDSL accounts for this overhead as:

SDSL: LineRate=DataRate+8000 [b/s]

Linecode parameters, according to the standard
To enable the use of a calculation model, dedicated to the used PAM-linecode, the required linecode parameters are defined by the SDSL standard. They include the bit density *b* (number of data bits that are encoded per symbol) for transporting bits at the LineRate. Three data bits are encoded per symbol, plus 1 redundant bit, as described in clause 9.3.1.1 of the SDSL standard [1]. This redundant bit improves the transmission performance by means of trellis encoding (coded PAM-16), since 16 levels per symbol are used. A PAM reference model for SDSL accounts for this as:

SDSL: b=3 bits per symbol

The resulting baseband for transporting symbols at the symbol rate $f_s = f_b$ / b include (dominant) frequencies up to at least (f_s / 2).

Model Parameter		**SDSL**
Data rate	f_d	192 … 2304 kb/s
Line rate	f_b	f_d + 8 kb/s
bits per symbol	b	3
Summation bounds in the PAM model	N_H N_L	+1 –2
Derived Parameter		
Symbol rate	f_s	f_b / 3

Table 2. *Values for the parameters of the performance model, resulting from the ETSI specification of SDSL [1].*

2.4.2. Parameters, extracted from ETSI performance requirements.

The remaining parameter values of the proposed model have been obtained by an iterative fit of these parameters to match the specified performance under specified stress conditions [1] as close as possible.
The fitted parameters are summarized in table 3. The parameter "required SNR", as used in the ANSI SpM report [2], and the parameter "SNR-gap" (Γ) as used in this document are similar, but differ by a factor (2^{2b}-1), or $10\times\log_{10}(2^{2b}-1)$ when expressed in dB. This factor equals 63 (or 18 dB) for b=3 bits per symbol. As a result, the "required SNR" equals 24.5 dB for SDSL when its "SNR gap" equals Γ=6.5 dB.

Model parameter		PAM model
SNR-Gap	Γ	6.5 dB
Echo suppression	η_e	70 dB
Receiver noise	P_{RN0}	–120 dBm @ 135 Ω
Derived Parameter		
Required SNR	SNR_{req}	$\Gamma\times(2^{2b}-1)$ =24.5 dB

Table 3. *Values for the parameters of the performance model, obtained from the ETSI performance requirements of SDSL [1].*

3. Usability of the proposed model

The usability of the model with the proposed parameter values, is highly dependent on how close the model can predict the required "reference" reach specified by ETSI. Figure 3 and 4 illustrate how close the proposed performance model for SDSL can predict the performance requirements from the associated ETSI standard [1]. Figure 3 is dedicated to SDSL with symmetrical PSDs and figure 4 to SDSL with asymmetrical PSDs. Both figures are dedicated for testloop 2, and noise models A, B and C. Other loops have shown similar results.
The "×" markers indicate the required reach according to the ETSI standard, while the "o" markers indicate the predicted reach according to the extracted SDSL performance model.
It can be concluded from figure 3 and 4 that over the full range the prediction of SDSL is quite close to the requirements. The predicted performance for SDSL is sometimes a slightly too optimistic, but never more then 4.5% in reach, or 125m. It is unclear if the real cause is that the model is too optimistic at 768 kb/s, or that the requirements for single pair SDSL systems are a slightly too relaxed.

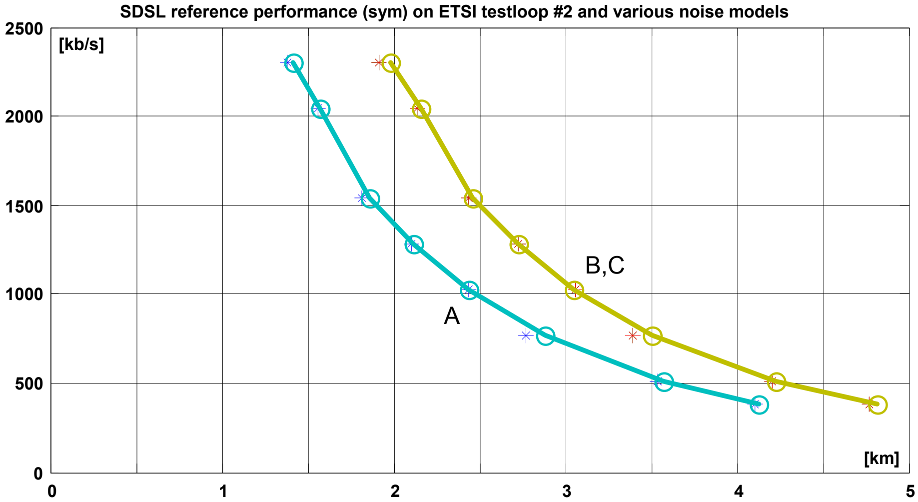

Figure 3*. Match between predicted reach-bitrate curves and reach-bitrate requirements from ETSI, for symmetrical SDSL, test loop 2 and noise model A,B and C. Mark that the performance under model B and C is almost the same.*

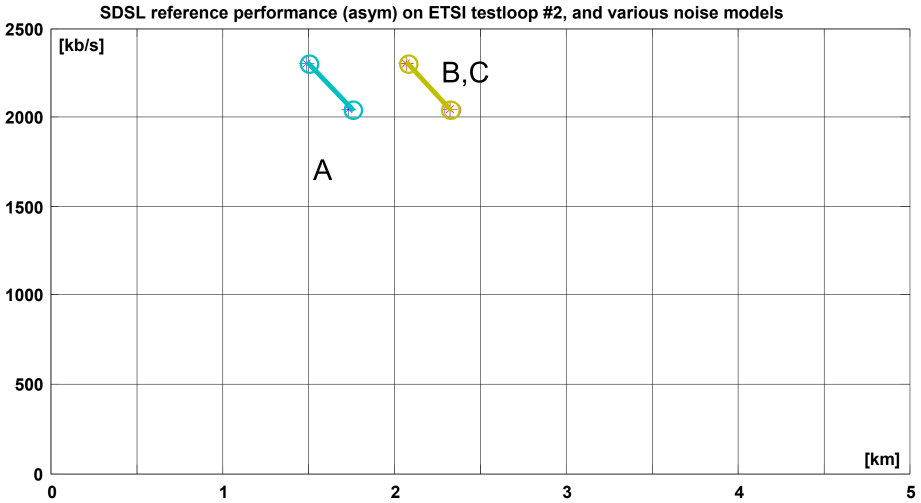

Figure 4. *Match between predicted reach-bitrate curves and reach-bitrate requirements from ETSI, for asymmetrical SDSL, test loop 2 and noise model A,B and C. Mark that the performance under model B and C is almost the same.*

It has been observed in laboratory experiments, with real SDSL modems, that when this model is applied to predict noise margin under weaker stress conditions (so noise margins significantly higher then 6 dB) the validity of the predicted noise margin may reduce. The model will predict a higher noise margin then observed. However, as soon as the modem under test fails at higher noise levels, and retrain its parameters, it will operate again but now at the predicted performance. So the "invalidity" of the model is less relevant at these conditions, and is more a weakness of the modem under test then of the model itself. Since this performance is out of scope of the ETSI performance requirements, it has been ignored here.

4. Proposed text

Begin of Literal text, proposed for inclusion into the draft of " SpM part 2"

6.3 Receiver performance model for "SDSL"

This calculation model is capable for predicting the performance of an ETSI compliant SDSL modem [1]. The validity of the model has been demonstrated for stress conditions (loss, noise) equal to the ETSI stress conditions described in the ETSI SDSL specification [1]. Reach predictions under these stress conditions are valid within about 4.5% in reach, and less then 125m. The validity of the predicted performance holds for a wider range of stress conditions.

6.3.1 Building blocks of the receiver performance model.

The receiver performance model for ETSI compliant SDSL is build-up from the following building blocks:

- The echo-loss model, specified in clause 7.2
- The basic model for the input block, specified in clause 5.1
- The generic PAM detection model, specified in clause 5.2.2
- The parameter values specified in table 4 of the succeeding clause.

6.3.2 Parameters, of the receiver performance model.

The parameter values, used in the receiver performance model for ETSI compliant SDSL, are summarized in table 4. Part of them are directly based on SDSL specifications. The remaining values are based on theory, followed by an iterative fit of the model to meet the ETSI reach requirements for SDSL under the associated stress conditions.
Various parameters are derived from the above-mentioned parameters. Their purpose is to simplify the required expression of the used PAM-detection model.

Model parameter		***PAM model***
SNR-Gap	Γ	6.5 dB
Echo suppression	η_e	70 dB
Receiver noise	P_{RN0}	–120 dBm @ 135 Ω
Data rate	f_d	192 … 2304 kb/s
Line rate	f_b	f_d + 8 kb/s
bits per symbol	b	3
Summation bounds in PAM model	N_H N_L	+1 –2
Derived Parameter		
Required SNR	SNR_{req}	$\Gamma \times (2^{2b}-1)$ =24.5 dB
Symbol rate	f_s	f_b / 3

Table 4. *Values for the parameters of the performance model, obtained from ETSI requirements for SDSL [1].*

End of Literal text, proposed for inclusion into the draft of " SpM part 2"

5. Conclusions

We have proposed a first receiver performance model for SDSL that can predict the ETSI reach requirements under ETSI stress conditions. It has been demonstrated that the predicted reach matches the specified reach quite well, so that the model is valid for this range of stress conditions. The contribution includes a literal text proposal for inclusion into the Spectral management report, part 2. We propose ETSI-TM6 to have this text adopted for inclusion.

6. References

[1] **ETSI-TS 101 524 v1.1.3 (2001-11):** "Transmission and Multiplexing (TM); Access transmission system on metallic access cables; Symmetrical single pair high bitrate Digital Subscriber Line (**SDSL)**", ETSI, november 2001.

[2] **ANSI T1E1.4/2001-002** "Draft proposed American National Standard, Spectrum Management for Loop Transmission Systems, Issue 2", may 2001 (based on T1.417-2001).

[3] **ETSI TM6(01)21**, Living List, Spectral Management part 2, ETSI-TM6 permanent document m01p21a2.pdf., june 2002.

[4] Rob F.M. van den **Brink**, *Model of basic input block, within xDSL receivers*, ETSI-TM6 contribution TD35 (021t35.pdf), Torino, Italy, feb 2002.

[5] Rob F.M. van den **Brink**, *Generic detection models for performance modeling*, ETSI-TM6 contribution TD35 (022t35.pdf), Sophia Antipolis, France, april 2002.