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TITLE **Receiver performance model for ETSI compliant HDSL-CAP**

PROJECT SpM - 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 CAP/QAM encoded signals have been proposed in a previous meeting of ETSI-TM6, but a *specific* performance model for ETSI compliant HDSL-CAP is currently lacking. This contribution proposes such a model and demonstrates how close the match is between predicted performance and the ETSI reach/bitrate requirements for HDSL-CAP.

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# 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 HDSL-CAP. 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 HDSL-CAP, 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 HDSL-CAP 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 HDSL-CAP. 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 HDSL-CAP.

# 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 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 HDSL [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 clause 6.3.2 and B.6.2.2 of [1]), based on the setup shown in figure 1. For each combination of noise model and test loop, a reach requirement is specified.

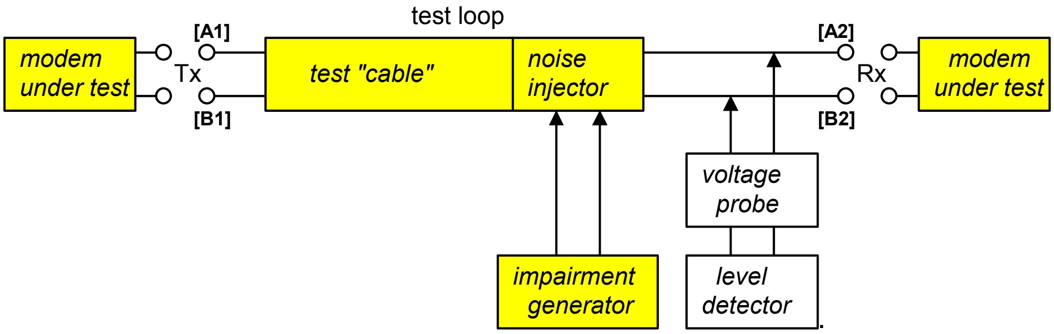


***Figure 1****. The ETSI setup that facilitates the reference tests conditions, to stress an HDSL-CAP modem into one transmission direction..*

***ETSI Noise injection***

The noise levels specified by ETSI hold under calibration conditions, and will change when injected into the loop using the specified injection method. It is injected as a *current* in such a way that the specified noise power is facilitated under the calibration condition that both ports of the noise injector are terminated with 135Ω. (Two resistors of 135 ohm in parallel makes 67.5 ohm, as specified in clause 6.3.3.3 of the HDSL standard [1]). This means (see clause 8.1.4.2 of the literal text proposal in this contribution), that impedance $Z_{cal}=R_V=135\Omega$.
The noise is injected at the receiver side of the victim HDSL-CAP modem, while the transmission in opposite direction operates at the same bitrate.

***ETSI Noise models ("impairment generator")***

Several noise models have been defined by ETSI in clause B.6.3.3.1 and 6.3.3.1 of [1]. These are artificial models, and identified as:

Noise Model A, "Increased Noise"; near white noise at 30 uV/sqrt(Hz)
Noise Model B, "Standard Noise"; near white noise at 10 uV/sqrt(Hz)
Noise Model C, No noise at all (only self-echo and self-PreAmp-noise)

Noise model A and B require the injection of noise, while noise model C is an "empty" noise model, since no noise is to be injected. It is only used to demonstrate that the internal receiver noise is sufficiently low, and gives guidance only to an approximation of that receiver noise value.

***ETSI Testloops***

The performance predicted by the proposed model for HDSL-CAP 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 B.6.3.2 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 2-5 and 7. Loop 6 with bridge taps has been ignored here.

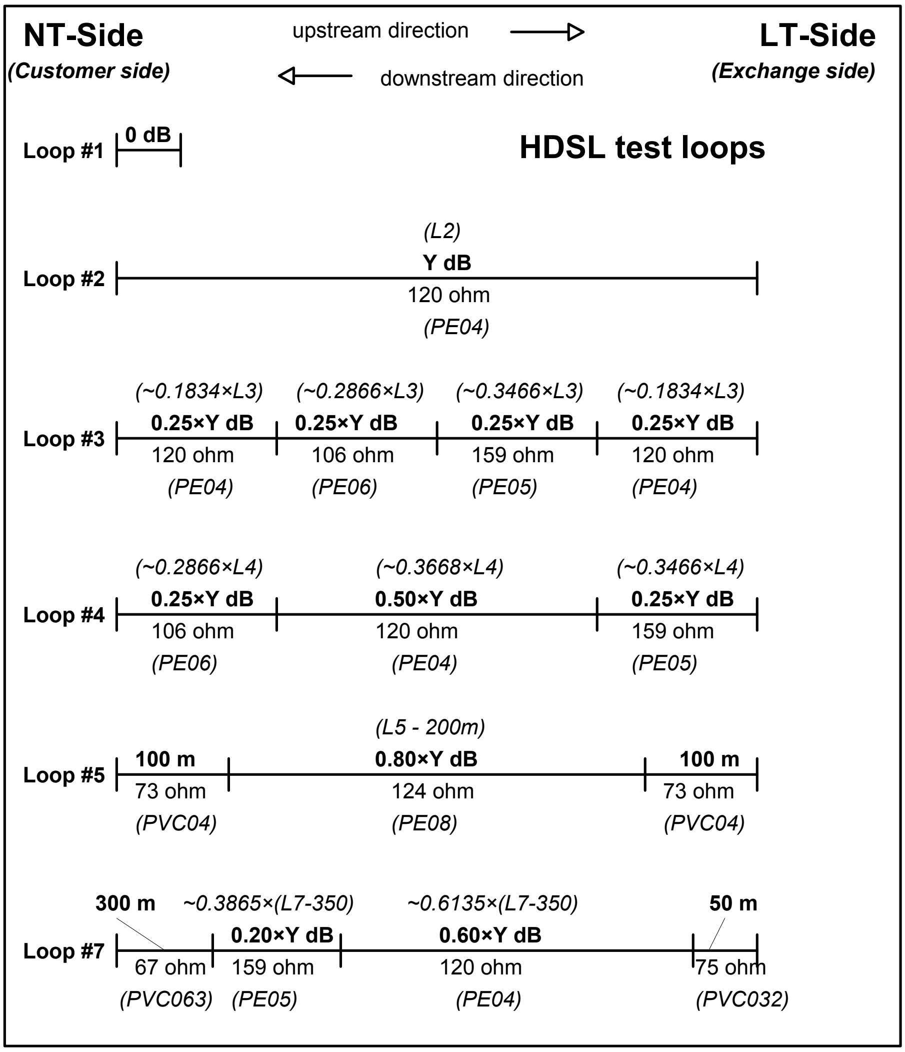


***Figure 2**. Configuration of HDSL testloops.*

# 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 0 dB for all reference stress conditions;
- bit-error rate: better then $10^{-7}$;
- duration: at least $10^{+9}$ bits (or 500 sec or 8.3 minutes)

In practice, it is not the noise margin that is verified, but the BER. If some BER<$10^{-7}$ is observed with the specified noise level, 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, is injected and an iterative fit forces the parameters of the model to predict operation at 0 dB noise margin. In other words, in expression 4 of clause 5.2.3 (see living list [3] of SpM-2) a value of m=1 (equals 0 dB) is used in the "noise offset format" of the effective SNR. The resulting required $SNR_{req}$ (or the SNR-gap $\Gamma$ if preferred) is found by evaluating that expression 4.*

These minimum performance requirements hold for a variety of reference stress conditions. Different loop lengths are used for the various noise models.

| | DataRate Per wire pair | Noise model | Electrical Length (Y) | Testloop |
|---|---|---|---|---|
| HDSL.CAP/2 | 1024 kb/s | A | 21 dB @ 150 kHz | 2-5, 7 |
| HDSL.CAP/2 | 1024 kb/s | B | 31 dB @ 150 kHz | 2-5, 7 |
| HDSL.CAP/2 | 1024 kb/s | C | 34 dB @ 150 kHz | 2-5, 7 |
| HDSL.CAP/1 | 2048 kb/s | A | 13 dB @ 150 kHz | 2-5, 7 |
| HDSL.CAP/1 | 2048 kb/s | B | 23 dB @ 150 kHz | 2-5, 7 |
| HDSL.CAP/1 | 2048 kb/s | C | 26 dB @ 150 kHz | 2-5, 7 |

***Table 1.*** *ETSI reach requirements (in terms of electrical length) for HDSL-CAP systems, under ETSI stress conditions*

## 2.3. Building blocks of the proposed model

The proposed receiver performance model for ETSI compliant HDSL-CAP 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 CAP/QAM detection model, specified in clause 5.2.3
- The parameter values specified in the succeeding clause 6.2.2 and 6.2.3.

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 HDSL-CAP specification, as explained below.
- The summation range $N_L \ldots N_H$, as used in the expression of the CAP/QAM-detection model (see expression 4, in clause 5.2.3, 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 HDSL-CAP 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 CAP/QAM-detection model.
The predicted performance has assumed that the transmit spectrum of HDSL-CAP equals the PSD-template summarized in clause 4.3.5, 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 CAP/QAM linecoding, as specified in clause 5.2.3 (see living list [3]). Some of the parameter values of that generic model are clearly specified by the HDSL standard [1]. They are summarized in table 2, and explained below. The summation bounds ($N_L \ldots N_H$) of the CAP/QAM model are chosen from theory, and do not find their origin in any HDSL specification.

***Bitrate overhead parameters, according to the standard***
To enable signalling, error correction and synchronisation, the actual LineRate on the copper wires of HDSL-CAP is higher than the DataRate (payload bitrate).
The performance model for HDSL-CAP accounts for this overhead as:

HDSL.CAP/2: DataRate: $f_d$ =2×1024 kb/s
LineRate: $f_b$ =1168 kb/s = 219/192×1024
HDSL.CAP/1: DataRate: $f_d$ =1×2048 kb/s
LineRate: $f_b$ =2320 kb/s = 435/384×2048

***Linecode parameters, according to the standard***
To enable the use of a calculation model, dedicated to the used CAP-linecode, the required linecode parameters are defined by the HDSL standard. They include the bit density (number of data bits that are encoded per symbol) for transporting bits at the LineRate, and the carrier frequency on which these symbols are CAP-modulated.

A linecode-specific reference model for HDSL-CAP accounts for these parameters as:
HDSL.CAP/2: *b*=5 bits per symbol;, $f_c$= 138.30 kHz Carrier frequency
HDSL.CAP/1: *b*=6 bits per symbol;, $f_c$= 226.33 kHz Carrier frequency
The resulting symbol rate $f_s = f_b$ / b, to transport this linerate $f_b$ equals
HDSL.CAP/2: *b*=5 bits per symbol;, $f_s$= 233.6 kbaud Symbol rate
HDSL.CAP/1: *b*=6 bits per symbol;, $f_s$= 386.7 kbaud Symbol rate
The resulting minimum frequency band for transporting symbols at the symbol rate $f_s = f_b$ / b covers a range from at least ($f_c$– $f_s$ /2) to ($f_c$+ $f_s$ /2).
HDSL.CAP/2: from below 21.5 kHz, to above 255.1 kHz
HDSL.CAP/1: from below 33.0 kHz, to above 419.7 kHz

***Overview of parameters***

| ***Model Parameter*** | | **HDSL.CAP/2** | **HDSL.CAP/1** |
|---|---|---|---|
| Data rate | $f_d$ | 2×1024 kb/s | 1×2048 kb/s |
| Line rate | $f_b$ | 1168 kb/s | 2330 kb/s |
| Carrier frequency | $f_c$ | 138.30 kHz | 226.33 kHz |
| bits per symbol | *b* | 5 | 6 |
| Summation bounds in the CAP/QAM model | $N_H$<br>$N_L$ | +3<br>0 | +3<br>0 |
| ***Derived Parameter*** | | **HDSL.CAP/2** | **HDSL.CAP/1** |
| Symbol rate | $f_s$ | $f_b$/b = 233.6 kbaud | $f_b$/b = 388.3 kbaud |

***Table 2.*** *Values for the performance parameters, extracted from the ETSI performance requirements under ETSI stress conditions.*

### 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 ($2^b$-1), or $10\times\log_{10}(2^b-1)$ when expressed in dB. This factor equals 31 (or 14.9 dB) for *b*=5 bits per symbol, and 63 (or 18 dB) for *b*=6 bits per symbol. As a result, the “required SNR” equals 21.7 dB for HDSL.CAP/2, and 24.8 dB for HDSL.CAP/1 when Γ=6.8 dB.

| ***Perf. parameter*** | | ***CAP model*** |
|---|---|---|
| SNR-Gap | $\Gamma$ | 6.8 dB |
| Echo suppression | $\eta_e$ | 60 dB |
| Receiver noise | $P_{RN0}$ | –105 dBm @ 135 Ω |
| ***Derived Parameter*** | | |
| Required SNR | $SNR_{req}$ | 21.7 dB (CAP/2)<br>24.8 dB (CAP/1) |

***Table 3.*** *Values for the performance parameters, extracted from the ETSI performance requirements under ETSI stress conditions.*

# 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 illustrates how close the reference performance model for HDSL-CAP can predict the performance requirements from the HDSL standard. This is shown for both performance models, various testloops and both noise models A and B.
The “×” markers indicate the required reach according to the ETSI standard, while the “o” markers indicate the predicted reach according to the extracted HDSL performance model.
It can be concluded from figure 3 that over the full range the prediction of HDSL.CAP/2 is quite close to the requirements. The predicted performance for HDSL.CAP/2 is sometimes too optimistic. It is unclear of the real cause is that the model is too optimistic, or that the requirements for single pair HDSL systems are too relaxed.

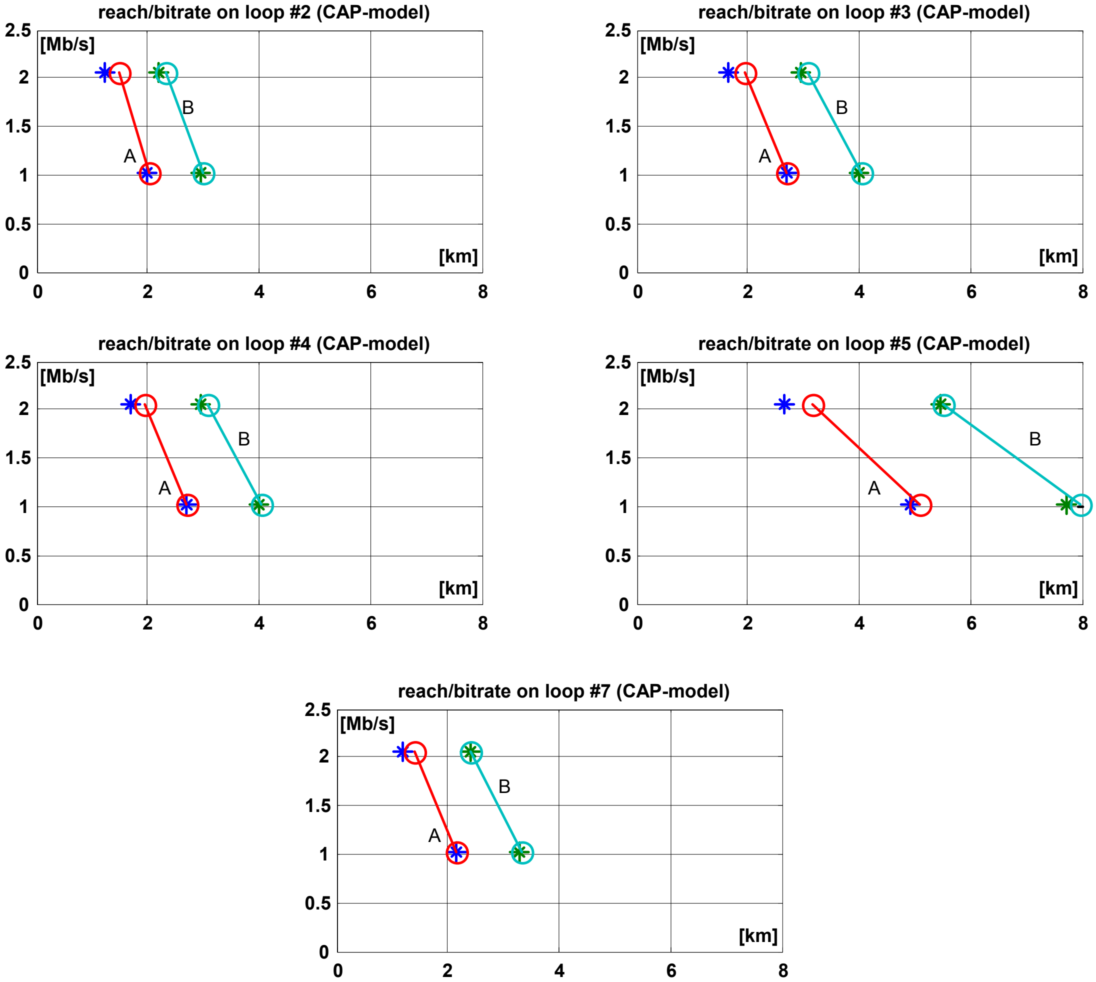


***Figure 3***. *Match between predicted reach-bitrate curves and reach-bitrate requirements from ETSI, for HDSL-CAP, several testloops, and noise model A and B.*

# 4. Proposed text

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

## 6.2 Receiver performance model for "HDSL-CAP"

This calculation model is capable for predicting the performance of an ETSI compliant HDSL-CAP 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 HDSL specification [1].

### *6.2.1 Building blocks of the receiver performance model.*

The receiver performance model for ETSI compliant HDSL-CAP 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 CAP/QAM detection model, specified in clause 5.2.3
- The parameter values specified in the succeeding clause 6.2.2 and 6.2.3.

### *6.2.2 Parameters, of the receiver performance model.*

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

| ***Model Parameter*** | | **HDSL.CAP/2** | **HDSL.CAP/1** |
|---|---|---|---|
| SNR-Gap | $\Gamma$ | 6.8 dB | 6.8 dB |
| Echo suppression | $\eta_e$ | 60 dB | 60 dB |
| Receiver noise | $P_{RN0}$ | –105 dBm @ 135 Ω | –105 dBm @ 135 Ω |
| Data rate | $f_d$ | 2×1024 kb/s | 1×2048 kb/s |
| Line rate | $f_b$ | 1168 kb/s | 2330 kb/s |
| Carrier frequency | $f_c$ | 138.30 kHz | 226.33 kHz |
| bits per symbol | $b$ | 5 | 6 |
| Summation bounds in the CAP/QAM model | $N_H$<br>$N_L$ | +3<br>0 | +3<br>0 |
| ***Derived Parameter*** | | | |
| Symbol rate | $f_s$ | $f_b$/b = 233.6 kbaud | $f_b$/b = 388.3 kbaud |
| Required SNR | $SNR_{req}$ | $\Gamma\times(2^b-1)$ =21.7 dB | $\Gamma\times(2^b-1)$ =24.8 dB |

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

Literal text, proposed for describing "current injection"

### *8.1.4.2 Current noise injection*

When cross talk is modelled by means of *current* noise injection, then it is assumed that the impedance dependency can be represented by the equivalent circuit diagram shown in figure 4.

- The *injection condition* holds when the performance is evaluated. Impedance $Z_{LX}$ represents the cable with its terminating impedance at the other ends of the line. $Z_{LX}$ is usually a frequency dependent and complex impedance.
- The *calibration condition* holds for the situation that noise has been evaluated. $Z_{cal}$ should be a well defined impedance. This can be a complex artificial impedance approximating $Z_{LX}$, or simply a fixed real impedance. In the special case that $Z_{cal} \equiv Z_{LX}$, the concept of "current injection" simplifies into "forced injection" as described in the previous clause.

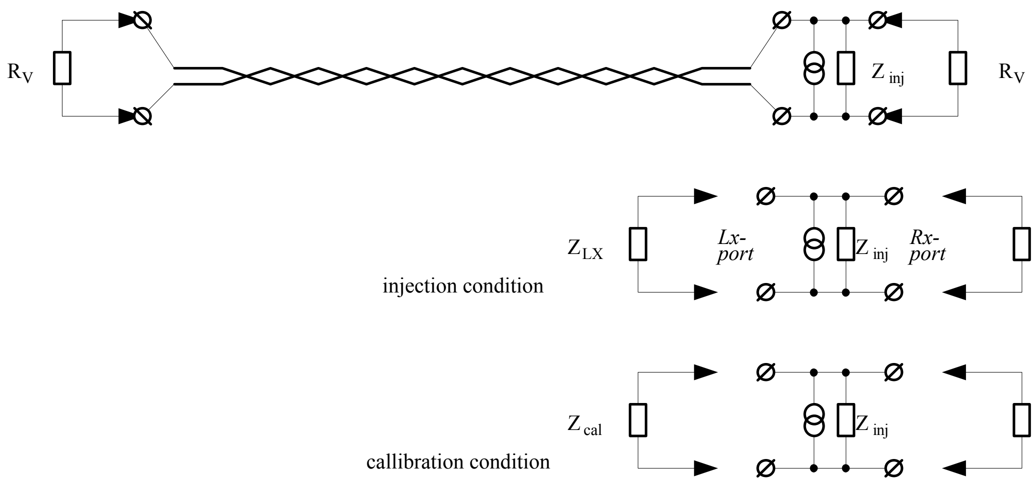


**Figure 4: Current injection enables modeling of the impedance dependent behavior of cross talk noise levels.**

The transfer function $H_{xi}(f)=(U_i/U_c)$ between (a) the signal voltage $U_i$ over impedance $R_V$ during injection condition, and (b) $U_c$ during calibration condition, equals:

$$H_{xi}(f, Z_{LX}) = \left( \frac{1/Z_{cal} + 1/Z_{inj} + 1/R_V}{1/Z_{LX} + 1/Z_{inj} + 1/R_V} \right)$$

**Expression 1: Transfer function to model impedance dependency according to the current injection method.**

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 HDSL-CAP 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 101 135 v1.4.1 (1998-02):** "Transmission and Multiplexing (TM); High bit-rate Digital Subscriber Line (**HDSL**); transmission system on metallic local lines; HDSL core specification and applications for 2048 kbit/s based access digital sections", ETSI, february 1998

[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.