
TITLE **Generic crosstalk models for two-node co-location**

PROJECTS SpM – part 2

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STATUS for Decision

ABSTRACT Part 2 of SpM requires a range of calculation blocks, to enable performance evaluations. One of them is the evaluation of crosstalk noise levels in a scenario. This contribution provides the literal text for the calculation blocks, to build topologies in which all disturbers are co-located at only two nodes.

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1. Rationale behind this proposal

Part 2 of the Spectral management report requires the description of performance models consisting of a range of individual calculation blocks. All these blocks together will enable reproducible and well-defined performance evaluations of (noisy) scenarios. The models of the building blocks that are proposed in this contribution are a few out of many building blocks that are required for part 2.

This proposal combines a few commonly used concepts to evaluate the crosstalk noise in a cable. The primary assumption within this concept is that all customers are virtually co-located, so that the model requires only two nodes (one on the LT side, and another one on the “common” NT side) connected by a multi wire pair cable. This approach is often used when modelling ADSL, HDSL and SDSL performance. For modelling VDSL, where customers are distributed along the line, or for modelling repeatered HDSL, where repeaters act as disturbers somewhere in the middle of a line, a more advanced multi-node approach is required.
This proposal is dedicated to the two-node case.

2. Literal text proposal

The text below proposes literal text for inclusion in clause 8.1 of the Spectral Management draft, part 2.

8.1 Generic crosstalk models for two-node co-location

The crosstalk models in this sub clause apply to scenarios in which it can be assumed that all customers are virtually co-located. The result is that such a crosstalk model requires only two nodes (one on the LT side, and another one on the "common" NT side). These nodes are interconnected by means of a multi wire pair cable.
Crosstalk models are built up from several building blocks, and the way these blocks are interconnected is defined by means of a topology diagram.

8.1.1 Basic diagram for two-node topologies

The basic flow diagram for describing a topology in which xDSL equipment is assumed to be co-located at two nodes (the two ends of a cable) is shown in figure 1 and 2. Up and downstream performance are evaluated separately. The approach of this diagram can be described in three distinct steps.

- The diagram combines for each node the output disturbance of individual disturbers (P_{d1}, P_{d2}, …) by modeling *crosstalk cumulation* as an isolated building block. This is because the cumulation from different disturbers cannot be modeled by a simple *linear* power sum of all individual disturbers. Since each wire pair couples at different ratio to the victim wire pair, the cumulation requires some *weighed* power sum that accounts for the statistical distribution of all involved crosstalk coupling ratios.
  By modeling crosstalk cumulation as an isolated building block, the cumulated disturbance can be thought as if it was virtually generated by a single equivalent disturber ($P_{d.eq}$). This has been indicated in figure 1 and 2 by a box drawn around the involved building blocks. Using the equivalent disturber concept as intermediate yields an elegant concept to break down the complexity of a full noise scenario into smaller pieces.
- Next, the diagram evaluates what noise level (P_{XN}) is coupled into the victim wire pair. Figure 1 and 2 illustrate what portion of the equivalent disturbance is coupled into the victim wire pair by using models for *NEXT* and *FEXT*. On top of this, background noise (P_{bn}) can be added to represent all remaining unidentified noise sources. Since it is a generic diagram, the power level of this background noise level is left undefined here, but commonly used values are zero, or levels as low as P_{bn}=–140 dBm/Hz.
- When all building blocks are modeled for the same impedance as implemented in the modem under study, the noise level (P_{RN}) received by the modem under test equals the level derived so far (P_{XN}). In practice, these models are normalized at some chosen reference impedance R_n, and this R_n may be different from the impedance implemented in the modem under study (targeted at its design impedance R_V). This "mismatch" will cause a change in the level of the disturbance, and this effect is modeled by the noise injection building block.

The succeeding clauses summarizes some generic models for the individual building blocks of figure 1 and 2.

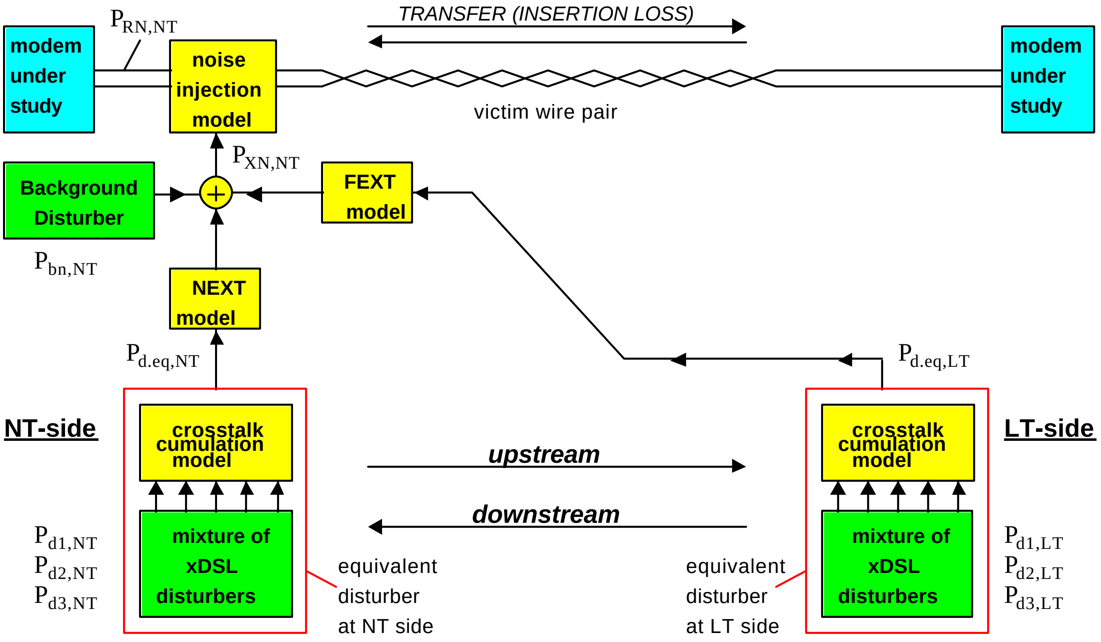


Figure 1: Flow diagram of the basic model for two-node topologies, for evaluating downstream performance

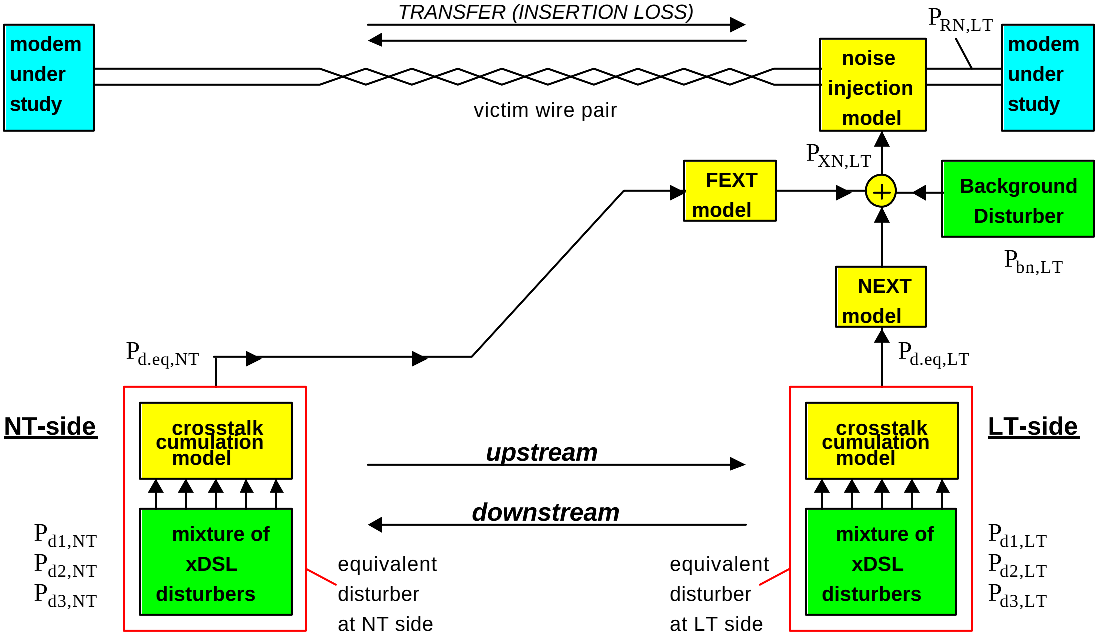


Figure 2: Flow diagram of the basic model for two-node topologies, for evaluating upstream performance

The transfer functions H_{next} and H_{fext} of the building blocks for NEXT and FEXT are linear and frequency dependent. The model for the topology assumes that all disturbers are uncorrelated, which causes that the crosstalk power P_{XN} behind the summation block is the sum of all individual powers. This transfer functions are specified in expression 1.

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

Expression 1: Evaluation of the crosstalk power levels, that flow into the noise injection blocks of the two-node topology models in figure 1 and 2.

8.1.2 *Models for crosstalk cumulation*

The noise that couples into a victim wire pair, and originates from several co-located disturbers connected to different wire pairs, cumulate in level. This cumulation cannot be modeled by a simple *linear* power sum of all individual disturbers, because each wire pair couples at different ratio to the victim wire pair. Therefore the cumulation requires some *weighed* power sum that accounts for the statistical distribution of all involved crosstalk coupling ratios.
On input, the cumulation building block requires the levels ($P_{d1}…P_{dN}$) of all involved individual disturbers that are co-located. On output, the cumulation building block evaluates the level of the equivalent disturbance ($P_{d.eq}$). This sub clause provides expressions to model building blocks for crosstalk cumulation.

8.1.2.1 FSAN sum for crosstalk cumulation

The FSAN sum is one of the possible expressions to model crosstalk cumulation, and is specified in expression 2. The (frequency dependent) power level of the equivalent disturbance, that cumulates from *M* individual disturbers, is expressed below.
The factor K_n weighs this sum when $K_n \neq 1$. For $K_n > 1$ the FSAN sum results in a power level that's is always equal or less then the linear sum (K_n) of these powers. This factor is cable dependent, and assumed to be frequency independent. Values ranging between $K_n=1/0,6$ and $K_n = 1/0,8$ have been observed in practice. On default, $K_n=1/0,6$ is commonly used, but this parameter must be explicitly specified when using this model for crosstalk cumulation in a performance evaluation.

$$P_{d.eq} = \left(P_{d1}{}^{K_n} + P_{d2}{}^{K_n} + P_{d3}{}^{K_n} + \cdots + P_{dM}{}^{K_n}\right)^{1/K_n}$$

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

In the special case that all *M* disturbers generates equal power levels (P_d), the FSAN sum simplifies into $P_{d.eq} = P_d \times M^{1/Kn}$.
The FSAN sum ignores differences in source impedances of different disturber types. For cumulating disturbance from sources with different impedances, their *available* power levels are to be combined according to the FSAN sum. This available power of a source is the power dissipated in a load resistance, equal to the source impedance.

8.1.3 *Models for crosstalk coupling*

The spread in crosstalk coupling between wire pairs in a real twisted pair cable is significant, and the coupling fluctuates rapidly when the frequency increases. The crosstalk from a single disturber is therefore random in nature.
When the number of co-located disturbers increases, the fluctuations reduce significantly. Models for crosstalk coupling take advantage of this effect and their simplicity increases when the number of co-located disturbers increases.

Equivalent crosstalk coupling of a cable is the ratio between the level of the crosstalk in the victim wire pair and the level of an equivalent disturber evaluated by some crosstalk cumulation model, while connecting as much individual disturbers as possible to the cable under study.
This crosstalk sum will be different for each wire pair, due to the random nature of the coupling. Commonly accepted models for equivalent crosstalk coupling represent 99% of the victim wire pairs. This is to approximate 100% of the cases, without being pessimistic for the very last extreme 1% case.
This sub clause provides expressions to model the building blocks for *equivalent* crosstalk coupling.

8.1.3.1 Basic models for equivalent NEXT and FEXT

Expression set 3 specifies how to model the transfer functions of the equivalent NEXT and FEXT building blocks. The specification is based on the following constants, parameters and functions:

- Variable **f** identifies the frequency.
- Constant **f_0** identifies a chosen reference frequency, commonly set to f_0 = 1 MHz.
- Variable **L** identifies the physical length of the cable between the two nodes in meters. Constant **L_0** identifies a chosen reference length, commonly set to L_0 = 1 km.
- Function **s_T(f, L)** represents the frequency and length dependent amplitude of the transmission function of the actual test loop, normalized to a reference impedance R_n. This value equals $s_T=|s_{21}|$, where s_{21} is the transmission s-parameter of the loop normalized to R_n This R_n is commonly set to 135Ω.
- Constant **K_{xn}** identifies an empirically-obtained number that scales the NEXT transfer function H_{next}(f, L).
- Constant **K_{xn}** identifies an empirically-obtained number that scales the FEXT transfer function H_{fext}(f, L).

$$\begin{aligned} H_{next}(f,L) &= K_{xn} \times \left(f \big/ f_0 \right)^{0.75} \times \sqrt{1-\left|s_T(f,L)\right|^4} \\ H_{fext}(f,L) &= K_{xf} \times \left(f \big/ f_0 \right) \times \sqrt{L/L_0} \times \left|s_T(f,L)\right| \end{aligned}$$

Expression 3: Transfer functions of the basic models for NEXT and FEXT

8.1.4 Models for crosstalk injection

Several sub models for various building blocks within the crosstalk model ignore the fact that when the modem and cable impedance will change, the noise (and signal) observed by the receiver will change as well. For instance, when the input impedance (Z_{xdsl}) of the receiver under test decreases, the received noise level will decreases as well. To account for this effect, a crosstalk injection block is included in the topology models in figure 1 and 2.
The transfer function of the crosstalk injection block identified as H_{xi}, and is frequency and impedance dependent. Expression 4 illustrates how to use this transfer function for evaluating the power level P_{RN} from power level P_{XN}.

$$P_{RN} = P_{XN} \times \left|H_{xi}\right|^2$$

Expression 4: Evaluation of the receive noise level from the crosstalk noise level under matched conditions, by a transfer function of the noise injector

A transfer function that models the impact of impedance mismatch can be very complex, and therefore several simplified transfer functions are commonly used to approximate this effect. This clause summarize a few of these approximations.

8.1.4.1 Forced noise injection

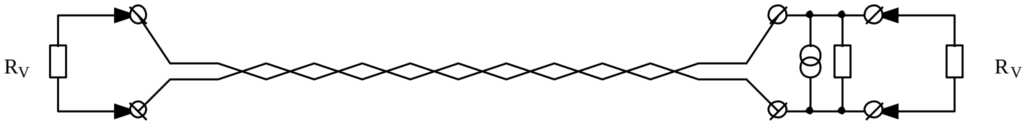
When crosstalk is modelled by means of *forced* noise injection, then all impedance and frequency dependency of noise injection is ignored. The associated transfer function is shown in expression 5.

$$H_{xi}(f) = 1$$

Expression 5: Transfer function for forced noise injection.

8.1.4.2 Current noise injection

When crosstalk is modelled by means of *current* noise injection, then it is assumed that the impedance dependency can be represented by the equivalent circuit diagram in figure [*].



ED NOTE. This issue is for further study, but should follow the ETSI-TM6 agreements for ADSL testing about noise injection and the way the injected noise level is defined by means of a complex calibration impedance.

End of literal text proposal