TITLE **Model of basic input block, within xDSL receivers**

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 SNR in a receiver, as interim result within an xDSL receiver model. This contribution provides the literal text for two related calculation blocks, one modeling the equivalent SNR, and another modeling the "echo loss".

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 formalizes a commonly used concept to evaluate the performance of an xDSL receiver into a straightforward calculation model. This concept results in the evaluation of the SNR (signal to noise ratio) of the received signal, as intermediate result, followed by a linecode specific detection block. The SNR of the input signal is deteriorated by internal receiver noise and echo.

Figure 1, describes this approach as a model of a block, and defines a naming convention of various flows. Most of this approach is very common, but it has been extended by modelling echo suppression as well. For many situations, this addition is less relevant, because state-of-the-art echo-cancers are quite sophisticated and effective. The importance of including echo cancellation in this building block is mainly to cover the case that *lacks* echo cancellation, such as for FDD systems like ADSL and VDSL. Residual frequency overlap in the guard bands between up and downstream spectra may cause some problem. By tweaking the value for echo suppression h, the absence or presence of echo cancellation can be controlled.

The model proposed in this contribution is a 100% linear model. In case the receiver gain is controlled, to enable a high dynamic range, the equivalent internal receiver noise P_{RN0} may vary with the signal level. For many situations this can be ignored (when crosstalk noise dominates the internal receiver noise), but in case this effect has a significant effect, a more advance non-linear calculation model is required. Such a non-linear model is beyond the scope of this proposal, but can always be added to the Spectral management report "part 2".

A simple but effectivemodel of echo-loss has been attached to this contribution, and completes the overall modelling of echo cancellation. It models the suppression caused by the analogue hybrid used for "isolating" received and transmitted signal in a transceiver. When this hybrid is perfectly balanced (loaded by the design impedance), no echo will flow into the receiver. When the cable impedance differs from this design impedance R_v the hybrid will be out of balance and some transmitted signal reflects into the receiver.
In the proposed model for echo-loss, the hybrid is modelled as a Wheatstone bridge, which is perfectly balanced when one branch is terminated with R_v. More advanced models for echo-loss

are beyond the scope of this contribution, but can always be added to the Spectral management report “part 2”.

2. Literal text proposal

The text below proposes literal text for inclusion in the Spectral Management draft, part 2
The clause numbers “5.1” and “7.2” refer to the table of contents of the first draft of “part 2”

5.1 Basic model of input block

This clause describes a linear (sub)model for xDSL receivers that enables the description of the linecode independent behavior of such a receiver. It describes how to evaluate the effective SNR, from various input quantities, as intermediate result. When combined with a (sub)model of a linecode dependent detection block a complete receiver model can be formed (see succeeding subclauses).
When non-linear behavior of the input block is relevant, such as for gain controlled analog frontends, more advanced modeling is required.

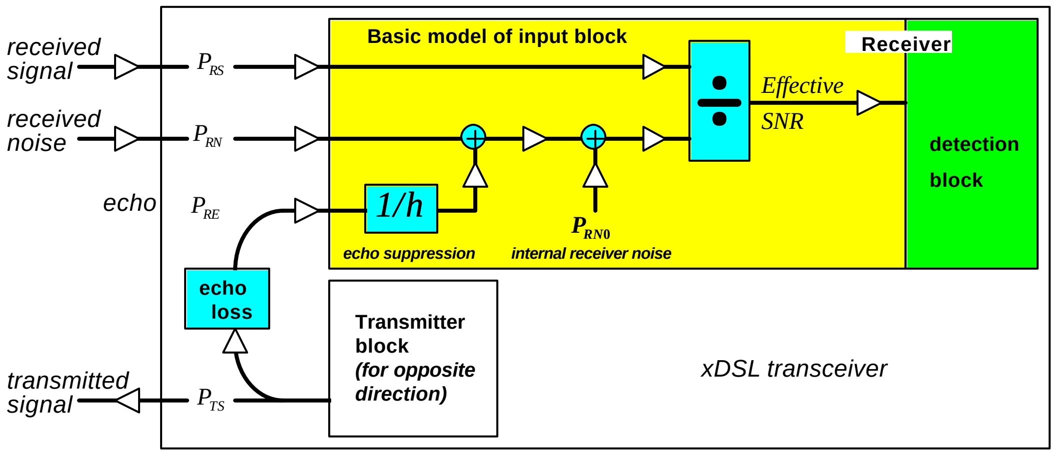


Figure 1: Flow diagram of a transceiver model, that incorporates the basic model of the input block.

<u>*On input*</u>, the basic input block requires values for *signal*, *noise* and *echo*. The flow diagram in figure 1 illustrates this for an xDSL transceiver that is connected via a common wire pair to another transceiver (not shown).

- The received <u>*signal*</u> power P_{RS} carries the data that is to be recovered. This signal originates from the transmitter at the other side of the wire pair, and its level is attenuated by cable loss.
- The received <u>*noise*</u> power P_{RN} is all that is received when the transmitters at both sides of the link under study are silent. The origin of this noise is mainly crosstalk from internal disturbers connected to the same cable (crosstalk noise), and partly from external disturbers (ingress noise).
- The received <u>*echo*</u> power P_{RE} is all that is received when the transmitter at the other end of the wire pair is silent, as well as all internal and external disturbers. It is a residue that will be received when a transmitter and a receiver are combined into a transceiver en co-connected via a hybrid to the same wire pairs. When the hybrid of that transceiver is unbalanced due to mismatched termination impedances (of the cable), then a portion (P_{RE}) of the transmitted signal (P_{TS}) will leak into the receiver which is identified as echo. The echo loss building block models this effect.

The echo loss can be modeled by the transfer function in expression 2, and is related to the cable characteristics and the transceiver termination impedances on both ends of the cable.

<u>*On output*</u>, the basic model of the input block evaluates a quantity called SNR (Signal to noise Ratio) that indicates to what degree the received signal is deteriorated by noise and residual echo. Due to signal processing by the receiver the *input* SNR (the ratio between signal power, and the powersum of noise and echo) will change into the *effective* SNR at some virtual internal point at the receiver. The effective SNR can be better or worse then the input SNR. Receivers with build-in echo cancellation can take advantage of a-priori knowledge on the echo, and can suppress most of this echo and thus improving the effective SNR. On the other hand, all analog receiver electronics produce shot noise and thermal noise, while the A/D-converter produces quantization noise. The combination of all these individual noise sources deteriorates the effective SNR.
The flow diagram of figure 1 illustrates how this effective SNR is evaluated by the basic model of the input block. It incorporates two parameters: (a) a *suppression factor* h that indicates how effective echo cancellation is implemented, and (b) an equivalent *receiver noise power* P_{RN0} that indicates how much noise is added by the receiver electronics. The basic input model evaluates the effective SNR as follows:

$$SNR\left(P_{RS}, P_{RN}, P_{RE}, P_{RN0}, h\right) = \frac{P_{RS}}{P_{RN} + P_{RN0} + P_{RE}/h^2}$$

In principle all parameters of the effective SNR can be assumed as frequency dependent, but this dependency has been omitted here. In addition, external change of signal and noise levels will modify the value of this effective SNR.

To simplify further analysis of performance quantities like noise margin and signal margin, a short-cut is used for the effective SNR by applying dedicated offset formats. The simplified SNR formula is now parameterized by a single offset parameter m and an optional frequency parameter f. The offset effective SNR is the effective SNR, evaluated when the received signal or the received noise has been modified by a factor m. The convention is that when m=1 (equals zero dB) the effective *offset* SNR equals the effective SNR itself. When the value of parameter m <u>in</u>creases, the effective offset SNR <u>de</u>creases. Two offset formats for this SNR are identified in expression 1.

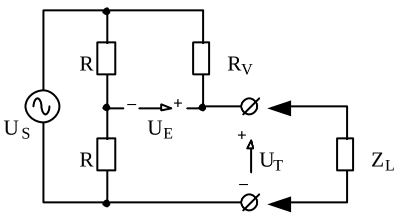
***Noise* offset format:**	$SNR_{ofs,N}(m, f) = SNR\left(P_{RS}(f), P_{RN}(f) \times m^2, P_{RE}(f), P_{RN0}(f), h(f)\right)$
***Signal* offset format:**	$SNR_{ofs,S}(m, f) = SNR\left(P_{RS}(f)/m^2, P_{RN}(f), P_{RE}(f), P_{RN0}(f), h(f)\right)$

Expression 1: Shortcuts for SNR, resulting from the basic model of the input block, using offset formats.

These shortcuts are used for modeling the detection block of a receiver. Mark that when the receiver noise becomes zero and the echo suppression infinite, the noise offset and signal offset formats become the same.

7.2 Basic model for echo loss

A model for echo loss describes a property of the hybrid in a transceiver, and models what portion of the transmitted signal reflects directly into the receiver. When the hybrid is perfectly balanced, no echo will flow into the receiver. When the cable impedance differs from the value where the hybrid is designed for, the hybrid will be out of balance and some transmitted signal reflects into the receiver.
The basic model for echo loss assumes that (a) the output impedance of the transceiver equals some value R_v, that (b) the hybrid is balanced when terminated with a load impedance Z_L equal to R_v, and that the hybrid can be represented by a straightforward Wheatstone bridge. This is illustrated in figure 2. The associated transfer function H_E is specified in expression 2.



$$\frac{U_E}{U_T} = \frac{U_T - U_s/2}{U_T} = 1 - \tfrac{1}{2} \times \frac{R_V + Z_L}{Z_L} = \frac{Z_L - R_V}{2 \cdot Z_L}$$

Figure 2: Flow diagram of the basic model for echo loss

$H_E(jw) = \frac{Z_L(jw) - R_V}{2 \cdot Z_L(jw)}$	$\frac{P_{RE}}{P_{TS}} = \left\lvert H_E(jw) \right\rvert^2$

Expression 2: Transfer function of the basic model for echo loss. The identifiers P_{RE} and P_{TS} refer to power flow values used in figure 1.

When using this basic model for echo loss in a full simulation, value R_V can be made equal to the design impedance of the modem under test, and value Z_L can be made equal to the complex and frequency dependent input impedance of the cable, terminated at the other cable end with a load impedance equal to R_V.

End of literal text proposal