TITLE **Extending the validity of receiver performance models**

PROJECTS Spectral Management, part 2

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STATUS for Decision

ABSTRACT Currently, simple receiver performance models have proven to be adequate for predicting the reach of various xDSL modems under ETSI stress conditions. These simple models are, however, inadequate for the FDD variants of ADSL under the full range of ETSI stress conditions. This contribution proposes adequate solutions, and forms the basis of two other contributions (TD14, TD15) proposing models for FDD variants of ADSL.

1. Limitations of the current simple model

The commonly used input model [2,4] is a simple model, which is applicable to many situations, such as modelling HDSL, SDSL and ADSL EC (Echo Cancelled). However the current "basic model" is too simple in special cases. These cases are quite relevant when modelling FDD variants of ADSL.

This contribution identifies the most striking limitations of the currently used model, and proposes a few additions to enhance it. These enhancements are the basis for TD14 [5] and TD15 [6], where models are proposed dedicated to the FDD variants of ADSL.

1.1. Problem 1: inadequate when tweaking guard band

The commonly used model is too simple when narrowing the guard band between the upstream and downstream spectra in case of FDD modems.
FDD modems without any echo cancellation on board require a guard band between the upstream and downstream spectra. This is to avoid spectral overlap of the slopes of the spectrum. Figure 1 shows that when the guard band of a FDD modem is narrowed, the residual overlap increases.

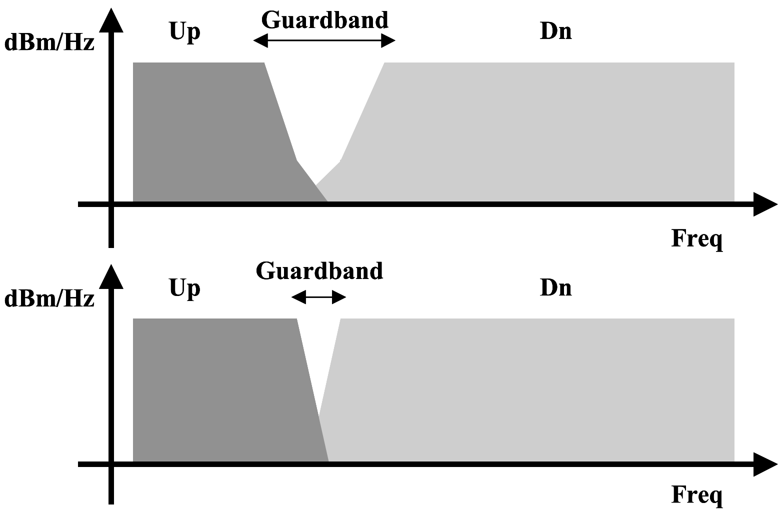


Figure 1: Narrowing the guard band of a FDD modem.

The need for a guard band for DMT modems is not a hypothetical issue. The assumptions used for evaluating the ETSI reach requirements [3] for the FDD variants of ADSL were explicitly 7 DMT tones were skiped for data transport. Apparently the loss of 7 tones for data transport is essential to compensate for the absence of echo cancellation.

So what will happen if a SpM study to the reach of ADSL.FDD ignores this need for a guard band, and allocates the full available FDD frequency band for datatransport. In other words, what will happen if the guard band of 7 DMT tones is removed (0 DMT tones) in these studies, as allowed by the standard. Will the reach increase, due to the additionals 7 DMT tones, or will the reach decrease due to the disturbance of other DMT tones? Figure 2 shows two possible curves, one when the performance increases, and one when it decreases.

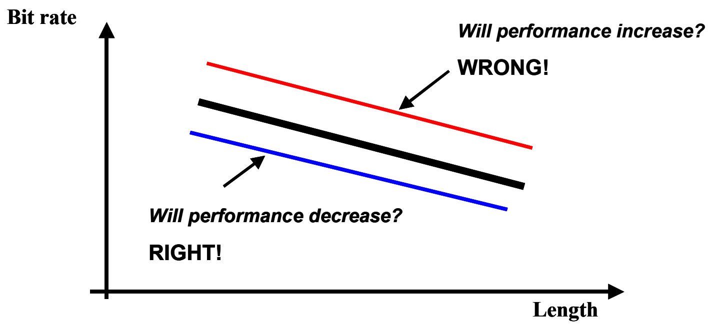


Figure 2: The effect of narrowing the guard band on the receiver performance.

The problem is that the simple performance model predicts an <u>in</u>crease. This must be wrong, otherwise there would have been no need for any guard band at all. The simple, commonly used model predicts wrong results, while an improved model should predict a <u>de</u>crease as soon as the guard band becomes too narrow. Such a model should account for echo as well, that disturbs the received signal when spectra are getting to overlap.

1.2. Problem 2: inadequate under high SNR conditions

The commonly used model is too simple under high SNR conditions.
When the noise decreases then the reach increases due to higher SNR values. This will occur when the loops are short, as shown in Figure 3, or when a scenario is dominated by FDD systems. In the latter case, the noise is kept as low as possible by minimizing all overlap in frequency bands. The ultimate example is the ADSL noise model FD, where all noise is supposed to be self noise of similar FDD systems.

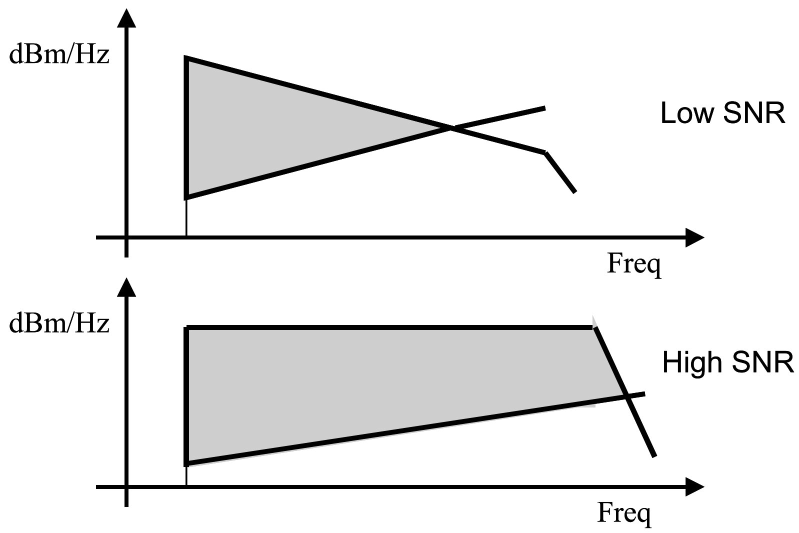


Figure 3: Increasing the SNR by shortening the loop

So what will happen if a SpM study is focussed on avoiding most of the spectral overlap. How much can be gained from that, and how much will the reach increase by such measures? Will this reach increase even further if FDD modems are used that are equipped with ultra low noise front ends? Figure 4 shows to possible curves when the noise is reduced significantly. Is it the most optimistic one, or will the performance be limited at some ceiling even when the SNR increases?

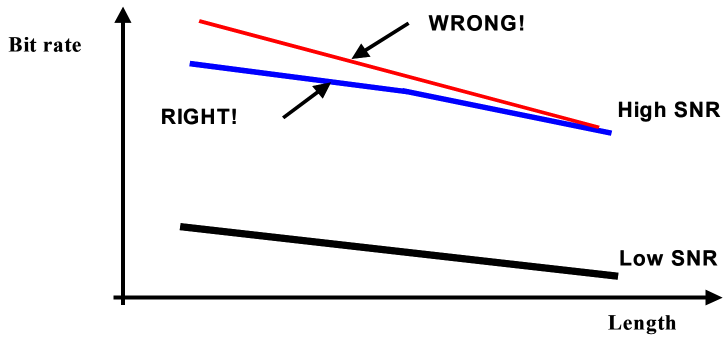


Figure 4: The effect of an increase in SNR on the receiver performance.

The problem is that the commonly used performance model predicts a nearly never ending <u>in</u>crease, while in practice the quality of the equalizer puts an additional limit before the receiver noise plays a role. When the transmitted signal, and equalized receive signal are not perfectly the same, some residual "noise" will limit the capacity. In the frequency domain, the difference between those two can therefore be modelled as an additional "noise" source. In the time domain one could call this inter symbol interference (ISI / ICI, see also [3]).

When scenarios with high SNR are not available or not of interest, the above problem is irrelevant. Some of the ETSI stress conditions for FDD ADSL, however, are resulting in scenarios with high SNR values. Especially with short loops and for noise model FD, the commonly used calculation model was not capable of making a fair prediction for all ETSI stress conditions. This makes the identified problem not a hypothetical case.

2. Solutions for improving current simple model

Some xDSL modems require a more sophisticated performance model containing more parameters. The solution is to expand the current performance model by accounting for more effects, and apply this higher order approach when needed. The input block of the commonly used performance model is a first order model, with only one parameter: "*receiver noise*". Expanding can be achieved by using more relevant parameters, including:

- The impact of *imperfect echo suppression*; this parameter may only be needed in case of FDD modems.
- The impact of *imperfect equalisation*; this parameter may only be needed in case of high SNR.

We prefer to keep the model as simple as possible, and an <u>all-linear model</u> has our preference. This contribution proposes several linear input models, each of them distinguished by the number and kind of parameters. Each parameter models a specific transceiver imperfection.

2.1. A first order input model

The common way to represent the input block of a receiver performance model, is essentially a first order input model (*accounts for only one imperfection: internal receiver noise*). This input model is quite a simplified model, and assumes that the SNR of the input signal is only deteriorated by received noise and internal receiver noise. Section 3 (clause 5.1.1) shows the associated flow diagram.
This simple input model is appropriated for many cases, especially when ultra low-noise scenarios are irrelevant and when a build-in echo cancellation is capable of suppressing the echo below the level of the receiver noise.

2.2. A second order input model (with echo)

Second order input model, accounting for two imperfections (internal receiver noise, imperfect echo suppression).
This enhanced input model uses a second order approach, by adding a second effect to the modeling: *echo coupling*. Section 3 (clause 5.1.2) shows the associated flow diagram. This diagram illustrates that a building block has been added (echo coupling), and that an additional suppressing parameter has been added to the input block (η_e = echo suppression) to suppress that echo in case the modem has an echo canceller on board.
The equivalent model of a linear hybrid has been described in section 3 (clause 5.2) to model the echo coupling from transmitter output to receiver input. The coupling of this hybrid is impedance dependent, as occurs in practice, and the natural echo loss of such a hybrid is typically in the order of 10-20 dB.
This addition is appropriated for modems without (or with restricted) echo cancellation, which is common for many FDD modems (ADSL.FDD, or VDSL).

Figure 5 shows how relevant the modelling of echo coupling is, compared to the commonly used first order input model. It shows the result of a simulation with an upstream "ADSL.FDD over POTS" modem, using noise model FA and loop 2, under ETSI stress condition [5]. The starting point is a performance prediction of this modem, when the guard band is 7 DMT tones, and without any echo suppression (η_e = 1, or 0 dB). The modem is assumed to transmit a PSD equal to the PSD template specified in the SpM-2 living list ([1], "rapporteurs proposal").
When the guard band is narrowed down to 0 DMT tones (the template description in [1] enable this in an unambiguous way) the performance changes. Two simulation results have been evaluated: a (wrong) prediction with a first order model, and a (plausible) prediction with our second order model.

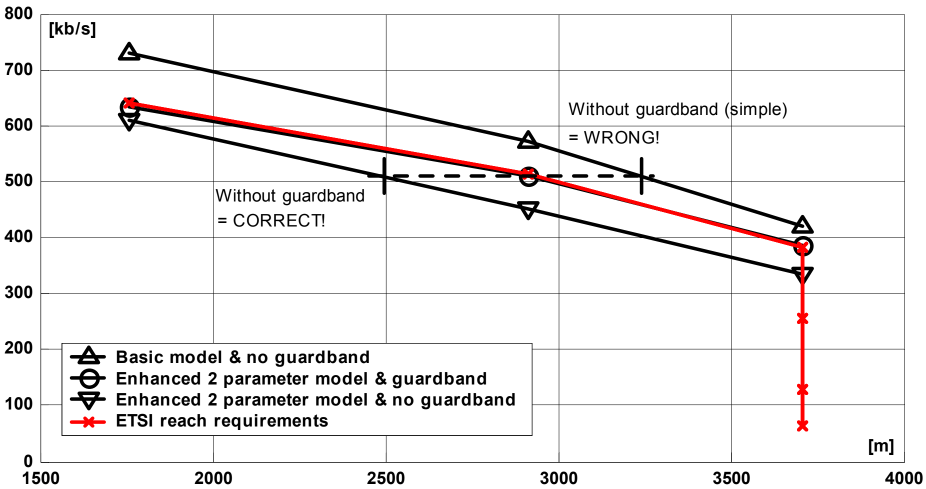


Figure 5: comparison of the simulation results using a basic or 1st order and enhanced 2 parameter or 2nd order input model.

Figure 5 illustrates that the difference between these two predictions is quite significant: **around 750m difference in reach**! The significance of this difference demonstrates how essential this enhancement of the model is for evaluating SpM scenarios for FDD modems.

2.3. A second order input model (with distortion)

Second order input model, accounting for another imperfections (internal receiver noise, imperfect distortion suppression).
This enhanced input model uses another second order approach, by adding another second effect to the modeling: *imperfect equalization*. Section 3 (clause 5.1.3) shows the associated flow diagram. A dedicated parameter controls the amount of equalizing imperfection: (η_d = distortion suppression).
The approach models the difference between transmitted signal and equalized received signal as if it was true noise that adds to the rest of the noise. A similar impact would have been achieved by simply 'clipping" the SNR in the detection block, as suggested in [3]. Since this effect is line code

independent, we prefer to model this in the input block, rather then in the detection block, and to model it in a linear way.

Figure 6 shows how relevant the modelling of imperfect equalization is, compared to the commonly used first order input model. It shows the result of a simulation with an upstream "ADSL.FDD over POTS" modem, using noise model FA and loop 2, under ETSI stress condition. The distortion suppression (η_d) is assumed to be 35 dB, and furthermore all assumptions summarized in TD14 [5] have been used (but without any echo coupling).

The starting point is a performance prediction of this modem, when the noise in increased by 13 dB, resulting in the lowest curve of Figure 6.Both the first and second order model predict (nearly) the same (low) performance, so they are equally applicable under such a scenario. Next the noise is decreased by 13 dB and the two models will then predict significantly different performance values: the first order model is too optimistic, and the second order model predicts a performance close to the ETSI reach requirements for these stress conditions.

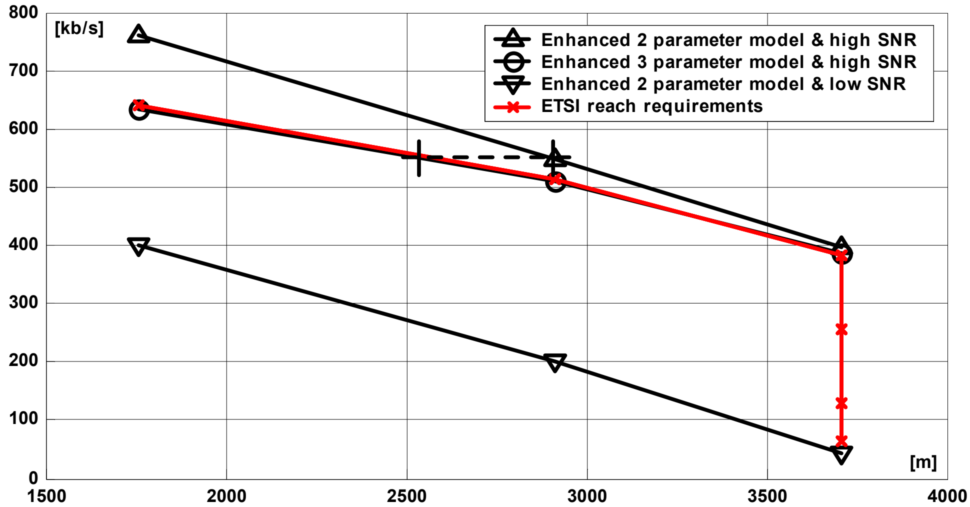


Figure 6: comparison of the simulation results using a 2nd order and 3rd order input model

Figure 6 illustrates that the difference between these two predictions is quite significant: **around 400m difference in reach**! The assumed imperfections of the equalizer, although they may appear to be very minor imperfections from a technical point of view, cannot be ignored in cases that the SNR is high. The significance of this difference demonstrates how essential this enhancement is for evaluating SpM scenarios characterized by low noise conditions. This is especially relevant for SpM studies to "upstream FDD ADSL" where the presence of imperfect equalization reduces the reach in upstream direction for the highest bitrates.

2.4. A third order input model (with echo + distortion)

Third order input model, accounting for three imperfections (internal receiver noise, imperfect echo suppression, imperfect distortion suppression).

This enhanced input model combines the above second order approaches, by accounting for both the impact of *echo coupling* and *imperfect equalization*. Section 3 (clause 5.1.4) shows the associated flow diagram. These are complementary effects, so using them both is useful when tweaking guard bands and in low noise scenarios. Both cases apply to scenarios with FDD modems

3. Literal text proposal

The text below proposes literal text for inclusion in clause 4 of the Spectral Management draft, part 2.

5 Generic receiver performance models for xDSL

A receiver performance model is capable of predicting up to what performance a data stream can be recovered from a noisy signal. In all cases it assumes that this recovery meets predefined quality criteria such as a maximum BER (Bit Error Ratio). Values like BER<10^{-7}, during a time interval of several minutes, are not uncommon.

The word *performance* refers within this context to a variety of quantities, including noise margin, signal margin and max datarate. When the receiver is ideal (zero internal receiver noise, infinite echo cancellation, etc), quantities like noise margin and signal margin become equal.

Performance models are implementation and linecode specific. Performance modeling becomes more convenient when broken down into a cascade of smaller submodels:

- a line code independent *input* (sub)model that evaluates the effective SNR from received signal, received noise, and various receiver imperfections. Details are described in clause 5.1.
- a *echo coupling* (sub)model that evaluates what portion of the transmitted signal flows into the receiver. Details are described in clause 5.2.
- a line code dependent *detection* (sub)model that evaluates the performance (e.g. the noise margin at specified bit rate) from the effective SNR. Details are described in clause 5.3.

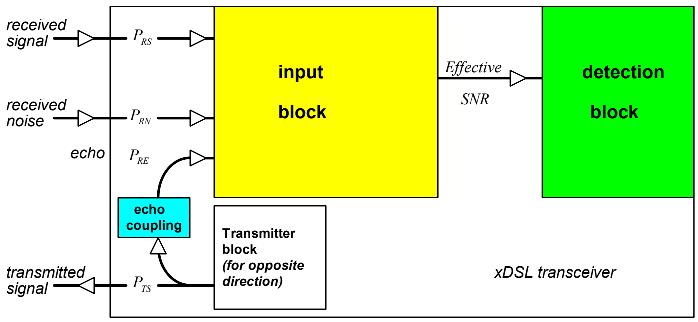


Figure 7: Flow diagram of a transceiver model, build up from individual submodels.

This clause details all the above mentioned sub models, being used for evaluating the performance of receivers under noise conditions. This clause 5 is dedicated to *generic* performance models only. Clause 6 is dedicated to *specific* models by assigning values to all parameters of a generic model.

5.1 Generic input models for effective SNR

An input (sub) model describes how to evaluate the effective SNR, as intermediate result (see figure 7), from various input quantities and imperfections.

On input, the input model for effective SNR requires values for *signal*, *noise* and *echo*. The flow diagram in figure 7 illustrates this for an xDSL transceiver that is connected via a common wire pair to another transceiver (not shown).

- The received *signal* 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 *noise* 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 cross talk from internal disturbers connected to the same cable (cross talk noise), and partly from external disturbers (ingress noise).
- The received *echo* 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 and is identified as echo. Models for echo coupling are specified in clause 5.2.

On output, the input model evaluates a quantity called effective SNR (Signal to noise Ratio) that indicates to what degree the received signal is deteriorated by noise, residual echo and all kinds of implementation imperfections. Due to signal processing in 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, the A/D-converter produces quantization noise, and the equalization has its limitations as well. The combination of all these individual imperfections deteriorates the effective SNR.
In principle all parameters of the effective SNR can be assumed as frequency dependent, but this dependency has often been omitted here for reasons of simplicity. In addition, external change of signal and noise levels will modify the value of this effective SNR.

Effective SNR, in offset format for margin evaluations
To simplify further analysis of performance quantities like *noise margin* and *signal margin*, the effective SNR is often expressed in its offset format, characterized by an additional parameter *m*. With this parameter *m* the external noise level can be increased (for noise margin calculations) or the external signal level can be decreased (for signal margin calculations). 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* increases, the effective offset SNR decreases.

5.1.1. First order input model

This input model is quite a simplified model that assumes that the SNR of the input signal is internally modified by internal receiver noise (P_{RN0}). Most imperfections of the receiver (such as imperfect echo suppression, imperfect equalization and quantization noise) are assumed to be concentrated in a single virtual internal noise source (P_{RN0}). Figure 8 shows the flow diagram of an xDSL transceiver model that incorporates a linear first order model for effective SNR evaluation.

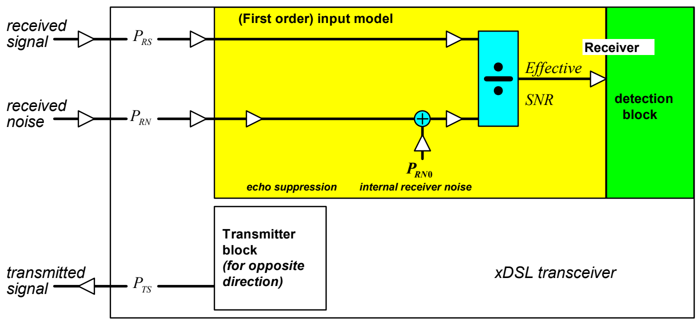


Figure 8: Flow diagram of a transceiver model that incorporates a linear first order input model for the determination of the effective SNR.

Expression 1 summarizes how to evaluate the effective SNR for this model, and it has been specified in plain and offset formats. Table 1 summarizes the involved parameters.

Plain format:	$SNR(f)$	=	$\frac{P_{RS}}{P_{RN} + P_{RN0}}$
Noise offset format:	$SNR_{ofs,N}(m, f)$	=	$\frac{P_{RS}}{P_{RN} \times m + P_{RN0}}$
Signal offset format:	$SNR_{ofs,S}(m, f)$	=	$\frac{P_{RS} / m}{P_{RN} + P_{RN0}}$

Expression 1: Effective SNR, in various formats

Input quantities	***linear***	***In dB***	***remarks***
Received signal power	P_{RS}	$10\times\log_{10}(P_{RS})$	*Frequency dependent*
Received crosstalk noise	P_{RN}	$10\times\log_{10}(P_{RN})$	*External noise*
Model Parameters			
Receiver noise power	P_{RN0}	$10\times\log_{10}(P_{RN0})$	*Internal noise*
Output quantities			
Signal to noise ratio (effective)	SNR	$10\times\log_{10}(SNR)$	*Frequency dependent*

Table 1: Involved parameters and quantities for a first order input model.

5.1.2. Second order input model (with echo)

This input model assumes that the SNR of the input signal is internally modified by two effects:

- an equivalent *receiver noise power* P_{RN0} that indicates how much noise is added by the receiver electronics.
- an *echo suppression factor* η_e that indicates how effective echo cancellation is implemented.

Therefore this input model is enhanced with a simple but effective model of echo coupling as specified in clause 5.2. It models the echo coupling caused by the analogue hybrid used for “isolating” received and transmitted signal in a transceiver. When echo cancelation is on board, the echo can be suppressed additionally by a parameter η_e. Figure 9 shows the flow diagram of this model.

The importance of including echo cancellation in this input model 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 deterioration of performance. By tweaking the value for echo suppression η_e, the amount of additional echo cancellation can be controlled.

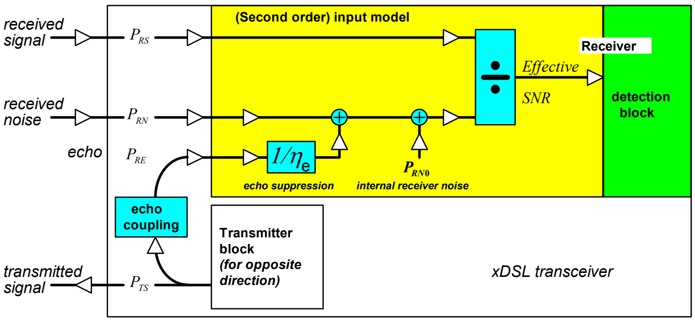


Figure 9: Flow diagram of a transceiver model that incorporates a linear second order input model for the determination of the effective SNR.

Expression 2 summarizes how to evaluate the effective SNR for this model, and it has been specified in plain and offset formats. Table 2 summarizes the involved parameters.

Plain format: $SNR(f) = \dfrac{P_{RS}}{P_{RN} + P_{RN0} + P_{RE}/\eta_e^2}$

Noise offset format: $SNR_{ofs,N}(m, f) = \dfrac{P_{RS}}{P_{RN} \times m + P_{RN0} + P_{RE}/\eta_e^2}$

Signal offset format: $SNR_{ofs,S}(m, f) = \dfrac{P_{RS}/m}{P_{RN} + P_{RN0} + P_{RE}/\eta_e^2}$

Expression 2: Effective SNR, in various formats.

Input quantities	***linear***	***In dB***	***remarks***
Received signal power	P_{RS}	$10\times\log_{10}(P_{RS})$	*Frequency dependent*
Received crosstalk noise	P_{RN}	$10\times\log_{10}(P_{RN})$	*External noise*
Received reflected power	P_{RE}	$10\times\log_{10}(P_{RE})$	*External noise*
Model Parameters			
Receiver noise power	P_{RN0}	$10\times\log_{10}(P_{RN0})$	*Internal noise*
Echo suppression	η_e	$20\times\log_{10}(\eta_e)$	*Quality of echo canceller*
Output quantities			
Signal to noise ratio (effective)	SNR	$10\times\log_{10}(SNR)$	*Frequency dependent*

Table 2: Involved parameters and quantities for a second order input model.

5.1.3. Second order input model (with distortion)

This input model assumes that the SNR of the input signal is internally modified by two effects:

- an equivalent *receiver noise power* P_{RN0} that indicates how much noise is added by the receiver electronics.
- a *distortion suppression factor* η_d that indicates how effective equalization has been implemented. It represents the difference between transmitted signal and equalized received signal, and any non-zero difference behaves like noise.

Figure 10 shows the flow diagram of this model.

The importance of including distortion suppression in this input model is mainly to extend the validity of the model to scenarios with relatively high SNR values. This is particularly of interest when studying scenarios for FDD modems.

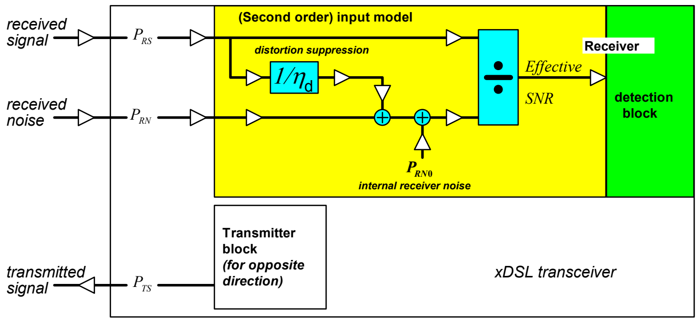


Figure 10: Flow diagram of a transceiver model that incorporates a linear second order input model for the determination of the effective SNR.

Expression 3 summarizes how to evaluate the effective SNR for this model, and it has been specified in plain and offset formats. Table 3 summarizes the involved parameters.

Plain format: $SNR(f) = \dfrac{P_{RS}}{P_{RN} + P_{RN0} + P_{RS}/\eta_d^2}$

Noise offset format: $SNR_{ofs,N}(m, f) = \dfrac{P_{RS}}{P_{RN} \times m + P_{RN0} + P_{RS}/\eta_d^2}$

Signal offset format: $SNR_{ofs,S}(m, f) = \dfrac{P_{RS}/m}{P_{RN} + P_{RN0} + P_{RS}/(\eta_d^2 \times m)}$

Expression 3: Effective SNR, in various formats.

Input quantities	***linear***	***In dB***	***remarks***
Received signal power	P_{RS}	$10\times\log_{10}(P_{RS})$	*Frequency dependent*
Received crosstalk noise	P_{RN}	$10\times\log_{10}(P_{RN})$	*External noise*
Received reflected power	P_{RE}	$10\times\log_{10}(P_{RE})$	*External noise*
Model Parameters			
Receiver noise power	P_{RN0}	$10\times\log_{10}(P_{RN0})$	*Internal noise*
Distortion suppression	η_d	$20\times\log_{10}(\eta_d)$	*Quality of equalizer*
Output quantities			
Signal to noise ratio (effective)	SNR	$10\times\log_{10}(SNR)$	*Frequency dependent*

Table 3: Involved parameters and quantities for a third order input model.

5.1.4. Third order input model

This input model assumes that the SNR of the input signal is internally modified by three effects:

- an equivalent *receiver noise power* P_{RN0} that indicates how much noise is added by the receiver electronics.
- an *echo suppression factor* η_e that indicates how effective echo cancellation is implemented. The second order input model evaluates the effective SNR as follows:
- a *distortion suppression factor* η_d that indicates how effective equalization has been implemented. It represents the difference between transmitted signal and equalized received signal, and any non-zero difference behaves like noise.

This model is essentially the combination of the two previous (second order) models, and is shown in figure 11.

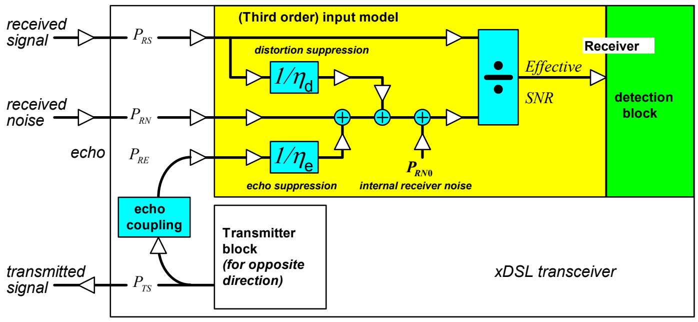


Figure 11: Flow diagram of a transceiver model that incorporates a linear third order input model for the determination of the effective SNR.

Expression 4 summarizes how to evaluate the effective SNR for this model, and it has been specified in plain and offset formats. Table 4 summarizes the involved parameters.

Plain format: $SNR(f) = \dfrac{P_{RS}}{P_{RN} + P_{RN0} + P_{RE}/\eta_e^2 + P_{RS}/\eta_d^2}$

Noise offset format: $SNR_{ofs,N}(m, f) = \dfrac{P_{RS}}{P_{RN} \times m + P_{RN0} + P_{RE}/\eta_e^2 + P_{RS}/\eta_d^2}$

Signal offset format: $SNR_{ofs,S}(m, f) = \dfrac{P_{RS}/m}{P_{RN} + P_{RN0} + P_{RE}/\eta_e^2 + P_{RS}/(\eta_d^2 \times m)}$

Expression 4: Effective SNR, in various formats.

Input quantities	***linear***	***In dB***	***remarks***
Received signal power	P_{RS}	$10\times\log_{10}(P_{RS})$	*Frequency dependent*
Received crosstalk noise	P_{RN}	$10\times\log_{10}(P_{RN})$	*External noise*
Received reflected power	P_{RE}	$10\times\log_{10}(P_{RE})$	*External noise*
Model Parameters			
Receiver noise power	P_{RN0}	$10\times\log_{10}(P_{RN0})$	*Internal noise*
Echo suppression	η_e	$20\times\log_{10}(\eta_e)$	*Quality of echo canceller*
Distortion suppression	η_d	$20\times\log_{10}(\eta_d)$	*Quality of equalizer*
Output quantities			
Signal to noise ratio (effective)	SNR	$10\times\log_{10}(SNR)$	*Frequency dependent*

Table 4: Involved parameters and quantities for a third order input model.

5.2 Generic model for echo coupling

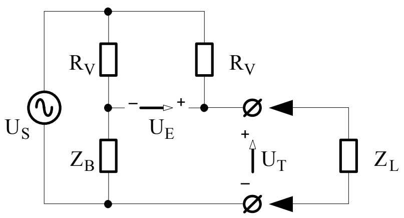
5.2.1 Linear echo coupling model

We propose to move clause 7.2 from the draft to this section, and to rephrase it as follows:

This model describes a property of linear hybrids in transceivers, and models what portion of the transmitted signal reflects directly into the receiver. The hybrid is characterized by two parameters:

- R_V, representing the output impedance of the transceiver. Commonly used values are the design impedances of the modems under test, including as 100Ω for ADSL and 135Ω for SDSL.
- Z_B, representing the termination impedance that causes that the hybrid is perfectly balanced. This means that when the hybrid is terminated with this "balance impedance", no echo will flow into the receiver. For well designed hybrids, this balance impedance is a "best guess" approximation of the "average" impedance of cables being used.

Figure 12 shows an equivalent circuit diagram of the above hybrid, represented as a Wheatstone bridge. The associated transfer function $H_E(j\omega)$ expresses what portion of the transmit signal will appear as echo.



$$H_E(j\omega) = \frac{U_E}{U_T} = 1 - \frac{Z_B}{R_V + Z_B} \times \frac{U_S}{U_T} = \frac{(Z_L - Z_B) \times R_V}{(R_V - Z_B) \times Z_L}$$

$$\frac{P_{RE}}{P_{TS}} = |H_E(j\omega)|^2$$

Figure 12: Flow diagram of the basic model for echo loss

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

Expression 5: Transfer function of the basic model for echo loss.
The identifiers P_{RE} and P_{TS} refer to power flow values used in figure 6.

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_B 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. Values for R_V and Z_B are implementation specific.

End of literal text proposal

4. References

[1] Rapporteur: "Living List for SpM part 2", ETSI-TM6 Permanent document TM6(01)21, (m01p21a6), Aug 29, 2003.
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