TITLE **Revised modelling of "ADSL.FDD over POTS" receivers, without echo parameters**

PROJECTS Spectral Management, part 2.

SOURCE: TNO Telecom / KPN

AUTHOR: Rob van den Brink

CONTACT: Rob F. M. van den Brink,
TNO Telecom
~~P.O. Box 421~~
~~2260 AK Leidschendam~~
PO Box 5050
2600 GB Delft
The Netherlands

tel ~~+31 70 4462389~~ +31.15.2857059
fax: ~~+31 70 4463166~~ +31.15.2857354
e-mail: R.F.M.vandenBrink@telecom.tno.nl

***the above numbers and e-mail address are changed since 1 January 2003, and changed again since 21 nov 2003.***

STATUS for Decision

ABSTRACT This contribution shows how close an "ADSL.FDD over POTS" receiver model can predict the ETSI reach requirements under ETSI stress conditions, when the model for the receiver has no parameters for echo, and when the template PSD of the transmitter has a fixed guard band between up and downstream transmission. This simplification was proposed in the previous TM6 meeting, in combination with another proposal to define only two fixed PSD templates ("adjacent FDD" and "guard band FDD"), instead of a flexible definition.

# 1. Rationale behind this proposal

In a previous contribution [8], we proposed a performance model for modelling "ADSL.FDD over POTS" receivers. The objective was to create a computer model, capable of predicting a performance that can be benchmarked against the performance requirements of an ETSI compliant "ADSL.FDD over POTS" modem. This means that the reach predicted by such a model, under the stress conditions of the associated ETSI ADSL specification [3], has to be close to the (minimum) reach required by that ETSI specification. In other words: not significantly worse and also not significantly better as this benchmark.
The model previously proposed in [8] was fully capable of meeting these objectives, however the desired increase of the validity range by including parameters for echo modelling was subject of discussion within ETSI-TM6 [11,12]. The echo modelling proposed in our contributions [7,8,9] was seen as not powerful enough to extend the validity of the performance model.

The proposed solution was not to extend the validity range by excluding echo modelling, and to restrict the need for an extended range by putting additional constraints to the template PSD of the transmitter. The proposed solution for that was twofold:

- Simplify the receiver model by leaving out all parameters related to echo coupling and echo cancellation.
- Reduce the flexibility of the FDD transmitter model, by restricting the SpM-standard to only two template PSDs: A so called "guard band FDD" version, that prevents disturbing echo by leaving 7 tones unused, and a so called "adjacent FDD" version, that assumes that the echo cancellation is so effective that it can be modelled by simply increasing the overall receiver noise floor.

In the current contribution, we demonstrate that the above-proposed solution works reasonably well, and that the resulting receiver performance models are adequate for SpM purposes with the above restrictions.
The inclusion of a parameter that accounts for imperfections in the equalizer remains essential, as is illustrated in this contribution as well. We propose to adopt the revised model in this contribution for the SpM-2 standard.

# 2. Proposed receiver performance model

The proposed performance model is constructed by defining values for the parameters of two generic sub-models:

- a generic linear input model, to evaluate the effective SNR from input signal, input noise and several implementation imperfections.
- A generic DMT detection model, to evaluate the margin or bitrate from the effective SNR and some other implementation imperfections, and captured in the latest Living List for SpM [1]

The values for the parameters of these generic models were allocated as follows:

- Some of these parameter values are clearly specified by the ADSL standard [3].
- Some of these parameters were taken from [4] where common simulation assumptions are summarized that were used for generating the performance numbers for the ADSL standard. A guard band of 7 DMT tones between up and downstream spectra was used, since this was seen as an essential assumption at the time these ETSI requirements were derived [4].
- Other values are extracted by fitting the predicted performance with the required performance for ETSI compliant modems. The simulation conditions are fully equal to the performance test prescriptions as specified in the ADSL standard, and even account for impedance mismatch between modem and cables, as well as a current noise injection based on calibration with complex impedances (see [3], clause 5.1.4). The transmitter was assumed to generate a template PSD labelled as "guard band FDD" in the latest SpM Living List [1] (revision 8)

Two mathematical models have been fitted for predicting the reference performance of the “ADSL.FDD over POTS” modems, one for the downstream and one for the upstream direction.

## 2.1. Model for input block, for downstream direction

For downstream receiver modelling of "ADSL.FDD over POTS", a simple first order input model has proven to be adequate for SpM purposes. This sub-model is shown in figure 1, and is commonly used. Only one parameter (the virtual receiver noise floor of -140 dBm) is used to model many imperfections of the modem.
All the remaining imperfections are incorporated in the effective SNR-Gap ($\Gamma$) of the DMT detection model, as detailed in section 2.3. Al kinds of associated parameter values are captured in table 1. The SNR gap was extracted from the reach requirements, and appeared to be 8.9 dB.

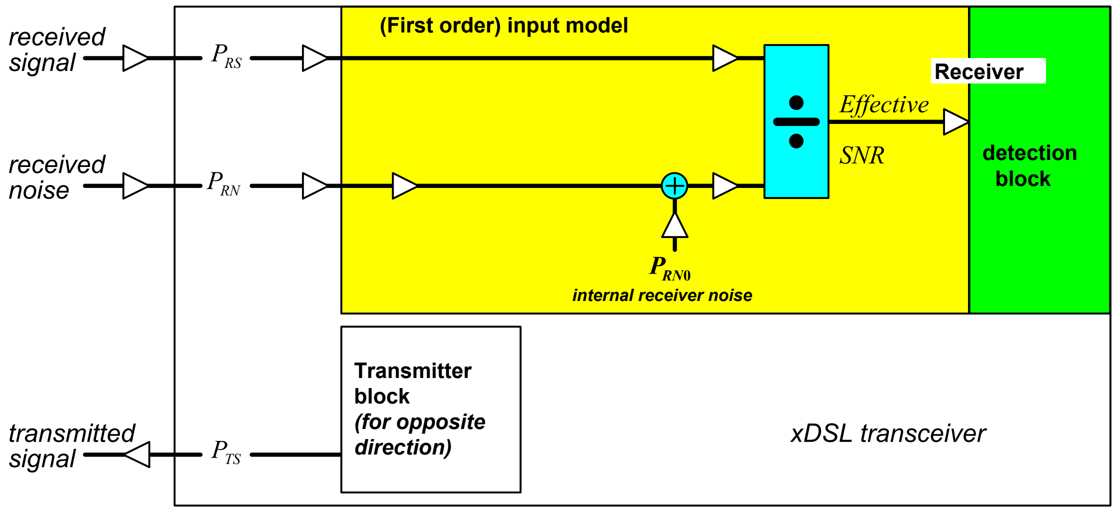


*Figure 1: Flow diagram of the proposed downstream receiver model, using a first order approach for modeling the input in a linear way.*

Section 4 shows the result when the predictions of this model are benchmarked against the associated ETSI reach requirements for downstream under ETSI test conditions. The match between predictions and requirements is very close but not perfectly equal, although the reach requirements were derived from modelling as well [4].

This is no true surprise. In [4] some modifications to the model were reported that are not related to what the receiver actually senses. These modifications were applied to simplify matters significantly:

- The implementation losses were made loop dependent by pragmatic values, instead of relating it to insertion loss and/or signal phases and/or loop impedances.
- The receiver noise floor was made dependent on the *length* of the loop, instead of relating it to signal levels and/or loop impedance

Additionally, [4] reported some refinements like making the receiver noise floor frequency *de*pendent. We studied these refinements as well, but concluded that (compared to other deviations) such a refinement will hardly bring the predicted performance closer to the requirements. As a result, and for the sake of simplicity, we left this noise floor therefore frequency *in*dependent, and kept all these ignored effects hidden in (additional) "implementation losses".

# 2.2. Model for input block, for upstream direction

The approach for modelling upstream performance is somewhat similar to downstream, but now a second parameter had to be added to the input block. As a rule of thumb, when the upstream bit-rate can exceed 400 kb/s, the use of a simple first order input model has appeared to be inadequate. Under these conditions the SNR will be high, and a first order model will predict a bit rate that is significantly higher than what is specified by the ETSI reach requirements (and will be observed on implemented modems).
An explanation for that deviation is that under high SNR conditions, the remaining imperfections of the equalizer cannot be ignored any longer. The equalizer recovers the transmitted signal, being distorted by the cable transfer function. This reconstruction can be very good in practice but will never be perfect. The difference between the transmitted signal, and the recovered received signal behaves like additional "noise" and puts an extra constraint on the maximum *effective* SNR that will be achieved after equalization. A maximum effective SNR value in the order of 35 dB was observed to be adequate for predicting the ETSI reach requirements for this modem.

We applied the second order input model, as introduced in [7], to restrict the maximum effective SNR in the receiver performance model for upstream. Figure 2 shows how this behaviour is modelled in a *linear* way, by including a second parameter $\eta_d$ that indicates how effective the residual "distortion" of the equalized signal is suppressed.
Mark that this is a *frequency domain* approach. In the time domain this behaviour is usually referred to as inter-symbol interference (ISI/ICI). In our specific case, a frequency independent value for $\eta_d$ has proven adequate (35 dB), but frequency dependent values are not excluded for the general case.

All the remaining imperfections are incorporated in the effective SNR-Gap ($\Gamma$) of the DMT detection model, as detailed in section 2.3. Al kinds of associated parameter values are captured in table [1]. The SNR gap was extracted from the reach requirements, and appeared to be 9.3 dB.

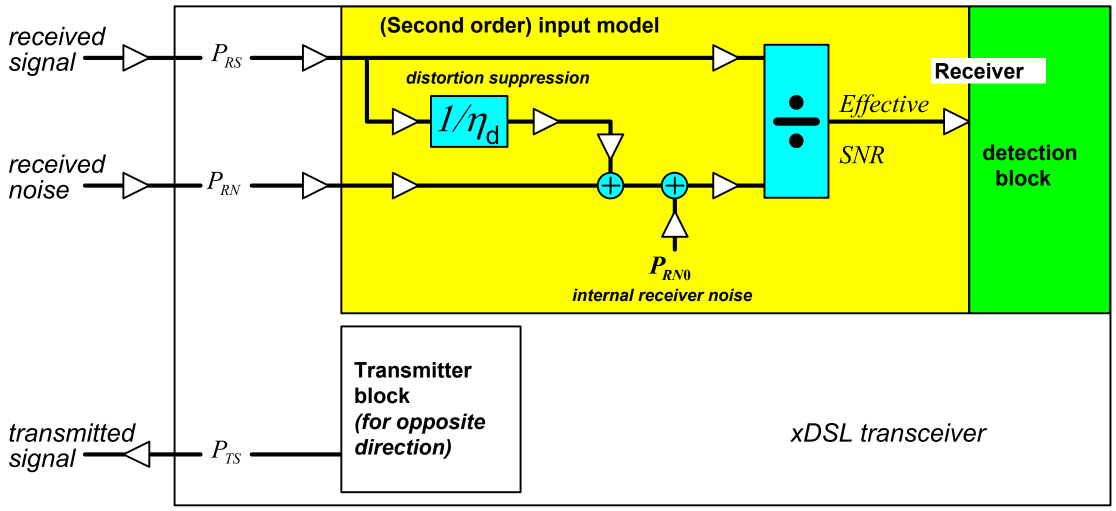


*Figure 2: Flow diagram of the proposed upstream receiver model, using a second order approach for modeling the input in a linear way.*

Section 3.1 shows the result when the prediction of this model is benchmarked against the associated ETSI reach requirements for upstream under ETSI test conditions. The match between prediction and requirements is very close but not perfectly equal, although the reach requirements were derived from modelling as well [4].
Again, this is no true surprise, for the same reasons as explained before. In addition, [4] reported a frequency dependent ISI/ICI-noise, but this refinements didn't bring us match that is significantly better. As a result, and for the sake of simplicity, we left this noise floor $P_{RN0}$ and distortion suppression $\eta_d$ both frequency <u>*in*</u>dependent, and kept all these ignored effects hidden in (additional) "implementation losses".

# 2.3. Proposed parameters, for both directions

We used the generic DMT model, as proposed in [6] and refined in [10], for modelling at what bit rate an ADSL modem can operate at 6dB noise margin. To keep the naming consistent, we applied the refined version of this DMT model, as summarized in the latest SpM-2 Living List [1]. In <u>*addition*</u> we applied a modified fractional bit-loading algorithm ("FBL-revised" for the time being), as show in expression 1. This because the current one in [1] is somewhat too pessimistic when the bit space becomes less then 2 bits. A bit space as low as 1.5 bit can still carry 2 bits, when the tone level is increased by 3 dB (this doubles the SNR). Therefore we additionally propose to update [1] according to expression 1, and make that the default "Fractional Bit Loading" algorithm.

| | | |
|---|---|---|
| $bb_k = \log_2\left(1 + 2 \times \frac{SNR_{ofs}(m,f)}{\Gamma}\right)$ | | *Bit-space / carrier* |
| $(bb_k \le b_{min})$ | $\Rightarrow$ | $load(b_k) \equiv 0$ |
| $(b_{min} \le bb_k)$ and $(b_k \le b_{max})$ | $\Rightarrow$ | $load(b_k) \equiv b_k$ |
| $(b_k > b_{max})$ | $\Rightarrow$ | $load(b_k) \equiv b_{max}$ |

**Expression 1: The bit-loading used in this model**

| ***Model parameter*** | | ***DMT model*** | | |
|---|---|---|---|---|
| | | ***Upstream*** | ***Downstream*** | ***Remarks*** |
| SNR-Gap (effective) | $\Gamma_{dB}$ | 9.3 dB | 8.9 dB | |
| SNR-Gap in parts | $\Gamma_{DMT\_dB}$<br>$\Gamma_{coding\_dB}$<br>$\Gamma_{impl\_dB}$ | 9.75 dB<br>4.25 dB<br>4.3 dB | 9.75 dB<br>4.25 dB<br>3.9 dB | |
| Receiver noise | $P_{RN0\_dB}$ | –120 dBm | –140 dBm | |
| Distortion suppression | $\eta_d$ | 35 dB | N/A (∞) | *See clause 5.1.4* |
| Symbol rate | $f_s$<br>$f_{sd}$ | 69/68 × 4000baud<br>4000 baud | 69/68 × 4000 baud<br>4000 baud | *See clause 5.2.4* |
| Data rate | $f_d$ | 64 … 640 kb/s | 64 … 6144 kb/s | |
| Line rate | <br>$f_{bd}$<br><br>$f_b$ | $f_{bl} = f_d + 16 \times f_{sd}$<br>$f_{bh} = (f_d + 8 \times f_{sd}) \times 1.13$<br>$f_{bd} = max(f_{bl}, f_{bh})$<br>$f_b = 69/68 \times f_{db}$ | $f_{bl} = f_d + 16 \times f_{sd}$<br>$f_{bh} = (f_d + 8 \times f_{sd}) \times 1.13$<br>$f_{bd} = max(f_{bl}, f_{bh})$<br>$f_b = 69/68 \times f_{db}$ | *See clause 5.2.4* |
| Bits per symbol | $b$ | $f_{bd} / f_{sd}$ | $f_{bd} / f_{sd}$ | |
| Available set of tones | *tones* | [7:30]<br>= [$k_1$ : $k_2$]<br><br>*Tone 31-37 are used for guard band* | [38:63, 65:255]<br>= [$k_1$ : $k_2$ , $k_3$ : $k_4$]<br><br>*Tone 64 = pilot tone* | *DMT tone k = 64 does not convey any bits because it is reserved as pilot tone.* |
| Center frequency location of tone k; k ∈ tones | $f_k$ | $f_k = k \times \Delta f$<br>$\Delta f$ = 4.3125 kHz | $f_k = k \times \Delta f$<br>$\Delta f$ = 4.3125 kHz | |
| Bit-loading algorithm | | FBL - revised | FBL - revised | *See clause 5.3.4* |
| Minimum bit-loading | $b_{min}$ | 2 | 2 | *Bits per sub-carrier* |
| Maximum bit-loading | $b_{max}$ | 15 | 15 | *Bits per sub-carrier* |

**Table 1: Values for the performance parameters extracted from the ETSI performance requirements under ETSI stress conditions.**

For an explanation of all the other parameters, see the SpM2-Living List [1]. For a description of the details about overhead, see [8] and the additional remarks in [10].

# 3. Validation of the reference model

This section shows the result when the predictions of these models are benchmarked against the associated ETSI reach requirements. The models are validated by figure 3 to 9, and 10 to 16, showing the predicted reach-bitrate curves (in red) and the required reach-bitrate curves (in green) when the different ETSI noise models (A to D) are applied to different ETSI test loops (1-7), all according to the associated ETSI stress conditions of the ADSL standard [3]. Receiver model and transmitter PSD template are all as described above.
Note that the upstream reach requirements, when stressed by noise model FB and FC, entirely or partly overlap. Furthermore note that the longest reach in the downstream direction limits the ETSI upstream reach requirements for the lowest bitrates.

Analysing the curves showing the ***downstream*** performance, it can be concluded that the performance prediction of “ADSL.FDD over POTS” over the full range is very close to the ETSI reach requirements. The maximum deviation between the predicted performance and the ETSI reach requirements is in the order of 100m, but it is often better.

Analysing the complete set of figures depicting the ***upstream*** performance, it can be concluded that the performance prediction of “ADSL.FDD over POTS” over the full range is very close to the ETSI requirements. The maximum deviation between the predicted performance and the ETSI requirements is in most cases significantly less than 200m, but is often better too.

## 3.1. “ADSL.FDD over POTS” downstream

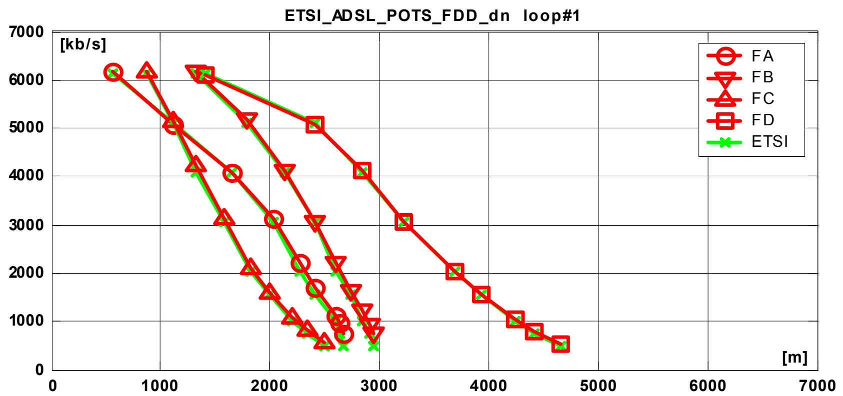

*Figure 3*

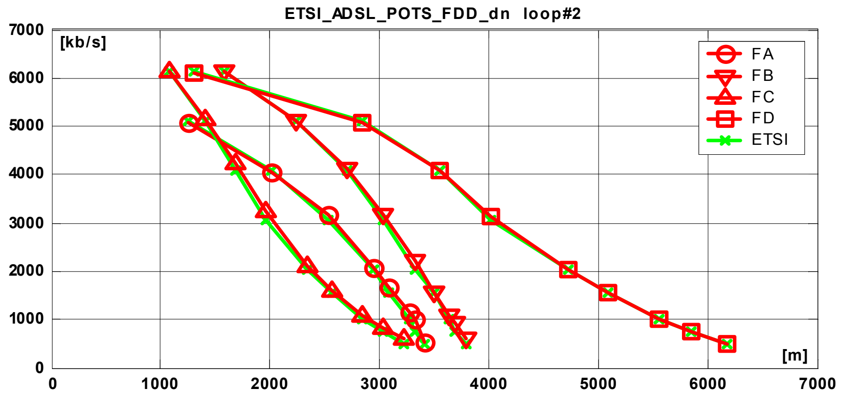

*Figure 4*

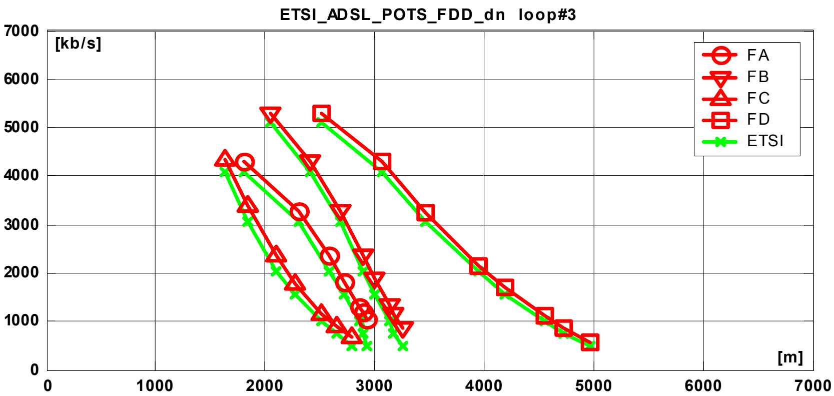


*Figure 5*

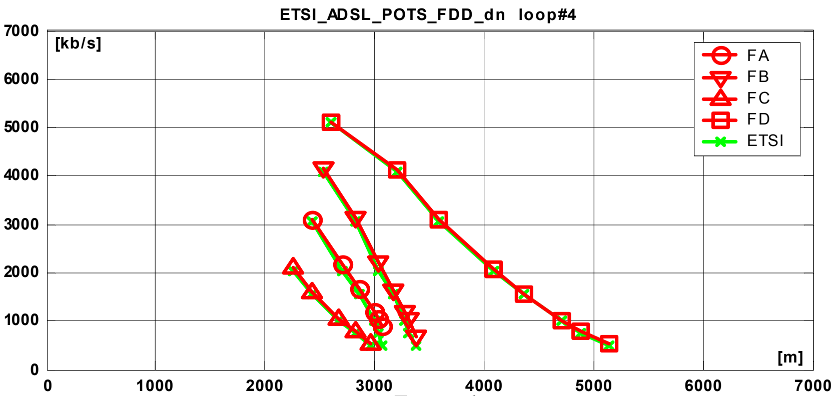


*Figure 6*

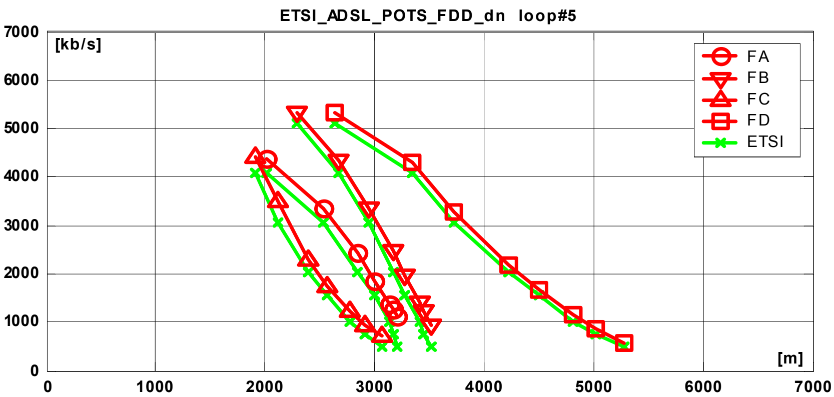


*Figure 7*

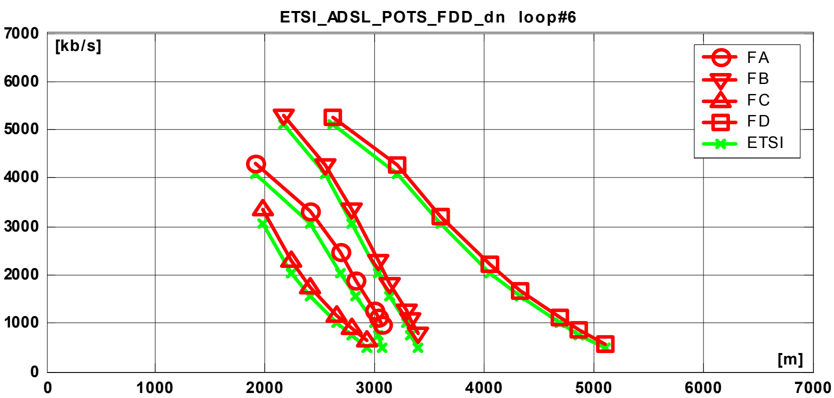


*Figure 8*

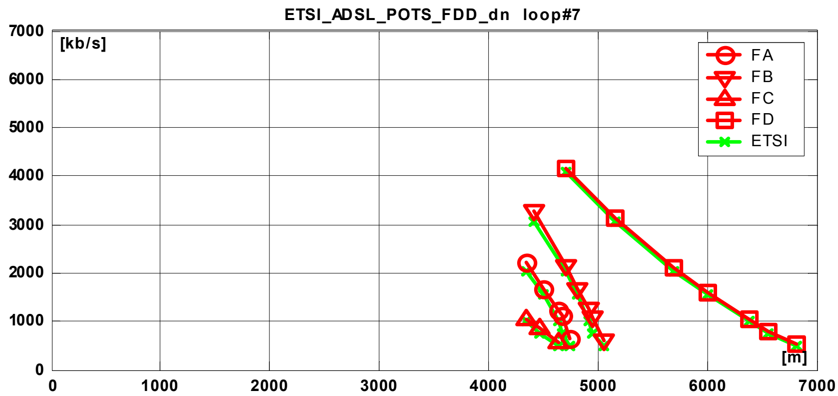


*Figure 9*

## 3.2. "ADSL.FDD over POTS" upstream

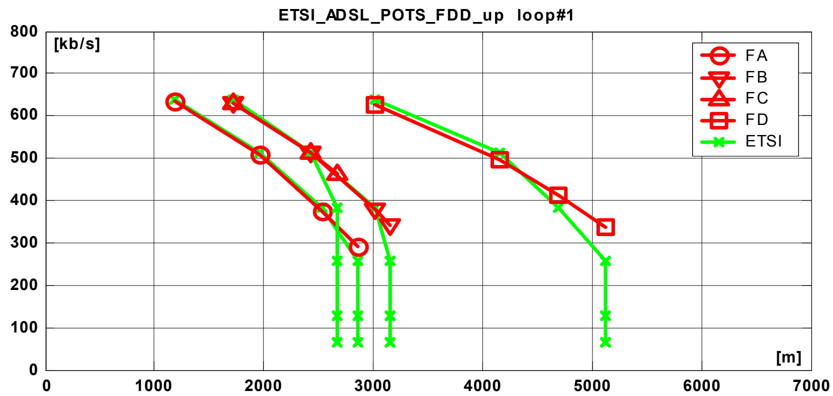


*Figure 10*

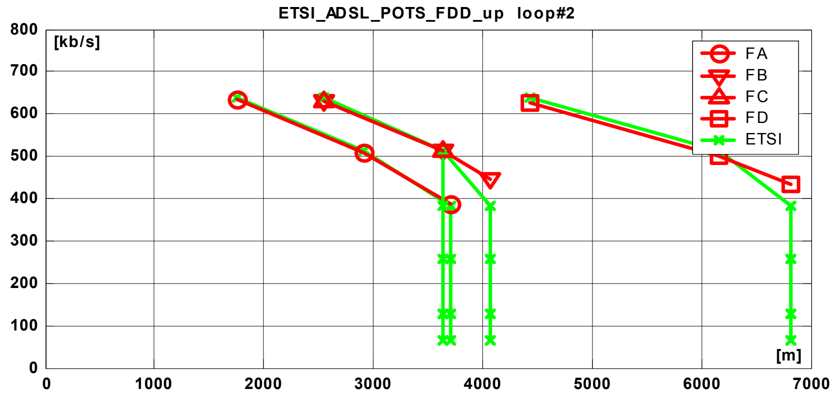


*Figure 11*

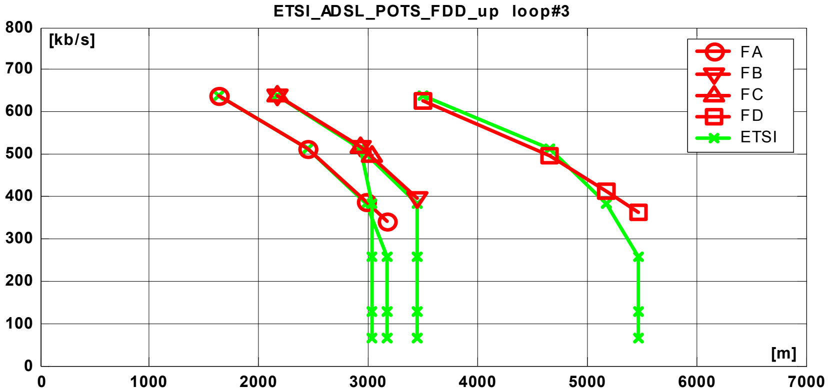


*Figure 12*

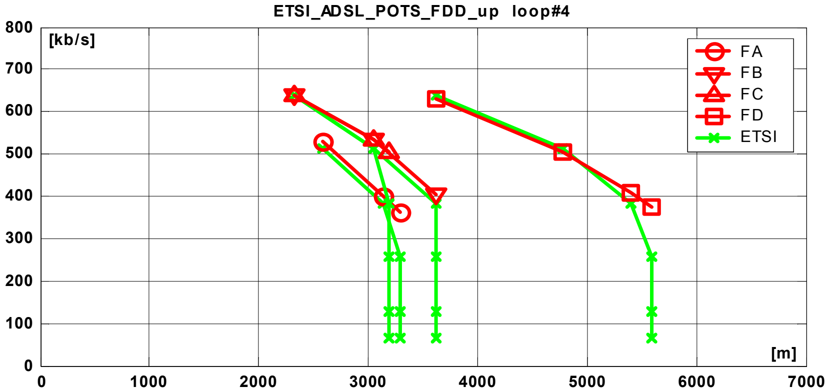


*Figure 13*

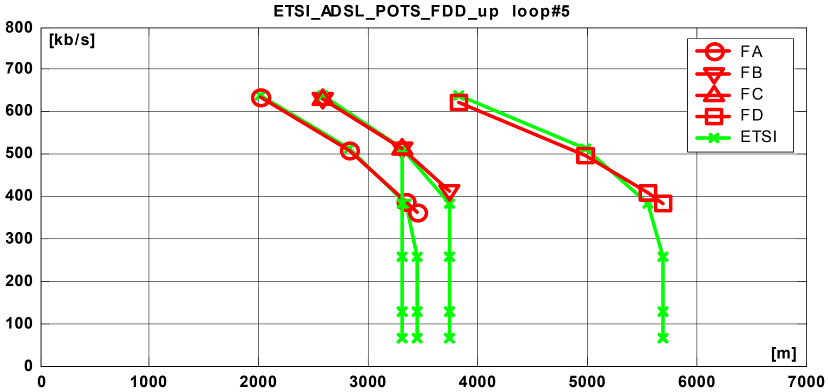


*Figure 14*

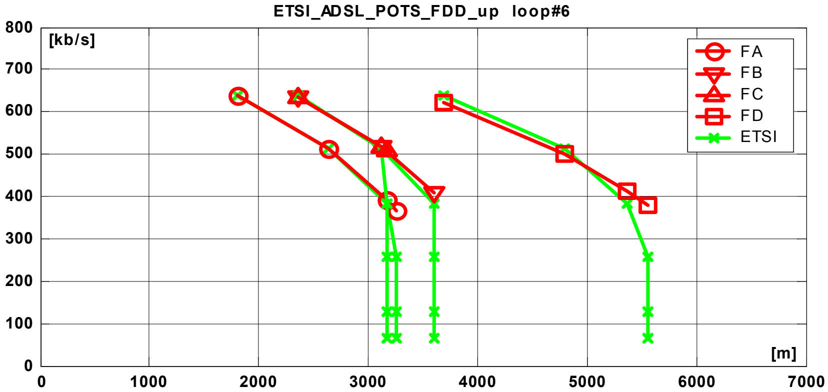


*Figure 15*

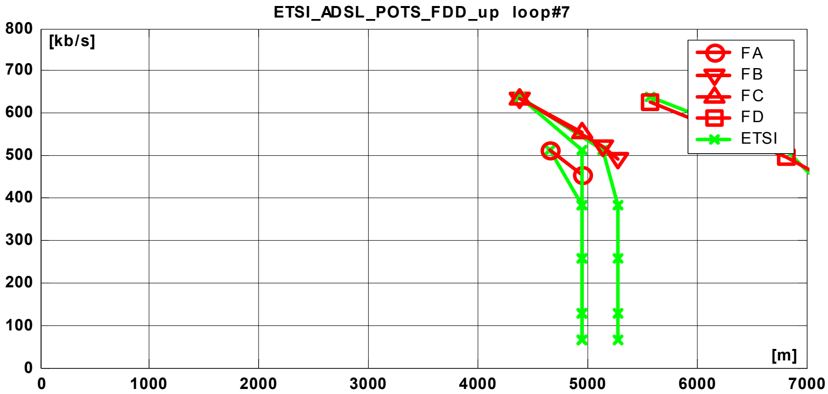


*Figure 16*

# 4. Demonstration of the need of distortion modelling

The use of an addition parameter $\eta_d$ in the input model for upstream is essential to fit the predicted performance to the required performance at higher bit rates. These higher bit rates occur when the SNR becomes relatively high.

Figure 17 shows the result when imperfections in the equalizer are ignored. A fair fit at lower bit rates, but a very poor fit at higher bit rates. Fine-tuning the effective SNR gap and/or the receiver noise did not sufficiently improve the match between predicted and required reach. If it was improved in one way, it was deteriorated in another way.

Figure 18 shows the result when a second order input model is applies to account for imperfections in the equalizer. It appears to be a good fit at most bit rates, and this is something that we could not achieve without this parameter. Therefore we propose to apply the second order approach to model the input of an upstream "ADSL.FDD over POTS".

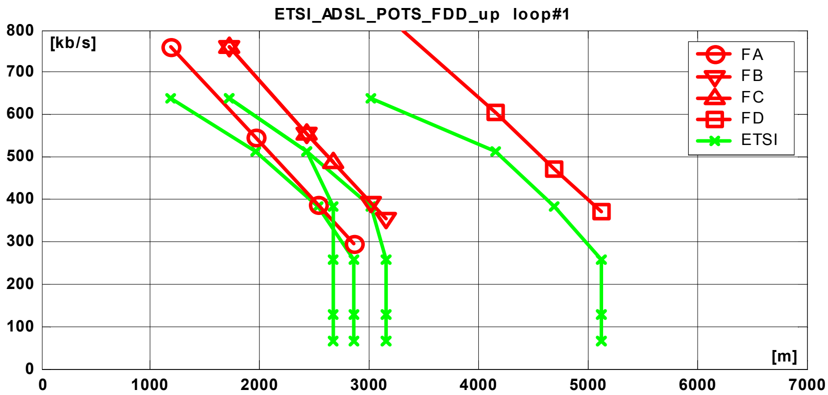


*Figure 17*

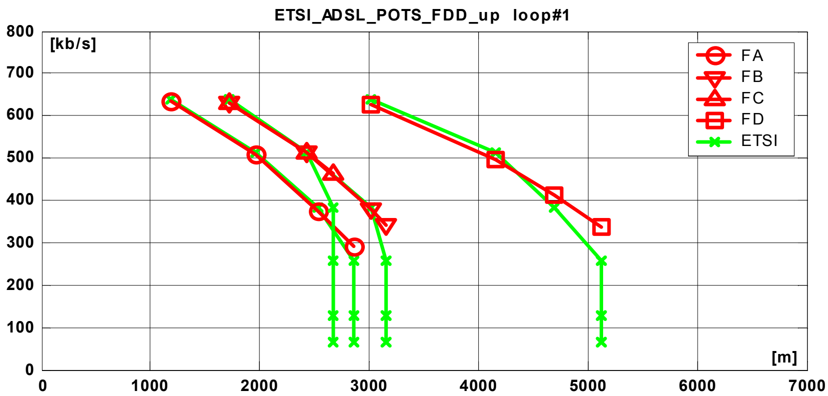


*Figure 18*

# 5. References

[1] Rapporteur: "Living List for SpM part 2", ETSI-TM6 Permanent document TM6(01)21, (m01p21a8), Feb 4, 2004.
[2] Rapporteur: "Draft for SpM part 2", ETSI-TM6 Permanent document TM6(01)20, (m01p21a6), Feb 4, 2004.
[3] ETSI-TS 101 388 v1.3.1 (2002-05): "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Asymmetrical Digital Subscriber Line (ADSL)-European specific requirements", ETSI, May 2002.
[4] T. Nordström*: "Proposal for ADSL Performance Requirements*", ETSI-TM6, WD20 (021w20), Torino, Italy, February 4-8, 2002.
[5] RFM van den Brink: "*Model of basic input block, within xDSL receivers*", ETSI-TM6, 021t35, Torino, 2002.
[6] RFM van den Brink: "*Generic DMT detection model*", ETSI TM6, 032t09, Reykjavik 2003
[7] RFM van den Brink, B Gerrits: *"Extending the validity of receiver performance models",* ETSI TM6, TD13 (033t13): Sophia Antipolis, sept *2003.*
[8] RFM van den Brink, B Gerrits: *"Receiver performance model for "ADSL.FDD over POTS",* ETSI TM6, TD14 (033t14): Sophia Antipolis, sept *2003*
[9] RFM van den Brink, B Gerrits: *"Receiver performance model for "ADSL.FDD over ISDN",* ETSI TM6, TD15 (033t15): Sophia Antipolis, sept *2003.*
[10] T. Nordström*: "Generic detection model for DMT-based modems*", ETSI-TM6, TD23 (034t23r2), Sophia Antipolis, France, November 17-12, 2003.
[11] S.Schelstraete*: "Discussion of enhanced ADSL receiver models"*, ETSI-TM6, TD39 (034t39r2), Sophia Antipolis, France, November 17-12, 2003.
[12] S.Schelstraete*: "Discussion of generic receiver model in SpM2"*, ETSI-TM6, TD40 (034t40r2), Sophia Antipolis, France, November 17-12, 2003.