
TITLE **Receiver performance model for “ADSL.FDD over POTS”**

PROJECTS Spectral Management, part 2.

SOURCE: KPN, TNO Telecom

AUTHORS*:* Rob van den Brink
Bas Gerrits

CONTACT: Rob F. M. van den Brink,
TNO Telecom
P.O. Box 421
2260 AK Leidschendam
The Netherlands

tel +31 70 4462389
fax: +31 70 4463166 (or +31 70 4463477)
e-mail: R.F.M.vandenBrink@telecom.tno.nl
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STATUS for Decision

ABSTRACT Various receiver performance models, for different xDSL modems, have been proposed for inclusion in part 2 of the SpM standard. A model for “ADSL.FDD over POTS” was still lacking. This contribution proposes a solution, which has been obtained by reverse engineering the ETSI performance requirements. The proposed solution predicts the ETSI requirements for the ETSI stress conditions quite well.

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1. Rationale behind this proposal

Part 2 of the Spectral management report [1,2] requires the description of performance models consisting of a range of individual calculation blocks. All these blocks together are for building up a generic receiver performance model. The model for the input block is to evaluate the effective SNR (signal to noise ratio) of the received signal, and the model for a line-code specific detection block is to evaluate from that the bitrate or margin.
A generic performance model can be made specific by defining all involved parameter values, as was done before for other flavours of ADSL [12,13], for SDSL [10,11] and for HDSL [9]. When that model predicts a performance, being well defined in some standard under well-defined (reference) stress conditions, then the resulting specific model is identified as a reference performance model.

This contribution proposes parameter values of a specific performance model for “ADSL.FDD over POTS”, capable of predicting the required performance of an ETSI compliant modems under ETSI (reference) stress conditions [3]. These ETSI performance requirements were dedicated to Frequency Division Duplexing modems, without any echo cancellation on board, and they therefore require a guard band of 7 DMT tones [4] between the upstream and downstream spectra.

The values of the proposed parameters were extracted from the ETSI performance requirements, and not on the originating performance simulations [4], because the requirements have been made mandatory for being "ETSI compliant" and because small discrepancies were reported orally within ETSI TM6 between the originating simulations and the performance requirements that finally have been agreed.
The resulting model has therefore become a slightly more sophisticated [14] then the models derived for the EC variants of ADSL [12,13]. The proposed additions have removed the above mentions discrepancy. These additions were required to account for (a) the apparent need of a guard band [4] of several DMT tones between up and downstream, and (b) to extend its validity range to predict extreme low noise conditions as well (e.g. for upstream, especially for noise model D).

2. Proposed receiver performance model

The reference performance model is based on a generic performance model, for which the parameter values are specified. Some of these parameter values are clearly specified by the ADSL standard [3] or are summarized in [4] where common simulation assumptions are given which are used to generate the performance numbers. Other values are extracted by fitting the predicted performance with the required performance.
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).

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 upstream direction. The calculation models consist of an input model evaluating the effective SNR [14] cascaded by a DMT detection model [5].

2.1. Model for input block, for downstream direction

Like many other models [9-13], the model being proposed here for downstream uses an input model to evaluate the effective SNR from the received signal and noise levels, and uses a detection model dedicated to DMT [5] to evaluate the available capacity (and thus the performance).
Unlike many other models, a simple *first order* input model has appeared to be inadequate here. The reason for this is that these FDD modems (without any echo cancellation) require a guard band of several DMT tones to separate upstream from downstream. As explained in detail in [14], a first order *receiver* model will predict a performance that is too optimistic when the *transmit* spectra fill up the full FDD band without any guard band. This is unacceptable for studying the SpM consequences of limiting and allocating spectra, and therefore the impact of echo has been included in the proposed model.

Error! Reference source not found. shows a *second order* approach for modelling the downstream transmission of "ADSL.FDD over POTS". This approach accounts for _two_ imperfections at the input to evaluate the effective SNR:

- at first the well known impact of the "internal receiver noise" (–140 dBm/Hz for P_{RN0})
- secondly the impact of the coupled echo that is not suppressed at all (0 dB for η_e)

The model for echo coupling [14], as detailed in section 2.3, assumes a passive hybrid, being optimally balanced for a specific complex impedance. This impedance is assumed to be a fair "average" of European cable impedances, and we have chosen to use a pragmatic value being specified in the ADSL standard for calibrating noise levels ([3], clause 5.1.4.1).
All the remaining imperfections are incorporated in the effective SNR-Gap (Γ) of the DMT detection model, as detailed in section 2.4. The extracted gap appeared to be 8.9 dB, and causes the proposed model to predict ETSI performance under ETSI stress conditions for this specific modem. Section 3 of this contribution summarizes the used parameter values; section 4 demonstrates how close this match will be under ETSI stress conditions.

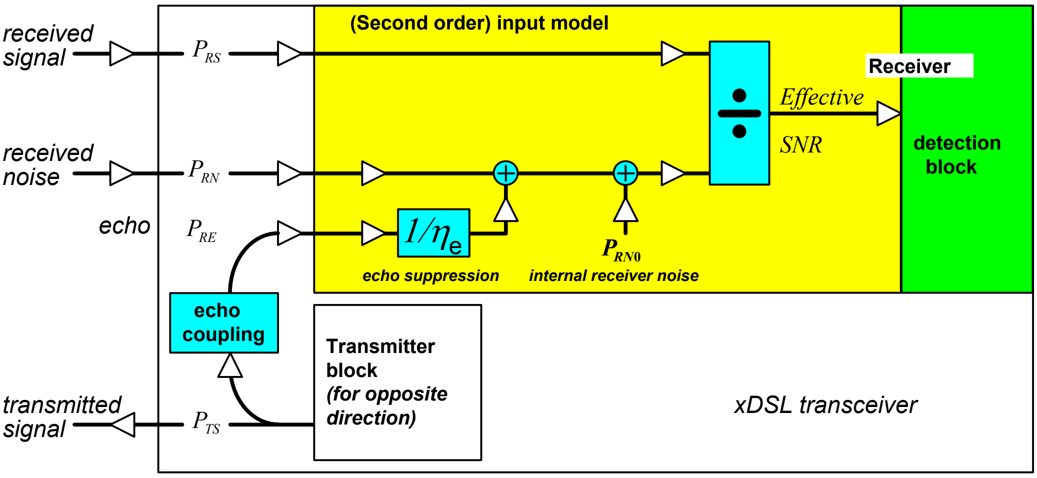


Figure 1: Flow diagram of the proposed downstream receiver model, using a second order approach for modeling the input in a linear way.

The use of higher order input models have been seriously considered for downstream modelling, however the range of ETSI stress conditions appeared to be not wide enough to enable a reproducible extraction of values for additional parameters.

2.2. Model for input block, for upstream direction

The approach for modelling upstream performance is somewhat similar to downstream, but now even a second order approach appeared to be inadequate for predict ETSI performance under all ETSI stress conditions of the ADSL standard. Especially when the SNR was quite high (for most loops under noise model D, or for short loops for all other noise models).
The reason is that under high SNR conditions, the remaining imperfections of the equalizer cannot be ignored any longer. The equalized received signal is somewhat "distorted" compared to what was transmitted, a terminology that makes sense in frequency domain analysis. One can also say that the detected signal is deteriorated by ISI/ICI, a terminology that may be appropriated in time domain analyses.

Error! Reference source not found. shows a *third order* approach for modelling the upstream transmission of "ADSL.FDD over POTS". This approach now accounts for *three* imperfections at the input to evaluate the effective SNR:

- at first the well known impact of the "internal receiver noise" (–135 dBm/Hz for P_{RN0})
- secondly the impact of the coupled echo that is not suppressed at all (0 dB for η_e)
- at third the impact of imperfect equalization (35 dB for η_d),

The "distortion suppression" (η_d), accounts for some residual "noise", representing the non-zero difference between the transmitted signal and the equalized received signal. This suppression factor may even be frequency dependent, however the range of ETSI stress conditions has appeared to be not wide enough to enable a reproducible extraction of frequency dependent values. Therefore a simple constant was considered as adequate for the job.
All the remaining imperfections are incorporated in the effective SNR-Gap (Γ) of the DMT detection model, as addressed in section 2.4. The extracted gap appeared to be 9.3 dB, and causes the proposed model to predict ETSI performance under ETSI stress conditions for this specific modem. Section 3 summarizes the used parameter values; and section 4 demonstrates how close this match will be under ETSI conditions.

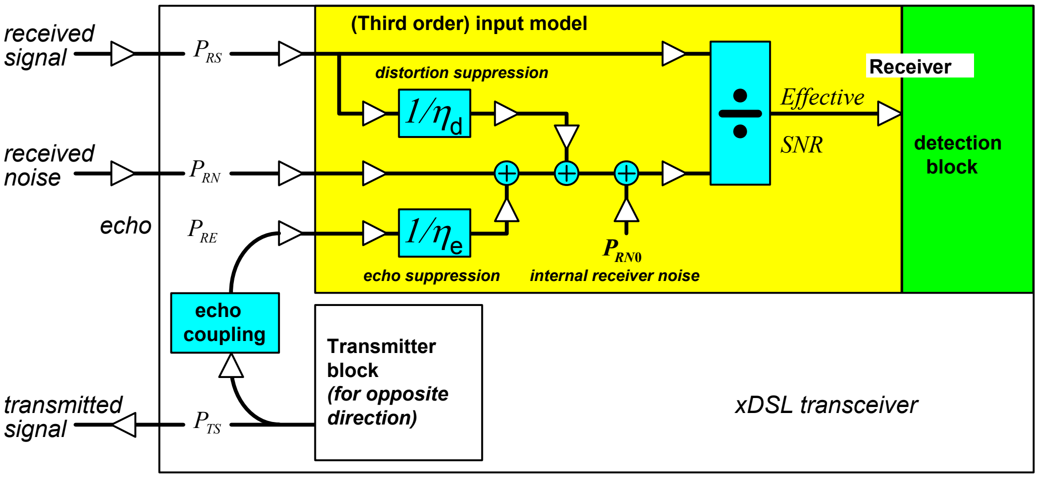
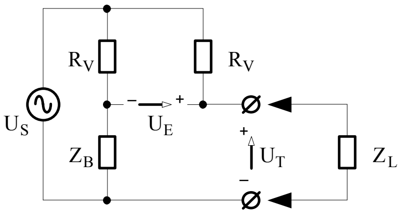


Figure 2: Flow diagram of the proposed upstream receiver model, using a third order approach for modeling the input in a linear way.

2.3. Model for echo coupling, for both directions

The approach for modelling what echo couples from the transmitter output into the receiver input is based on assuming a linear hybrid, which has an output impedance R_V. It has been assumed that the hybrid is optimised for a specific complex load impedance Z_B (the "balance impedance"), meaning that when the hybrid output is terminated with that impedance no echo will couple into the receiver. In practice, however, the line impedance Z_L will be a slightly different from this balance impedance causing some residual echo.

Figure 3 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 coupled into the receiver.



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

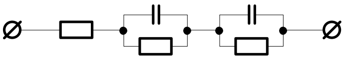
$$\frac{P_{RE}}{P_{TS}} = \left| H_E(j\omega) \right|^2$$

Figure 3: Flow diagram of the basic model for echo loss

For extracting the ADSL performance parameters, value R_V was made equal to the design impedance of ADSL, value Z_L was made equal to the impedance of the actual test loop and its termination, and value Z_B was made equal to the complex impedance for ADSL noise level calibration ([3], clause 5.1.4.1) as best guess "average" of European cable impedances.

$R_V = 100\Omega$

$Z_B = (120\Omega) + (150\Omega//47nF) + (750\Omega//150nF)$



2.4. Model for DMT detection block, for both directions

The approach for modelling at what bitrate an ADSL modem can operate at 6dB noise margin, the generic DMT model being proposed in [8] was applied. Many of the associated parameter values were taken from the standard [3] or from what has been agreed among vendors according to [4].

To enable signalling, error correction and synchronisation, the actual line rate on the copper wires of ADSL is higher than the data rate (payload bitrate). According to [4] a 13% Reed Solomon overhead and 32kbps framing overhead is assumed, however for (low) data rates with S=16, a value of R=16 has been assumed instead of 13% coding overhead (for details see the ITU ADSL specification). The precise description of these assumptions equals:

Rate1 = (datarate + 8×symbolrate) × 1.13 [b/s]
Rate2 = (datarate + 16×symbolrate) [b/s]
LineRate = max(Rate1,Rate2)

For extracting the implementation losses from the extracted effective SNR gap, a raw coding gain of 4.25 dB is assumed for both directions, as described in [4].

3. Literal text proposal

The text below proposes literal text for inclusion in clause 6 of the Spectral Management draft, part 2.

5 Generic receiver performance models for xDSL

See current draft

5.1 Generic input models for effective SNR

See text proposal in TD13 [14]

5.1.1 First order linear input model

See text proposal in TD13 [14]

5.1.2 Second order linear input model (with echo)

See text proposal in TD13 [14]

5.1.3 Second order linear input model (with distortion)

See text proposal in TD13 [14]

5.1.4 Third order linear input model

See text proposal in TD13 [14]

5.2 Generic models for echo coupling

See text proposal in TD13 [14]

5.2.1 Linear echo-coupling model

See text proposal in TD13 [14]

5.3 Generic detection models

See current draft and living list [1,2]

5.3.4 Generic DMT detection model

See current living list [1]

6 Specific receiver performance models for xDSL

See current draft [2]

6.5 Receiver performance model for "ADSL.FDD over POTS"

This calculation model is capable for predicting the performance of an ETSI compliant "ADSL.FDD over POTS" modem. The reach predictions of this model are close to the ETSI reach requirements under the ETSI stress conditions as specified in the ETSI ADSL specification [3]. Deviations between the predictions and requirements in most cases within 150m. The validity of the predicted performance holds for a wider range of stress conditions.

6.5.1 Building blocks of the downstream receiver performance model

The downstream receiver performance model for ETSI compliant "ADSL.FDD over POTS" is build-up from the following building blocks:

- The generic linear input model, specified in clause 5.1.2. This is a second order model that accounts for two imperfections: internal receiver noise (P_{RN0}) and echo suppression (η_e).
- The echo-coupling model, specified in clause 5.2.1. This is a linear hybrid, which has R_V=100Ω as output impedance and Z_B = (120Ω) + (150Ω//47nF) + (750Ω//150nF) as balance impedance.
- The generic DMT detection model, specified in clause 5.3.4.
- The parameter values specified in Table 1.

6.5.2 Building blocks of the upstream receiver performance model

The upstream receiver performance model for ETSI compliant "ADSL.FDD over POTS" is build-up from the following building blocks:

- The generic linear input model, specified in clause 5.1.4. This is a third order model that accounts for three imperfections: internal receiver noise (P_{RN0}), echo suppression (η_e) and distortion suppression (η_e).
- The echo-coupling model, specified in clause 5.2.1. This is a linear hybrid, which has R_V=100Ω as output impedance and Z_B = (120Ω) + (150Ω//47nF) + (750Ω//150nF) as balance impedance.
- The generic DMT detection model, specified in clause 5.3.4.
- The parameter values specified in Table 1.

6.5.3 Parameters of the receiver performance model

The parameter values, used in the receiver performance model for ETSI compliant "ADSL.FDD over POTS" modems, are summarized in Table 1. Parts of them are directly based on ADSL specifications. The remaining values are extracted from the ADSL performance requirements [3] or based on theory.

Model parameter		**DMT model**		
		Upstream	**Downstream**	**Remarks**
SNR-Gap (effective)	Γ_{dB}	9.3 dB	8.9 dB	
SNR-Gap in parts	Γ_{DMT_dB} $\Delta\Gamma_{coding\_dB}$ $\Delta\Gamma_{impl\_dB}$	9.75 dB 4.25 dB 4.3 dB	9.75 dB 4.25 dB 3.9 dB	
Receiver noise	P_{RN0_dB}	–135 dBm **-120 dBm?**	–140 dBm	
Distortion suppression	η_d	35 dB	N/A	*See clause 5.1.4*
Echo suppression	η_e	0 dB	0 dB	*See clause 5.1.4*
Echo model		Linear hybrid (see text)	Linear hybrid (see text)	*See clause 5.1.4*
Symbol rate	f_s	4000 baud	4000 baud	
Data rate	f_d	64 … 640 kb/s	64 … 6144 kb/s	
Line rate	f_b	$f_{bl} = f_d + 16 \times f_s$ $f_{bh} = (f_d + 8 \times f_s) \times 1.13$ $f_b = \max(f_{bl}, f_{bh})$	$f_{bl} = f_d + 16 \times f_s$ $f_{bh} = (f_d + 8 \times f_s) \times 1.13$ $f_b = \max(f_{bl}, f_{bh})$	
Bits per symbol	b	f_b/b	f_b/b	
Available set of tones	*tones*	[7:30] = [k_1 : k_2] *Tone 31-37 are used As guard band*	[38:63, 65:255] = [k_1 : k_2 , k_3 : k_4] Tone 64 = pilot tone	*DMT tone k = 64 does not convey any bits because it is reserved as pilot tone.*
Carrier frequency of tone 1	f_c	4.3125 kHz	4.3125 kHz	
Bit-loading algorithm		Fractional	Fractional	*See clause 5.3.4*
Minimum bit-loading	Δb_{min}	2	2	*Bits per carrier*
Maximum bit-loading	Δb_{max}	15	15	*Bits per carrier*

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

End of literal text proposal

3. Validation of the reference model

In this section the validity of the reference model for ETSI compliant “ADSL.FDD over POTS” is graphically demonstrated by plotting the ETSI performances requirements and the performance predicted by the reference models in one figure. They are all evaluated under the ETSI stress conditions for ADSL [3], and by assuming a transmit PSD equal to the template in [1] ("rapporteurs proposal").

The figures below illustrate how close the reference performance model for “ADSL.FDD over POTS” can predict the performance requirements from the ADSL standard. Figure 4 through Figure 10 are dedicated to the upstream “ADSL.FDD over POTS” receiver while Figure 11 through Figure 17 are dedicated to the downstream receiver. These figures depict for test loop #1 to loop #7 the predicted reach-bitrate curves under four noise models.

Each plot shows two curves, one for the predicted reach-bitrate and another for the ETSI reach requirements. The green curve with the “×” markers indicate the required reach according to the ETSI standard, while the red curves indicate the predicted reach according to the extracted ADSL performance model. Note that the upstream reach requirements belonging to noise model FB and FC entirely or partly overlap. Furthermore note that the ETSI upstream reach requirements for the lowest bitrates are limited by the longest reach in the downstream direction.

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 less than **100m**, but in the exceptional cases (model FD) within **300m**.

Analysing the graphics 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 requirements. An exception holds for noise model FD in loop #1, and the reason for that is unclear. The maximum deviation between the predicted performance and the ETSI requirements is in most cases less than **150m**, but in a few exceptional cases (model FD) within **400m.**

4.1. “ADSL.FDD over POTS” upstream

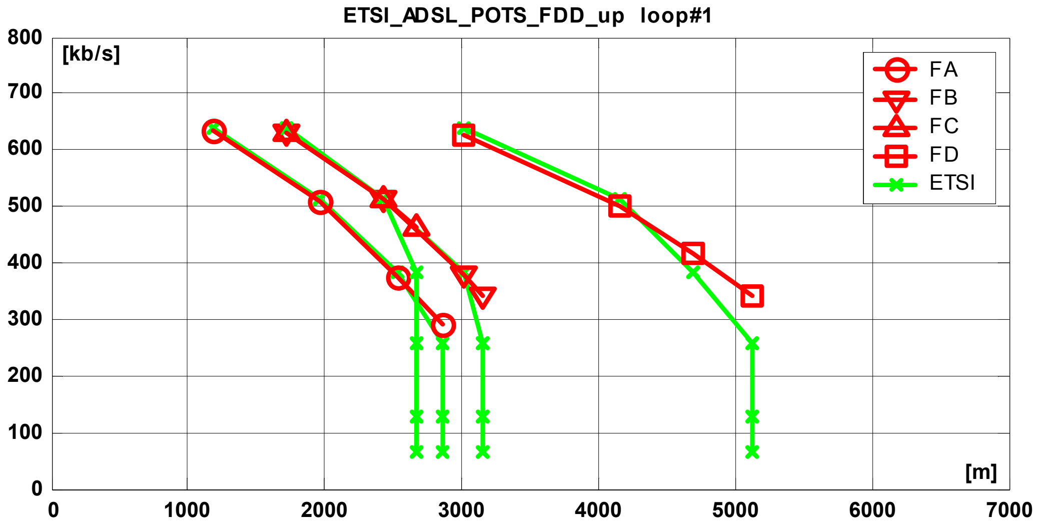


Figure 4

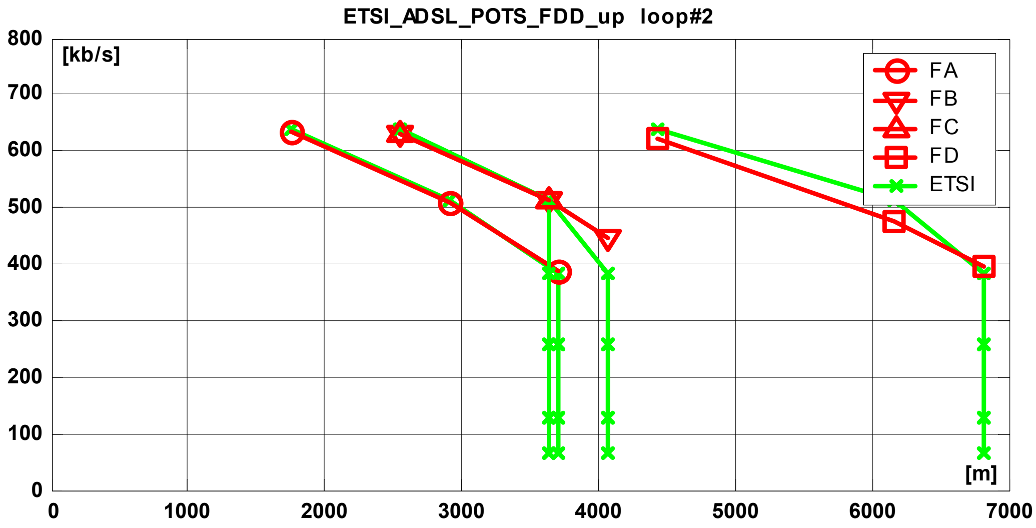


Figure 5

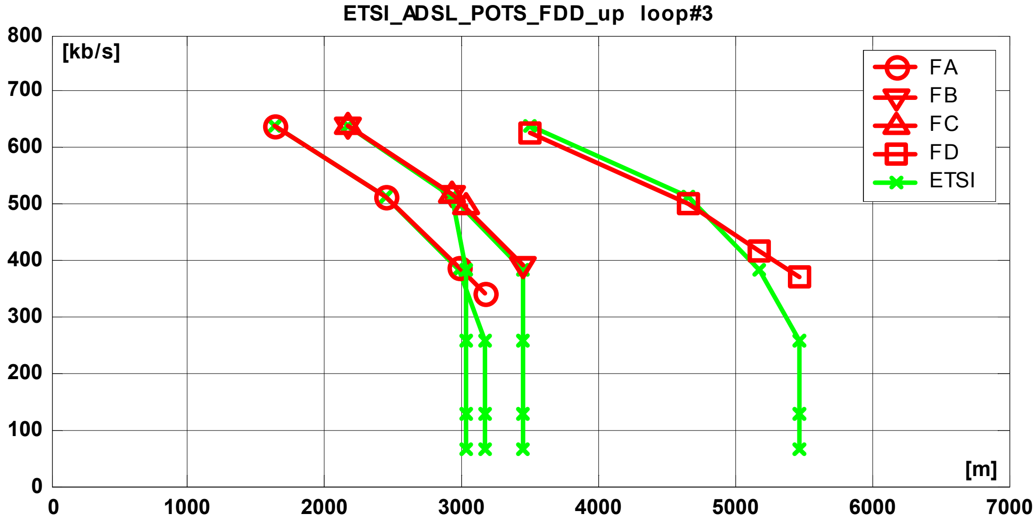


Figure 6

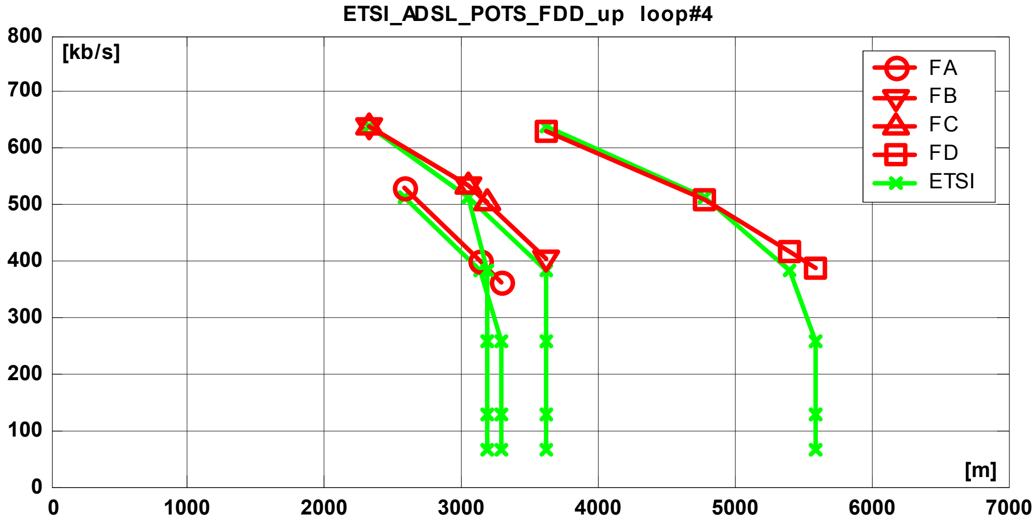


Figure 7

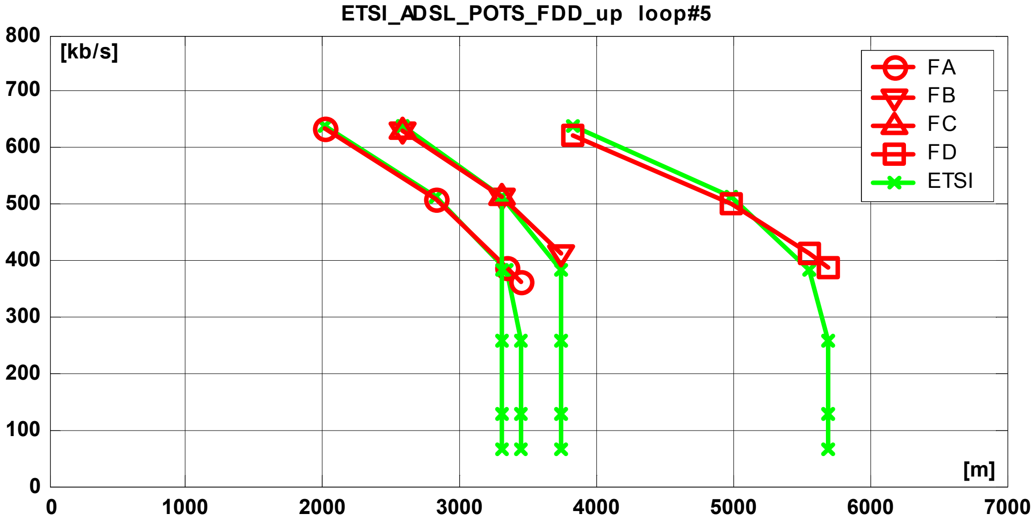


Figure 8

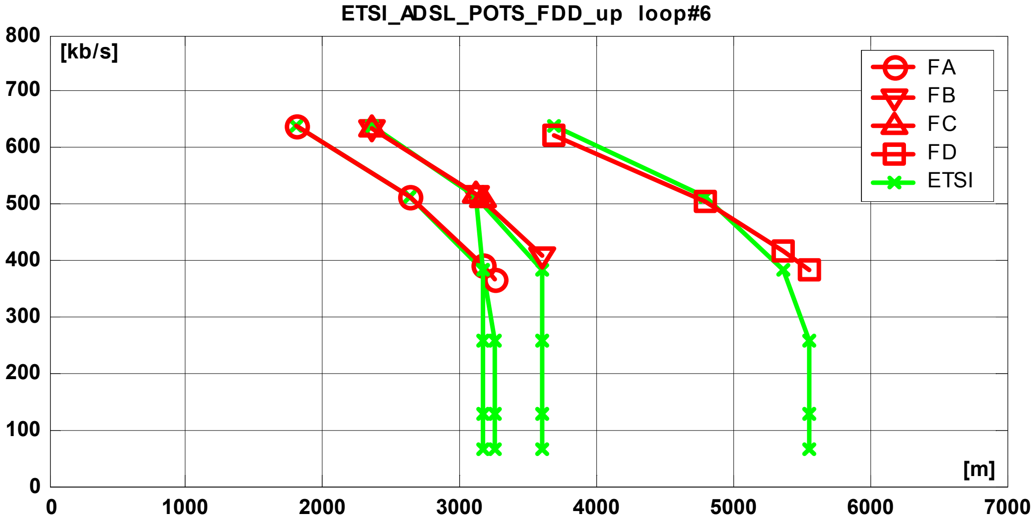


Figure 9

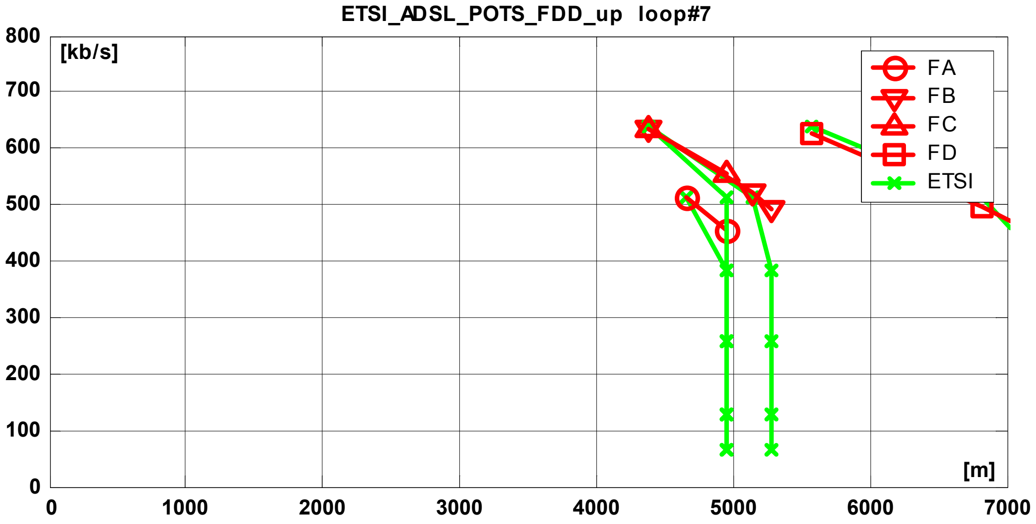


Figure 10

4.2. “ADSL.FDD over POTS” downstream

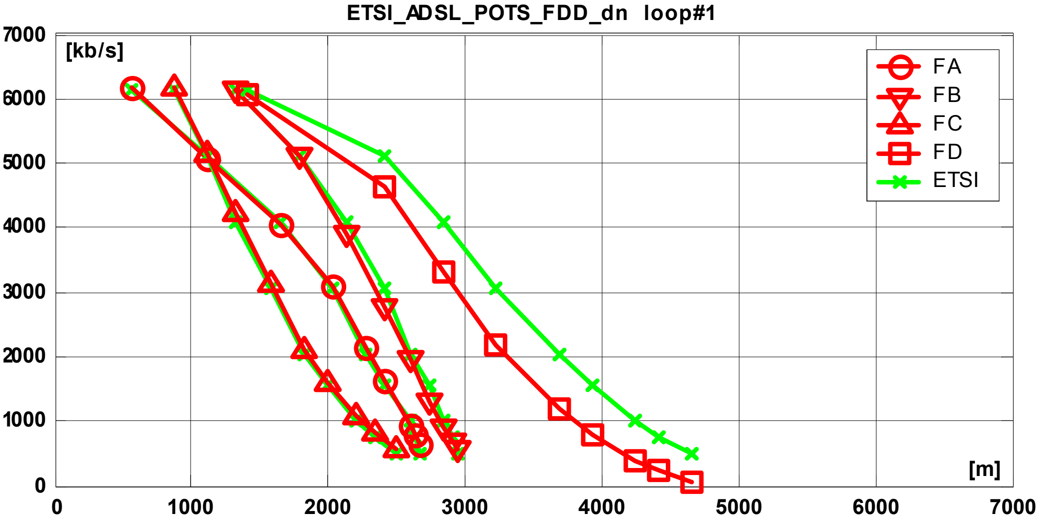


Figure 11

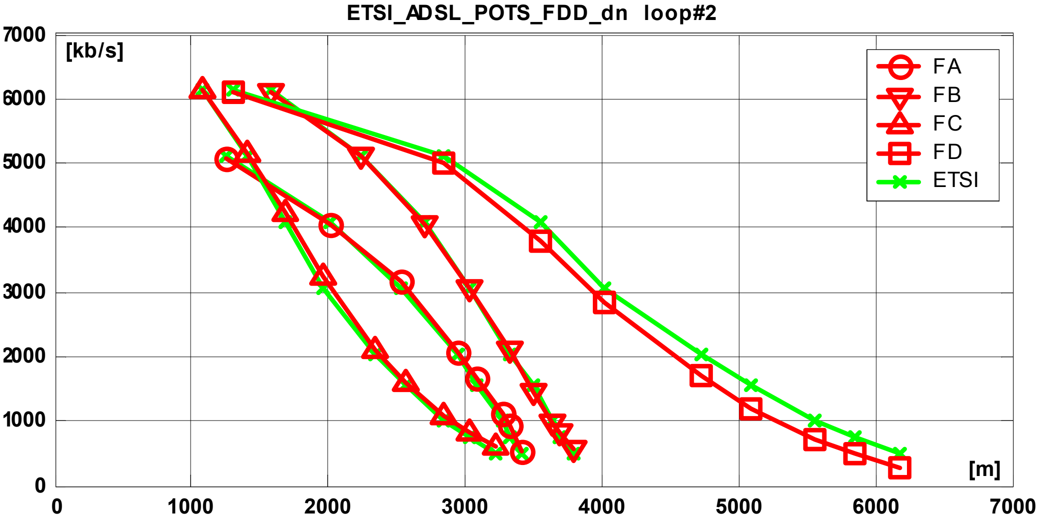


Figure 12

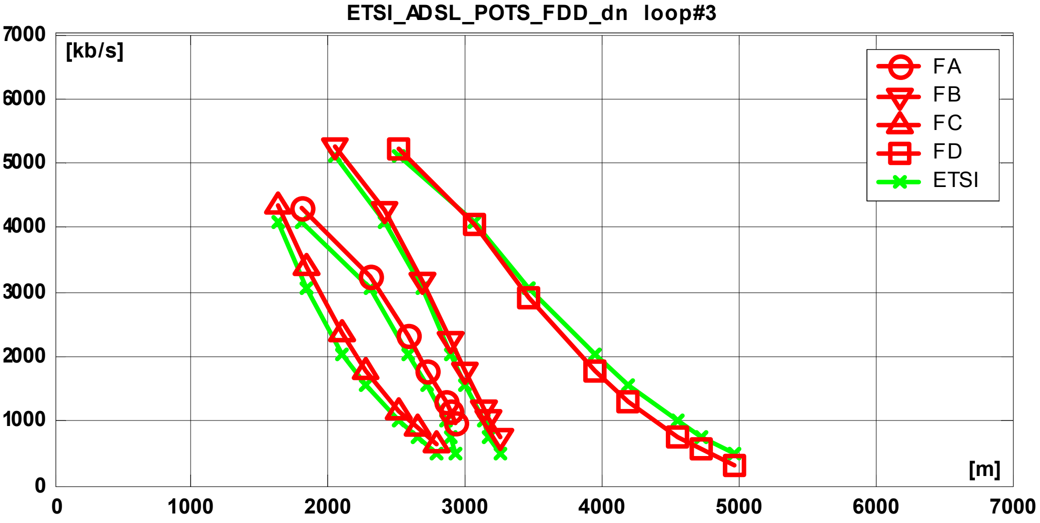


Figure 13

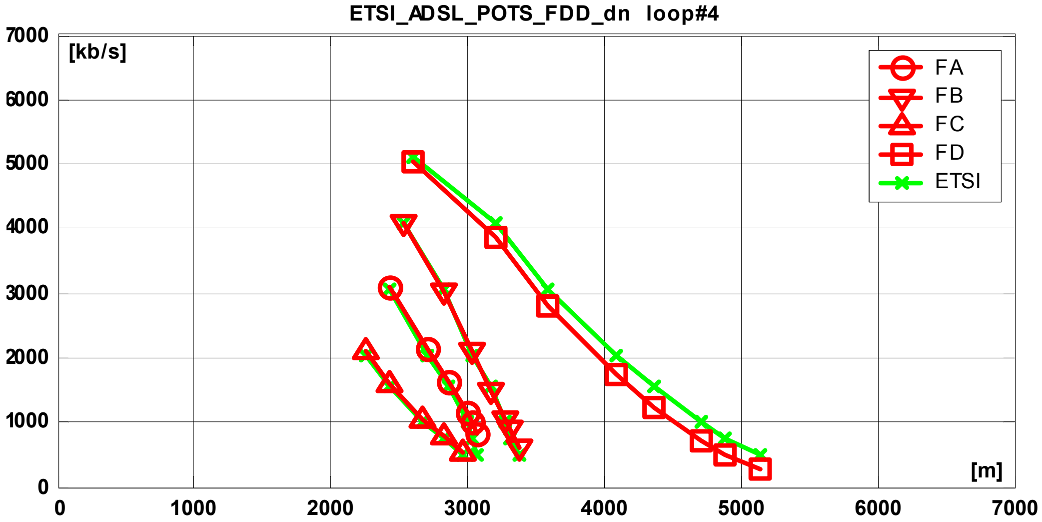


Figure 14

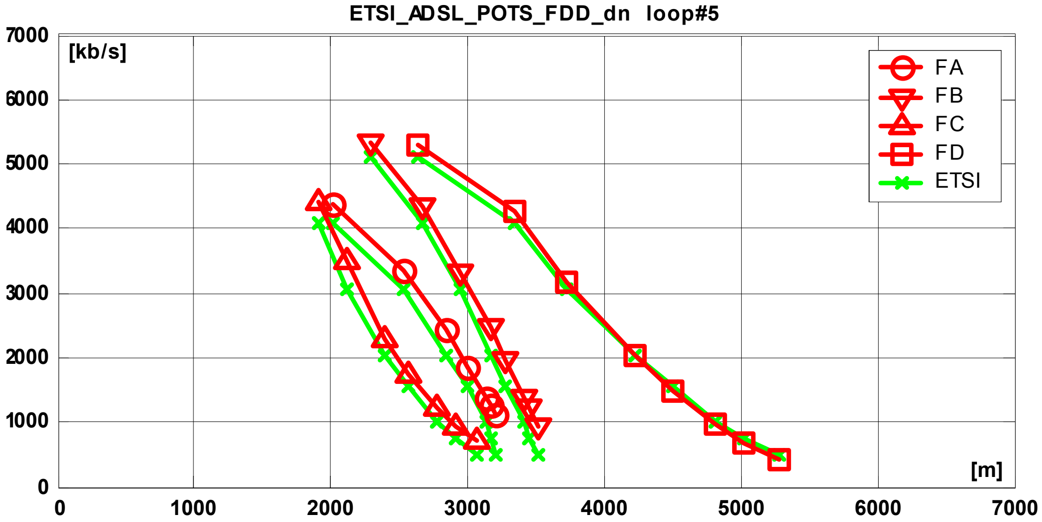


Figure 15

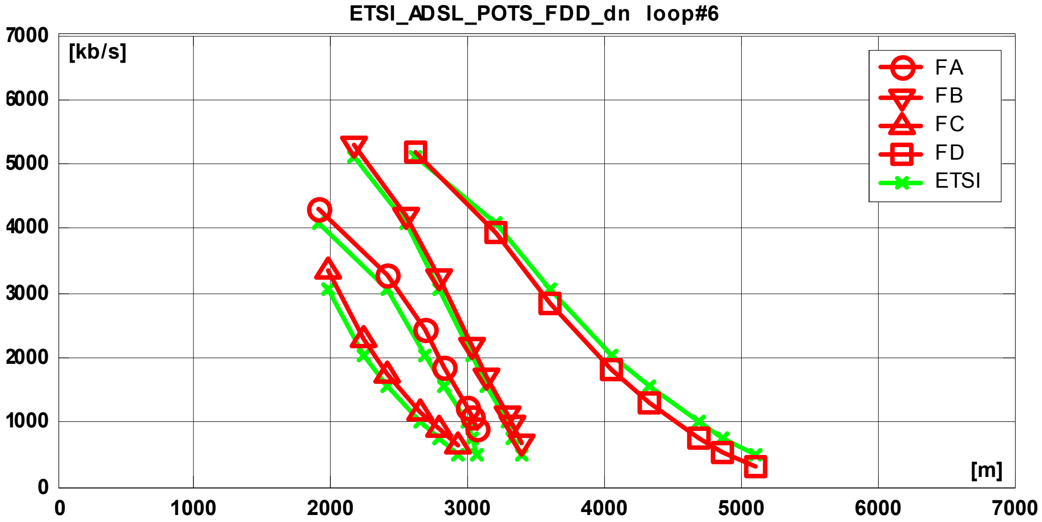


Figure 16

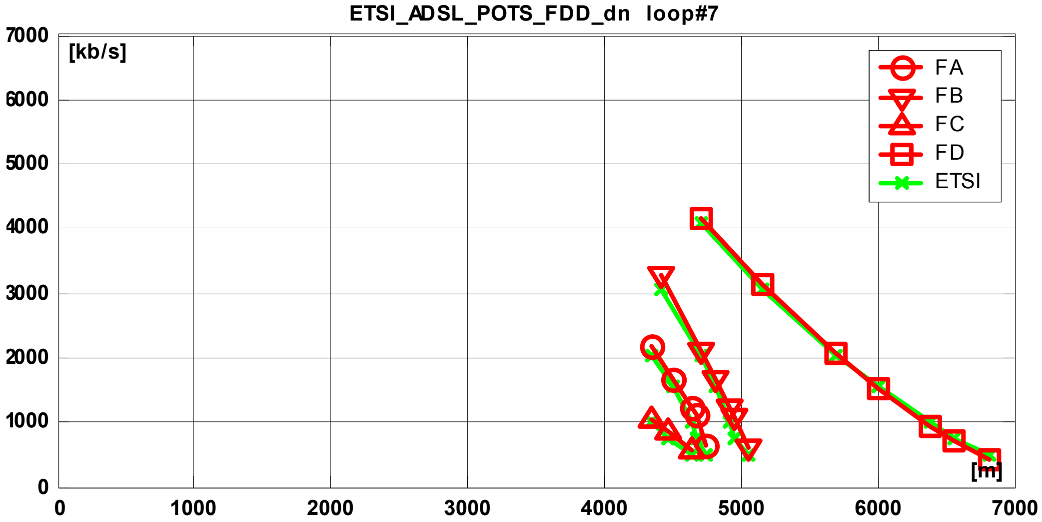


Figure 17

5. References

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