The art of Spectral Management
Upstream power back-off for VDSL2

Whitepaper on DSL – Rob F.M. van den Brink, TNO, The Netherlands, Oct 2009

Abstract: *Spectral Management (SpM) involves managing an access network such that different systems can co-exist with each other. In relation to DSL systems, spectral management ensures that they can co-exist within the same cable. The use of spectral signal limits (specified via mandatory access rules) is necessary for all DSL deployments, and serves a common interest of all involved DSL operators.*

VDSL2 is a new technology, and can be deployed from remote locations such as street cabinets to shorten the loop to the home and thus increase the achievable bitrate. However, when all VDSL2 modems at customer premises transmit at full power, VDSL2 will only work well for customers that are close to the street cabinets. This situation can be improved significantly by reducing the transmit powers of nearby customers. This is called upstream power back-off, or simply UPBO.

Such reductions can only be effective if they are tailored to underlying business needs, and on geographic and electrical characteristics of the network. These are all country or region specific, and should not be copied blindly from neighbouring countries. This paper shows how effective UPBO improves upstream bitrates for a variety of criteria, and how to define UPBO in an indisputable and implementation independent manner for specifying access rules.

1. INTRODUCTION

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. Unlike ADSL2 or ADSL2plus, it can deliver data rates of tens of Mb/s or higher, which makes VDSL2 appropriate for offering multiple video services simultaneously. To enable these higher bitrates, VDSL2 has to be deployed via loops that are relatively short, preferably not exceeding 1 km. When the local loop is too long a shorter loop can be achieved by deploying VDSL2 in the subloop from remote locations (like street cabinets being fed via fiber).

Since VDSL2 systems have to share the cables with other DSL systems as well, they can easily disturb each other. All kinds of spectral management measures [7] are required to prevent this undesired behaviour.

One such measure is upstream power back-off (UPBO) to prevent VDSL2 from only working well for nearby customers. The rationale behind UPBO is that bitrates on longer loops can be improved significantly at a small penalty in bitrates on shorter loops. By reducing the transmitted upstream power on shorter loops, the crosstalk into longer loops will be reduced as well. The amount of UPBO depends therefore on the length of the subloop.

Such reductions should be tailored to underlying business needs, the geographic characteristics of the access network, loop characteristics, and they are all country or region specific.

2 PERFORMANCE ENHANCEMENT OF UPBO FOR VDSL2

Figure 2 shows how effectively UPBO can improve the bitrate of remotely located customers. This has been evaluated by simulation [4,2] for a subloop with only 20 VDSL2 systems, using realistic assumptions for insertion loss, crosstalk coupling, distribution of customers along the line, cabinet location, and for a chosen UPBO regime.

- The solid line represents the predicted upstream bitrates for the hypothetical (and unrealistic) case that all 20 VDSL2 customers are (virtually) co-located at a certain distance. This distance is subsequently swept from 50 to 1600m.
- The round markers represent the predicted upstream bitrates for the more realistic case that customers are distributed along the line. The density of customers is represented by clustering the customers at fixed distance and by assuming different numbers of customers in each cluster (5 customers at 150m, 6 at 300m, 3 at 450m, etc, as illustrated in Figure 1). All modems are assumed to transmit at full power, without any UPBO.
- The square markers represent the same as above, but now for a chosen UPBO regime.

Figure 2 illustrates that UPBO brings a significant improvement in upstream bitrate to all customers beyond 200m, at only a small penalty in bitrate for customers below 200m. These nearby customers still have an advantage over the remote customers, and represent only 9% of all customers (in this example), so this penalty is hardly an issue in practice.

Note that this UPBO regime can even approximate the bitrate under the hypothetical conditions that all 20 VDSL2 modems are (virtually) co-located. This holds in our example for customers up to 800m (90% of all customers in this example).

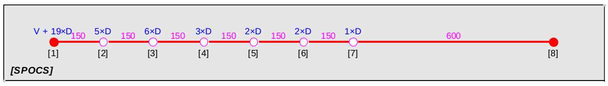

Figure 1:*. Customers are distributed along the line, with a given density. This topology model assumes a representative number of VDSL2 modems, clustered at equal distances.*

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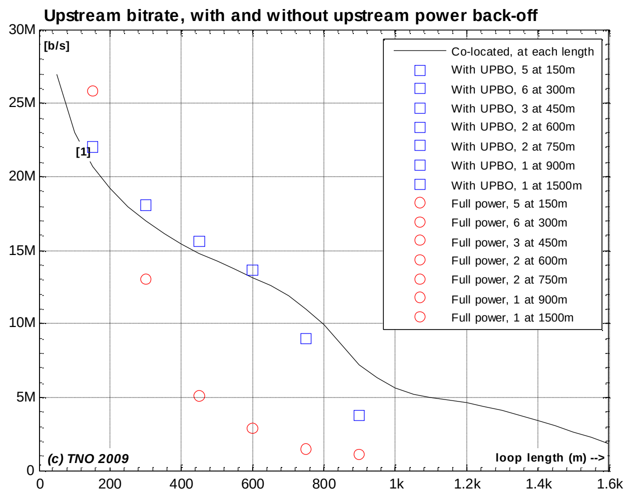


Figure 2: *An example of how much improvement can be achieved in upstream by UPBO. The upstream bitrate increases significantly for VDSL2 customers between 200 and 1000m, at a small penalty for customers <200m. The markers show the predicted bitrates under realistic assumptions; the round markers for without UPBO, and square markers for with UPBO. The solid line represents an over simplification, assuming that all customers are collocated (so that UPBO is not needed anymore)*

3. SPECTRAL BEHAVIOUR OF UPBO

The amount of upstream power back-off is frequency dependent and also dependent on the length of the subloop. Whereas PBO in downstream [9] has only one PSD shape per cabinet (and thus one per secondary cable), PBO in the upstream direction has multiple PSD shapes in the same secondary cable.

Figure 3 shows the upstream transmit signal of VDSL2 modems for a chosen UPBO regime, for a discrete number of customer premises (150, 300, 600 and 900m). It transmits in three upstream bands (U0, U1, and U2) according to a chosen frequency allocation plan [8]. The customer modem that is the nearest to the cabinet (150m) has to back-off its transmit power for about 20-35dB. The one at the far end is allowed to inject its upstream signal at full power. The power reduction for the two others is noticeable, but not as much as for the nearest one.

UPBO is only meaningful for upstream frequencies that are strictly separated from downstream frequencies, in combination with topologies where nearby and distant customers served via the same cable are very different in distance [7]. Therefore UPBO is only applied for frequencies above 2.2MHz and not in the legacy upstream band (U0). This makes UPBO mainly a VDSL2 issue, and it is not so relevant for legacy equipment such as ADSL, SDSL and HDSL.

4. SELECTING UPBO REGIMES

If UPBO improves the performance of VDSL2 in the upstream direction, what settings will give the best result? The meaning of “best” is ambiguous, related to the type of service offer and also to the geographic distribution of customer premises. This gives some freedom on what to select. The full design of an adequate UPBO regime is beyond the scope of this paper, but we will show by simulation [4,2] how much variation can be achieved under different regimes.

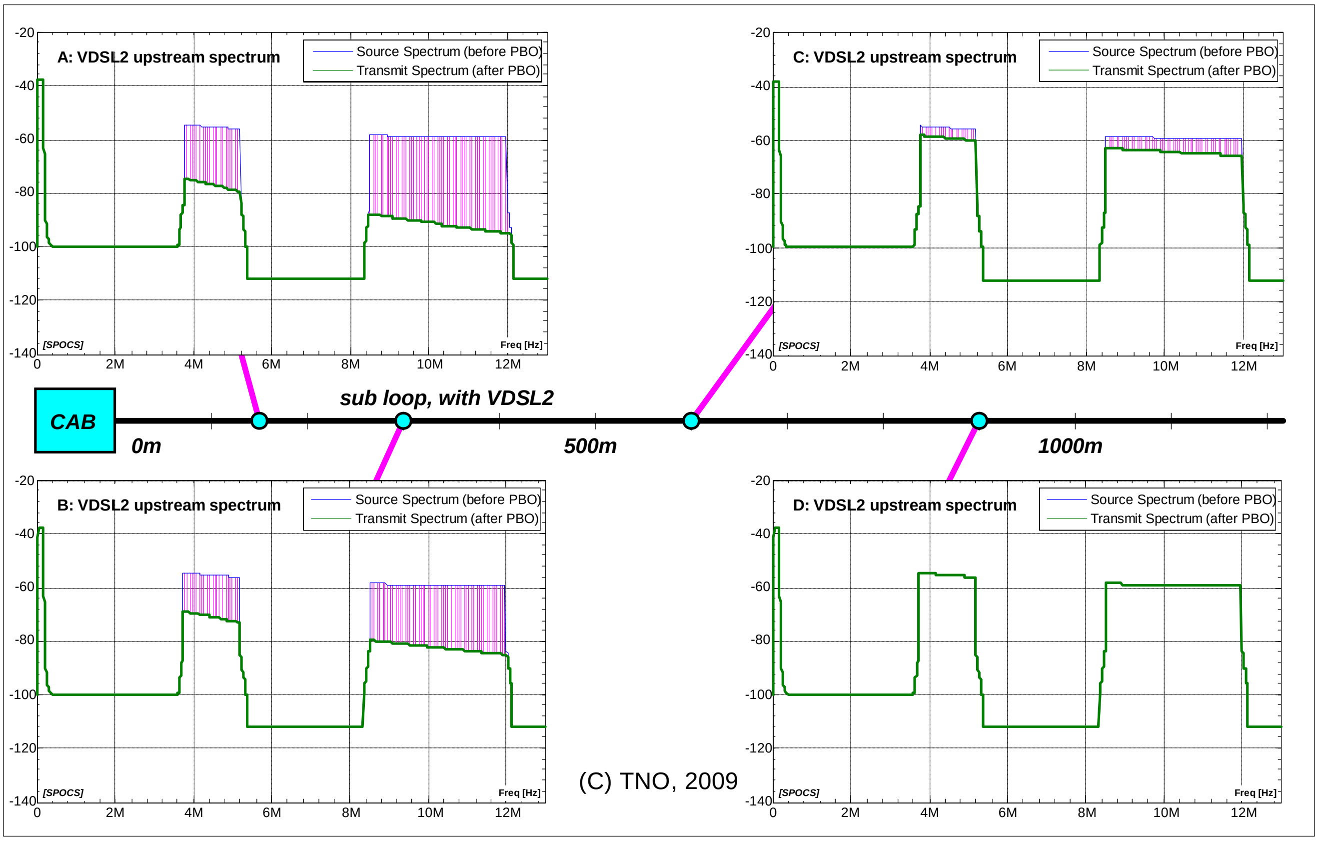
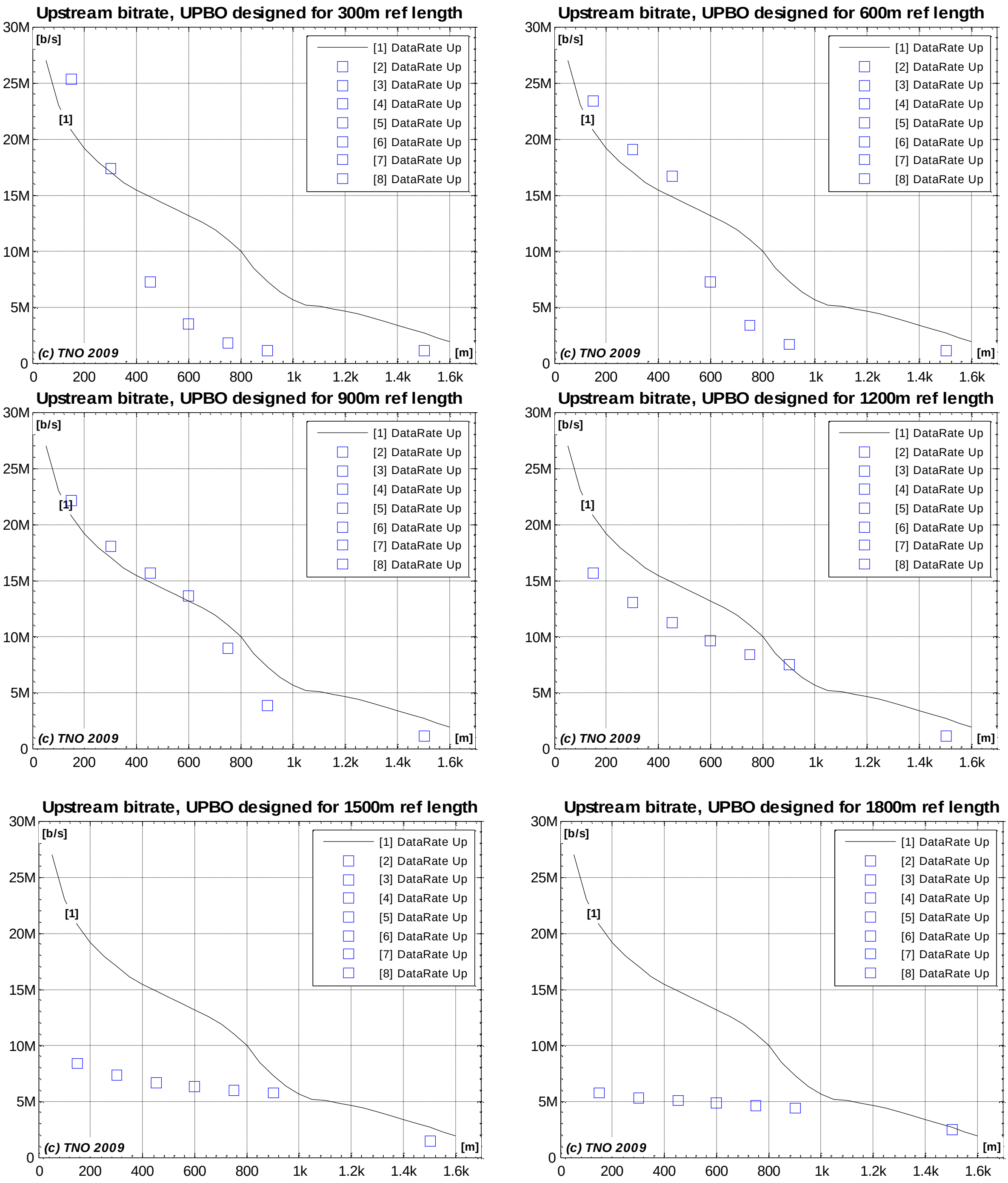


Figure 3: *The amount of UPBO changes with the location of customer modems. The reduction is maximal in short loops, and minimal in long loops.*

The VDSL2 standard defines a set of capabilities to enable UPBO. It is controlled centrally via the VDSL2 management system by means of 2 parameters (called “a” and “b”) for each upstream frequency band (U1, U2, etc. See [3]). The modem pair makes its own estimate on loop characteristics and loop length. It evaluates via a complex expression how much UPBO should be applied as a function of the frequency.

Finding the values of one of these parameters (named “a”) is rather straight forward, and directly related to the transmit PSD level of the associated upstream band before any UPBO is applied. The value of the other (named “b”) is directly related to a physical quantity called *reference length*, which is a design parameter. Its definition is such that for loop lengths equal or longer than the reference length, UPBO will not yield any power reduction. This reduction will only occur for loop lengths shorter than the reference length, meaning that UPBO is mainly beneficial within this reference length.

As a result, UPBO is mainly controlled by a single parameter (the reference length), or more precisely a single parameter per upstream band. To keep it simple, we will choose them to be equal for all upstream bands (U1 and U2 in our examples), but it is recommended to bring refinement



Upstream bitrate, UPBO designed for 300m ref length

Upstream bitrate, UPBO designed for 600m ref length

Upstream bitrate, UPBO designed for 900m ref length

Upstream bitrate, UPBO designed for 1200m ref length

Upstream bitrate, UPBO designed for 1500m ref length

Upstream bitrate, UPBO designed for 1800m ref length

Figure 4: Change in distribution of upstream bitrates among various customer locations, when UPBO is designed for different reference lengths.

in a practical design by selecting reference lengths that are somewhat different for each band. A DSL performance simulator [4] is required to design an adequate UPBO regime.

Figure 4 shows how much improvement can be achieved for upstream bitrates under different UPBO regimes. These regimes differ in reference length, ranging from 300m up to 1800m. If this reference length was set to zero, then no UPBO would have been applied.

The topologies are the same as used in Figure 1 and 2. The solid line is to facilitate an easy comparison and represent the upstream bitrate if all customers are virtually collocated (so that UPBO is not needed anymore). The markers represent a more realistic prediction, assuming that customers are clustered at different locations, as shown in Figure 1.

The plots in Figure 4 illustrate that when the reference length increases, more customers will benefit from it. However, the longer it gets the less beneficial it will be for those who live within the reference length, but it is the only way to offer some upstream bitrate to remote customers.

It is a matter of business needs which of these UPBO regimes can be considered as optimal, but the 900 and 1200m variants of these examples are good candidates. As a rule of thumb: if you can favour 90% of the customer premises with a given UPBO regime, then you may be close to optimal.

5. SPECIFYING UPBO VIA ACCESS RULES

Improving the performance of distant modems is only feasible if a sufficient amount of UPBO is applied to *all* involved VDSL2 modems. Since this has to be mandatory for all involved DSL operators, it needs to be well-specified by means of an access rule [1]. However, it is not obvious how to do such a specification.

Mandatory rules should be unambiguous to enable an indisputable verification whether a modem complies with such rules, and should not discriminate between DSL products from different vendors. This can only be facilitated when rules are defined without any assumption about the implementation details of equipment, i.e. a black-box approach that specifies spectral limits at the outside of the modem.

The same applies for rules to grant access to the subloop. Therefore, it is not a good approach to specify UPBO in an access rule such as: “UPBO shall be compliant with ITU *product* standard G.993.2 [3], and here are the associated parameter settings”.

Let’s explain this via implementation specific details of VDSL2. The VDSL2 standard defines a set of capabilities to enable UPBO. It is controlled via the VDSL2 management system by means of 2 parameters per upstream band. The modem evaluates the desired UPBO behaviour via a complex standardized expression, and via its own estimate of the loop length.

If UPBO is specified in an access rule via parameter settings then how should such a rule be dealt with if improved algorithms are implemented in products such as VDSL3, VDSL4 and VDSL5 that are invented in future? Moreover, how should mixed-mode VDSL2 deployments (from central offices as well from nearby cabinets) deal with such a rule? Modems will then estimate different loop lengths, for the different points of deployments causing the standardized UPBO algorithm to behave differently from the same customer location. This will diminish the effect of UPBO.

But if *different* modem types and deployments do not violate the *same* spectral limits at the outside of the modem, then they do not disturb the UPBO mechanism, and should be granted access (from a pure spectral management point of view). Therefore using spectral limits for UPBO in access rules is a much better approach.

This is analogous to speed limits in ordinary traffic rules to prevent road accidents. Traffic rules specify speed limits in a neutral manner (km/hour) so that they can be verified *from the outside of the vehicle*. This enables an indisputable verification of whether the vehicle is exceeding the speed limits. Traffic rules do not specify the measurement of speed in an implementation-specific manner (e.g. what the speedometer of the vehicle indicates) because this would be susceptible to argument.

For this reason, the Dutch and British access rules have been specified [1] in a black-box manner, by means of spectral limits and not by means of modem settings. The access rules are essentially a set of spectral limits. It is up to the involved DSL operator (and its VDSL2 vendor) to ensure that its modems do not exceed these limits. How they achieve that is irrelevant from a spectral management point of view.

If access rules specify UPBO by means of spectral limits, how should this be done if these limits vary with the location of customer premises? There are several possibilities:

- One option is to specify spectral limits as a function of the insertion loss of the loop (between cabinet and customer premises), for instance measured at 1 MHz.
- Another option is to specify two *fixed* spectral limits at *two* different locations, as shown in Figure 5. Limit #1 holds for the cabinet location and Limit #2 for any point of injection (wherever it is situated in the loop). Limit #1 is the most restricting one, and is very close to Spectrum “A” in Figure 3. Limit #2 is restricting only in long loops and is very close to Spectrum “D” in Figure 3. It is up to the modem to estimate the insertion loss of the loop and to calculate what transmit level complies with both limits.

Verifying compliance with rules following the first approach requires an additional measurement of the insertion loss. This requires a disruption of the service to verify an operational VDSL2 modem pair. This inconvenience does not hold for the second approach. The British access rules follow the first approach, and the Dutch rules the second one.

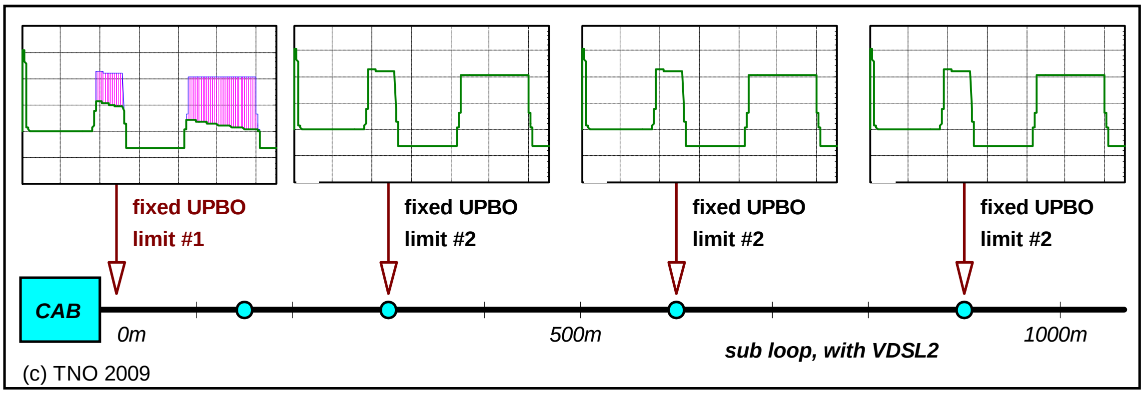


***Figure 5:**. Specifying position-dependent limits by means of only two spectra.*

6. SUMMARY

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. UPBO is a mechanism to reduce the upstream transmit power for modem links via short loops. It will significantly enhance the bitrate of systems via longer loops, at a small penalty for those via short loops.

The required amount of power back-off depends on many factors, including the insertion loss of the loop, the geographic distribution of customer premises along the loop, and the location of customer premises. It requires a DSL performance simulator to find the most appropriate UPBO regime for specific geographic conditions.

Such reductions should be tailored to underlying business needs and network properties, and these are all country or region specific. Moreover, the use of UPBO has to be mandatory for all players, otherwise it will not be effective.

The preferred method for specifying UPBO in access rules is via spectral limits at the output of the modems. This enables an indisputable and implementation independent verification if modems comply with such rules. This cannot be facilitated if access rules "specify" UPBO via parameter values for instructing the management system of VDSL2.

7. REFERENCES

[1] ETSI TR 101 830-1, "Spectral Management, part 1: Definitions and signal library", 2008.

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[3] ITU-T, Recommendation G993.2 "Very high speed Digital Subscriber Line Transceivers 2 (VDSL2)" (including all corrigenda).

[4] SPOCS, a simulation tool compliant with ETSI TR 101 830-2, www.tno.nl/spocs

[5] Rob F.M. van den Brink, "*Cable reference models for simulating metallic access networks*", ETSI/STC TM6 permanent document, June 1998.

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[6] Rob F.M. van den Brink, "*The art of deploying DSL; Broadband via noisy telephony wiring*", TNO 35090, White paper on DSL, Oct 2009 (revision from June 2008)

[7] Rob F.M. van den Brink, "*The art of Spectral Management; Access rules for VDSL2*"; TNO 35091, white paper on DSL, Oct 2009.

[8] Rob F.M. van den Brink, "*The art of Spectral Management; Frequency allocations for VDSL2*"; TNO 35092, White paper on DSL, Oct 2009.

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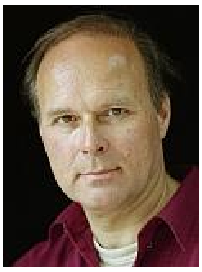
[10] Rob F.M. van den Brink, "*The art of Spectral Management; Upstream power back-off for VDSL2*"; TNO 35094, White paper on DSL, Oct 2009.

Rob F.M. van den Brink graduated in Electronics from Delft University in 1984, and received his PhD in 1994. He works as a senior scientist within TNO on broadband access networks.



Since 1996, he has played a very prominent role in DSL standardisation in Europe (ETSI, FSAN), has written more than 100 technical contributions to ETSI, and took the lead within ETSI-TM6 in identifying / defining cable models, test loops, noise models, performance tests, and spectral management. He is the editor of an ETSI-TM6 reference document on European cables, and led the creation of the MUSE Test Suite, a comprehensive document for analyzing access networks as a whole. He also designed solutions for Spectral Management policies in the Netherlands, and created various DSL tools for performance simulation (SPOCS, www.spocs.nl/en) and testing that are currently in the market.

He has also been Rapporteur/Editor for ETSI since 1999 (on Spectral Management: TR 101 830), Board Member of the MUSE consortium (2004-2008, www.ist-muse.org) and Work Package leader within the Celtic 4GBB Consortium (2009-2011, www.4gbb.eu).