TITLE **Time domain requirements on noise in performance tests**

PROJECT VDSL, part 1 (Also applicable to SDSL, HDSL and ADSL)

SOURCE: KPN Research
authors: Bas van den Heuvel, Rob van den Brink

CONTACT R.F.M. van den Brink tel: +31 70 3325389
KPN Research, fax: +31 70 3326477
PO Box 421 email: R.F.M.vandenBrink@research.kpn.com
2260 AK Leidschendam email: B.M.Heuvel@research.kpn.com
The Netherlands

STATUS For approval

ABSTRACT *We present a literal text proposal for the VDSL performance tests in part 1. It solves the problem of inadequate time domain requirements on the impairment noise. Our solution is to specify a* ***mask on the amplitude distribution****. This mask specifies how close the impairment noise shall be to truly gaussian noise and what its crest factor shall be. We propose a match within 10% from gaussian, and a crest factor 5, but the actual values of these numbers are open for discussion.*

1 Introduction

The current VDSL performance test [1] puts a few requirements on the nature of the various noise signals to be used:

> "The noise shall be random in nature and gaussian distributed. The crest factor of the noise source shall be between 5 and 8"

The characterisation above of the amplitude distribution of the noise for performance tests has been argued to be both insufficient and impracticable [2,6]. The insufficiency is mainly related to the fact that the above prescription leaves a lot of ambiguity with respect to the amplitude distribution of the actual impairment noise signal. This has been shown to lead to ambiguous test results [2]. Furthermore, although the need to have high crest factors is widely acknowledged [3,4], the requirement of both gaussian behaviour and of high crest factor in practice leads to very long noise signals.

One should note that only noise of infinite length can be truly gaussian distributed: for real-life noise of finite length, one has to specify how 'close' the signal should be to truly gaussian noise.

This contribution contains a literal text proposal for the VDSL performance test. The idea is to specify that up to a certain value of the crest factor (e.g. 5) the noise shall be distributed within ε (e.g. 10%) of a truly gaussian distribution. This is accomplished through defining a mask for the amplitude distribution function of the actual impairment noise [6]. This is an exact way of specifying how 'close' the actual noise has to be to truly gaussian noise.

The use of such a mask defines the framework for putting time domain requirements on the noise signals. However, the details of the mask are open to discussion: it still has to be verified experimentally that the proposed values are such that the resulting mask is sufficiently tight to lead to unambiguous test results.

This paper is organised as follows. Section 2 contains the text proposal. The details of this proposal and the motivation for the chosen values are discussed in Section 3. Section 4 contains the conclusions.

2 Text proposal

9.3.x. Time domain profile on crosstalk noise sources

The noise, as specified in the frequency domain in sub-clause [*] to [*], shall be random in nature and near gaussian distributed. This means that the amplitude distribution function of the combined impairment noise injected at the adding element (see Figure 11) shall lie between the two boundaries as illustrated in figure [y] and defined in table [x].

The amplitude distribution function F(a) of noise u(t) is the fraction of the time that the absolute value of u(t) exceeds the value "a". From this definition, it can be concluded that F(0) = 1 and that F(a) monotonically decreases upto the point where "a" equals the peak value of the signal. From there on, F(a) vanishes:

$$F(a) = 0 \text{, for } a \geq \left| u_{peak} \right| .$$

The boundaries on the amplitude distribution ensure that the noise is characterised by peak values that are occasionally significantly higher than the rms-value of that noise (up to 5 times the rms-value).

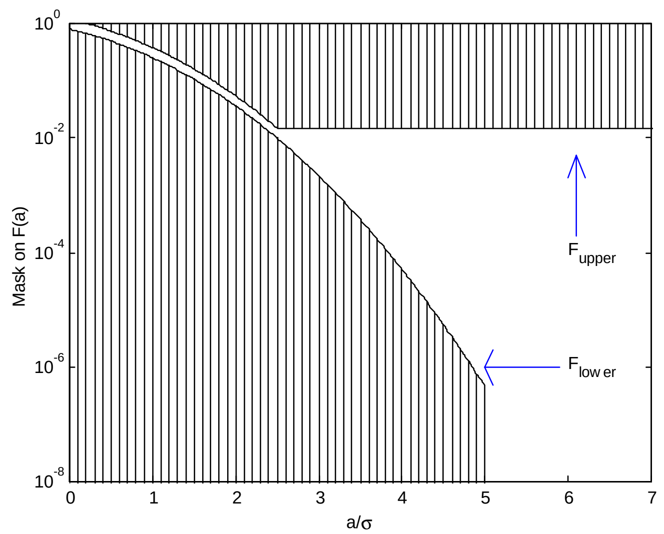

Figure y: Mask for the Amplitude Distribution Function: the non-shaded area is the allowed region. The boundaries of the mask are specified in Table x.

boundary (σ = rms value of noise)	**interval**
$F_{lower}(a) = (1 - \varepsilon) \cdot \{1 - erf((a/\sigma)/\sqrt{2})\}$	$0 \leq a/\sigma < CF$
$F_{lower}(a) = 0$	$CF \leq a/\sigma < \infty$
$F_{upper}(a) = (1 + \varepsilon) \cdot \{1 - erf((a/\sigma)/\sqrt{2})\}$	$0 \leq a/\sigma < A$
$F_{upper}(a) = (1 + \varepsilon) \cdot \{1 - erf(A/\sqrt{2})\}$	$A \leq a/\sigma < \infty$

parameter	**value**
crest factor	CF = 5
gaussian gap	ε = 0.1
	A = CF/2 = 2.5

Table x: Upper and lower boundaries of the amplitude distribution function of the noise.

The meaning of the parameters in table [x] is as follows:

- CF denotes the minimum crest factor of the noise, that characterises the ratio between the absolute peak value and rms value (CF= $|u_{peak}|$ / u_{rms}).
- ε denotes the gaussian gap that indicates how 'close' near gaussian noise approximates true gaussian noise.
- A denotes the point beyond which the upper limit is alleviated to allow the use of noise signals of practible repetition length

3 Motivation

An important time domain characteristic of a noise signal is the crest factor, which is defined as $CF = |u_{peak}| / u_{RMS}$. Details of the 'peakedness' of the noise are given by the *amplitude distribution function* [5] of u(t), which is defined as follows. For the signal u(t) the amplitude distribution function F(a) is the fraction of the time that the absolute value of |u(t)| exceeds a. In formula:

$$F(a) = \frac{1}{T} m\left(\left\{t \in [0,T] \middle| \, |u(t)| > a\right\}\right),$$

with T the total length of the signal, and μ the Lebesgue-measure. Note that amplitude distribution function F(a) equals 1 for a = 0, and monotonically decreases upto the point where a equals the peak value of the signal. From there on, F(a) vanishes.

For a stochastic signal of infinite length the realised amplitude distribution of the signal is related to the probability density as follows:

$$F(a) = P(|u| > a) = 2\int_a^{\infty} p(x)dx,$$

with p(x) dx the probability of finding the value of the signal between x and x+dx.

For a *truly* gaussian signal with a RMS value equal to one, p(x) is the standard normal distribution function. For a sample of infinite length, this leads to an amplitude distribution given by:

$$F(a) = P(|u| > a) = 1 - \frac{2}{\sqrt{p}} \int_o^{a/\sqrt{2}} \exp\left(-t^2\right)dt = 1 - erf\left(a/\sqrt{2}\right).$$

This means that for *truly* gaussian noise with an RMS value of σ, the crest factor is infinite, and the amplitude distribution function is given by

$$F(a) = \left(1 - erf\left(\frac{a}{\sqrt{2}s}\right)\right), \qquad a \geq 0 .$$

The text proposal demands that the amplitude distribution function of the impairment noise injected at the adding element in the measurement set-up shall be bound from below by the mask:

$$F_{lower}(a) = (1-e) \cdot \left(1 - erf\left(\frac{a}{\sqrt{2}s}\right)\right), \;\; 0 \leq \frac{a}{s} < CF,$$

with σ the RMS value of the signal.

The lower limit is obtained by demanding that up to value CF, the measured amplitude distribution is bounded from below by the true gaussian distribution, up to an accuracy of ε. This guarantees that the actual noise signal:

1. has a sufficiently high crest factor (viz. larger than CF)
2. is close to an ideal gaussian distribution.

The value of 5 for the crest factor CF in the proposal confirms to present minimum value for the crest factor. The value of 5 is based on the following order-of-magnitude argument. The requirement for proper functioning of the link under test is that the Bit Error Ratio shall be below 10^{-7}. This means that the number of bits that must have been transported during the test must be of the order of 10^8. At a bit rate of R bit/s, this means a duration of the measurement of 10^8/R seconds.

At a bandwidth of R Hz[1], the noise signal has of the order of R independent values of the noise signal per second. During the measurement time determined above (10^8/R seconds) this means that we have 10^8 independent noise values. A sample of gaussian noise with length 10^8 will have a crest factor somewhere between 5 and 6. Hence we demand the impairment noise (which itself may have a *repetition* length less than 10^8/R seconds) to have a crest factor of at least 5.

The proposal also defines an upper limit to the amplitude distribution. Note that an upper limit is already implicitly present through the fact that the amplitude distribution function is related to the RMS power of the signal by the following *power constraint*:

$$u_{RMS}^2 = \int_{-\infty}^{\infty} a^2 p(a)da = -\int_{0}^{\infty} a^2 F^{'}(a)da = 2\int_{0}^{\infty} F(a)ada\ .$$

This integral condition on the amplitude distribution function, together with a tight *lower* limit (i.e. ε is small), already puts an effective *upper* limit on the amplitude distribution.

The reason that the upper limit is rather loose, is to allow noise signals of a practicable length. Consider a limited noise signal: either the number of points N is limited or, equivalently, the repetition time T is limited (the effective number of points is then of the order N = T/B, with B the bandwidth of the signal) . For such a signal the measured amplitude distribution will have a granularity of 1/N. This means that a requirement like e.g. "F(5) should be between 1e-8 and 1e-7" cannot possibly be obeyed by a signal of (effective) length N = 1e6. The constant value in the upper limit in the mask thus implicitly leads to a lower bound on the effective number of points in the noise signal.

4 Conclusions

The present proposal solves the problem of inadequate time domain requirements on the impairment noise. It defines the framework for specifying time domain requirements on the impairment noise. The use of a mask for the amplitude distribution function allows to define the nature of the actual impairment noise in a precise way.

The currently proposed numbers provide a realistic mask for noise signals of a practicable length, but the precise values are open for discussion.

It is an open issue whether the noise defined through the current values in the mask leads to unambiguous test results: further study has to show whether the mask is sufficiently tight.

5 References

[1] ETSI TM6, DTS/TM-06003-1(draft) v0.0.7 (1998-2), “Transmission and Multiplexing; Access Transmission on Metallic Access Cables; Very High Speed Digital Subscriber Line (VDSL); Part 1: Functional Requirements”, February 1998.
[2] KPN Research, “PSD + Crest factor is not sufficient to specify noise in performance tests”, ETSI TM6, TD16, June 22nd-26th , Luleå, Sweden..
[3] Schmid Telecom AG, “Proposal for the modification of the HDSL test noise”, ETSI TM6, TD11, April 20th - 24th, Antwerp, Belgium.
[4] P. Nurfluss, A. Kliger, “Proposal to include high crest factor noise in the 2B1Q HDSL performance tests”, ETSI TMD, TD40, January 26th - 30th, 1998, Madrid, Spain.
[5] S. Boyd, “Multitone Signals with Low Crest Factor”, IEEE Transactions on Circuits and Systems, Vol. CAS-33, no. 10, october 1986.
[6] KPN Research, “Specification of crest distribution mask for noise in performance tests”, ETSI TM6, TD42, September 21st -25th , Vienna, Austria.

[1] Bandwidth and bit rate are assumed roughly proportional for this order-of-magnitude argument.