
TITLE **PSD + Crest factor is not sufficient to specify noise in performance tests**

PROJECT VDSL, part 1 (Also HDSL and ADSL)

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STATUS For discussion

ABSTRACT *The current VDSL performance test [1] puts requirements on the nature of the noise signals to be used in the performance test. We will show that in some cases different noise signals that all satisfy the constraints of [1], lead to different noise margins of the modem under test of up to 3 dB. This means that a tighter specification of the noise signals is required.*

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1 Problem description

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

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

The crest factor of a signal is defined as $CF = |V_{peak}| / V_{RMS}$. The characterisation above of the amplitude distribution of the noise for performance tests is (1) insufficient and (2) impracticable:

1. **Insufficient**. In this contribution, noise signals with equal PSD but with different crest factors are observed to have a different impact on a test modem. We will show that in some cases the value of the crest factor of the test signal can make a difference of upto 3 dB in the determination of the noise margin of the modem under test. A more precise prescription of the crest factor and probably also of other temporal characteristics of the test noise signals is required, to define a testing procedure with unambiguous results
2. **Impracticable**. For a gaussian distributed noise signal, the crest factor will grow with the length of the signal. In practice, very long gaussian distributed noise signals are necessary to obtain the high crest factors of the VDSL performance test.

These two facts call for improvements in the prescription of the noise signal such that:

1. the testing procedure is defined such that it provides unambiguous test results,
2. the test noise signals can have a reasonable, practical length.

Further study is required to decide which detailed requirements must be posed on the noise signal

2 Introduction

This contribution is organised as follows. Above the problem with the current definition of test noise signals was described. We will first collect some facts on the relation between the length of a gaussian noise signal and the crest factor. After this, a possible way to improve the prescription of noise signals is given.

Next we present the main results of our contribution, which are the measurements with signals with equal PSD but with different crest factors.

Note that this contribution does not go into the question how high the necessary crest factor should be. It also does not investigate possible other characteristics of the amplitude distribution function that influence the error behaviour of the test modems. This has to be investigated independently.

3 Crest factor and length of a gaussian noise signal

We will discuss the case of white gaussian noise. Consider the following probabilistic experiment. A noise signal is constructed by taking the values from a gaussian distribution. The complete sample consists of N sample values $\{x_n\}$ (n = 1 …N), where the x_n are drawn from a gaussian distribution. Since al the samples are independent, the resulting noise is white.

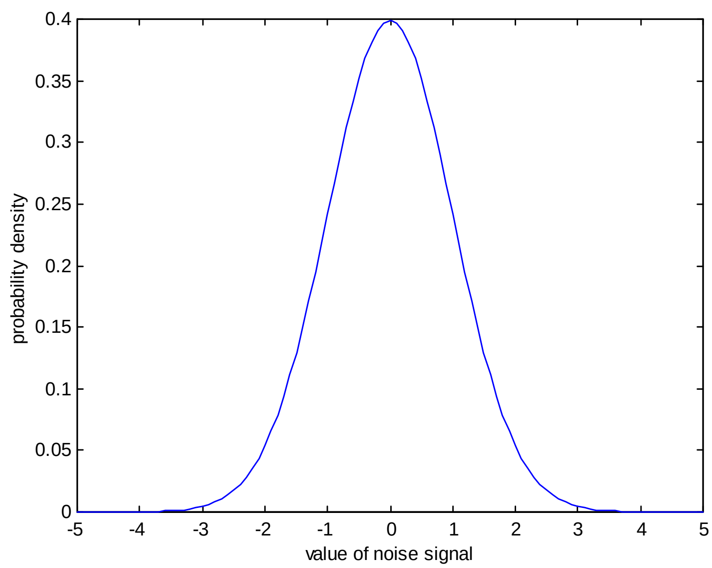

Figure 1: Amplitude distribution function for gaussian noise (σ = 1). For a limited number of samples drawn from this distribution, the peak value (and hence the crest factor) will be relatively low due to the exponentially decaying tails of the distribution.

Figure 1 shows the gaussian distribution (with standard deviation σ = 1). It is given by:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-x^2 / 2\sigma^2) .$$

The Crest Factor is

$$CF = \frac{|V_{peak}|}{V_{RMS}} = \frac{\max(|x_n|)}{\sigma} .$$

The probability function for the stochast CF can be calculated exactly. This function is plotted in Figure 2 for various values of N. An indication of the expected Crest Factor of a sample of size N can be read off from this plot. To obtain high crest factors, one needs prohibitively large numbers of samples due to the exponential tails of the normal distribution: for a crest factor of 8 one expects to need more than 10^{14} samples. Clearly, this is an impracticable requirement.

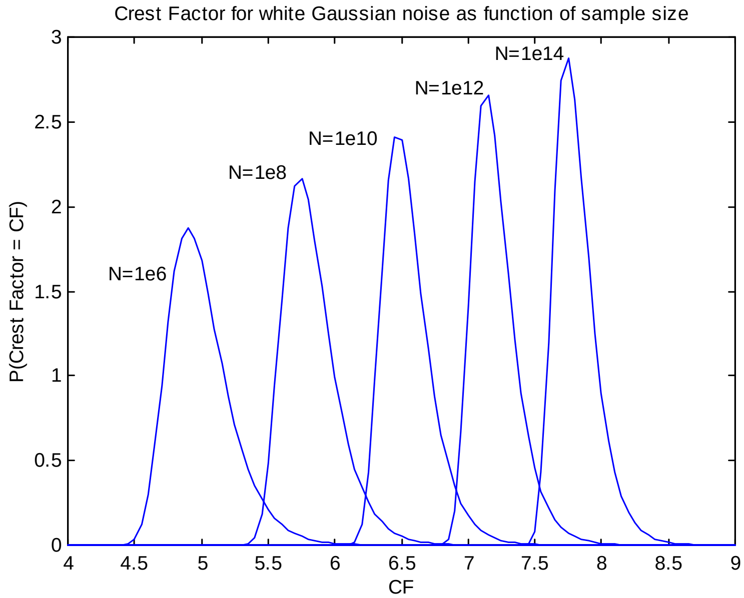

Figure 2: Probability density of the crest factor for samples of various sizes. This illustrates that e.g. 10^{10} samples are required to generate a gaussian distributed noise signal with a crest factor of the order of 6.5.

To obey the condition on a noise signal to have *both* a gaussian distribution *and* a high crest factor is impracticable, due to the length of the required signals. The need for a high crest factor in test signals is widely acknowledged [2,3]. Hence we propose to relax the condition of the gaussian distribution, while insisting on high crest factors of the test signal.

For instance, this can done by adjusting the exponential tails of the normal distribution in such a way that more statistical weight of the distribution is moved to the larger values of the sample. An example of this is sketched in Figure 3: the amplitude distribution depicted there is the sum of a truncated gaussian distribution and a uniform distribution.

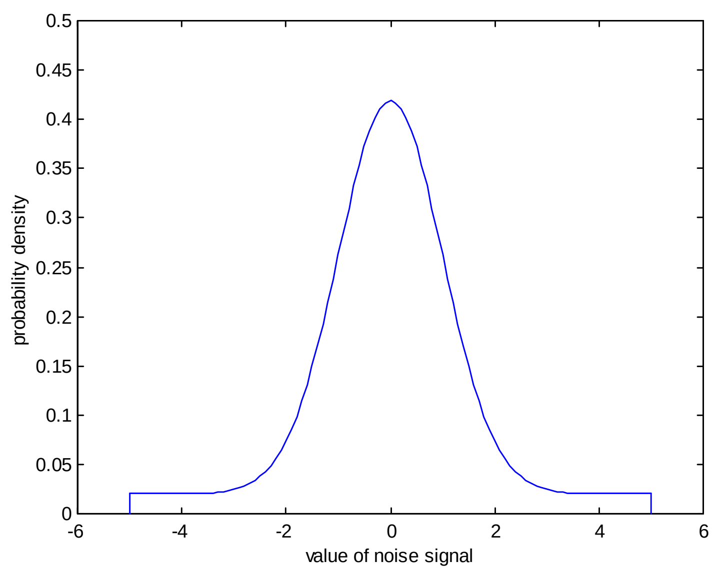

Figure 3: An alternative amplitude distribution function. Already for a relatively small number of samples drawn from this distribution, the peak value of the signal is expected to be close to the edges of the distribution.

The value for the crest factor to be prescribed by such an alternative amplitude distribution is still to be determined. It is also not clear yet how other details of the amplitude distribution might influence the impact of such a noise signal on the error performance of the test modem. This is subject to further research.

4 Description of experiments

To proof that the current prescription of test noise signals is inadequate, we used the standard set-up [1] for inserting noise signals (see Figure 4). A VDSL modem pair was connected over 500 meter cable (0.5 mm). The impairment generator we used was an LeCroy Arbitrary Wave Generator (AWG). This instrument can play back signals of upto 1 million samples at a speed upto 400 Msamples/s. The produced noise signal could be attenuated in steps of 1 dB and was subsequently inserted on the VDSL modem link using a passive insertion network as the adding element. The VDSL modems offered the possibility to monitor the BER on the transmission line (that is, the Bit Error Ratio before FEC correction took place). This pre-FEC BER was measured as a function of the attenuation of the disturbing signal.

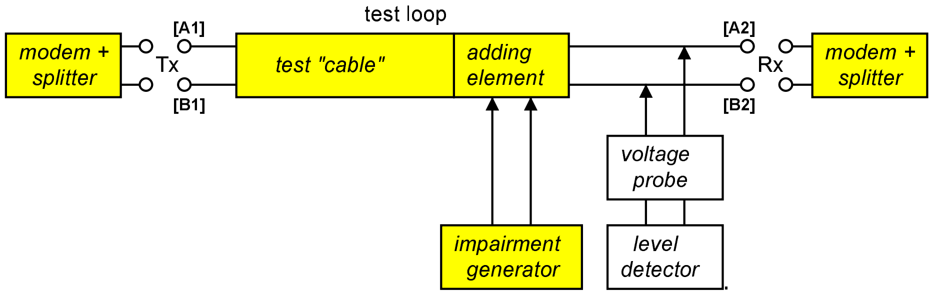

Figure 4: Measurement set-up.

The AWG contained various sets of signals, where all the signals in one set had the same PSD, but had different crest factors. These pseudo random noise signals were created using an algorithm implemented in MATLAB (see appendix). The two disturber spectra that we used were a 2B1Q spectrum with additional low-pass filtering, and the spectrum corresponding to the G3.LT.B noise signal, as described in [1]. Both disturbing spectra and the VDSL modem signal (we choose the upstream channel) are depicted in Figure 5.

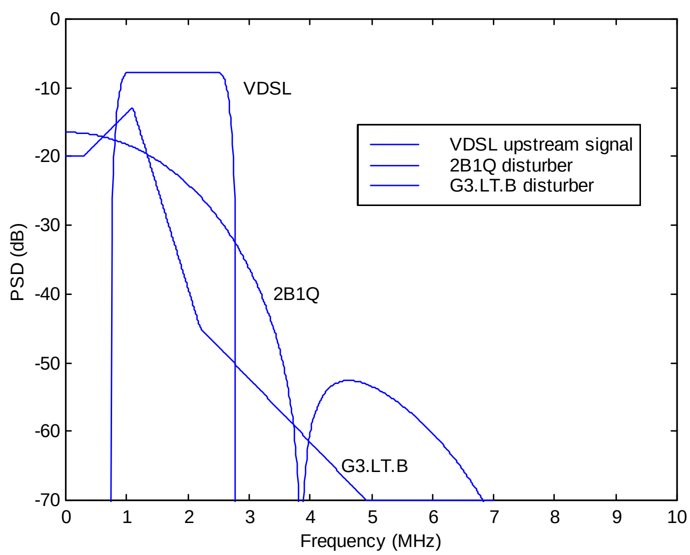

Figure 5: Spectrum of VDSL signal and of disturbers.

4.1 Disturber with 2B1Q spectral envelope

The first set of signals is described in Table 1.

Signal	Number of points	Crest factor
Random 1	131072	4.2
Random 2	12500	3.7
Random 3	12500	6.5
Random 4	12500	5.5

Table 1: Crest factors of the different 2B1Q signals.

The signals in this set had the PSD of a 2B1Q signal with some additional low-pass filtering. The signals within this set differed by the number of points that a sample contained, and by the crest factor of the signal. As an example, Figure 6 shows the signal 'Random 4' in the time and in the frequency domain.

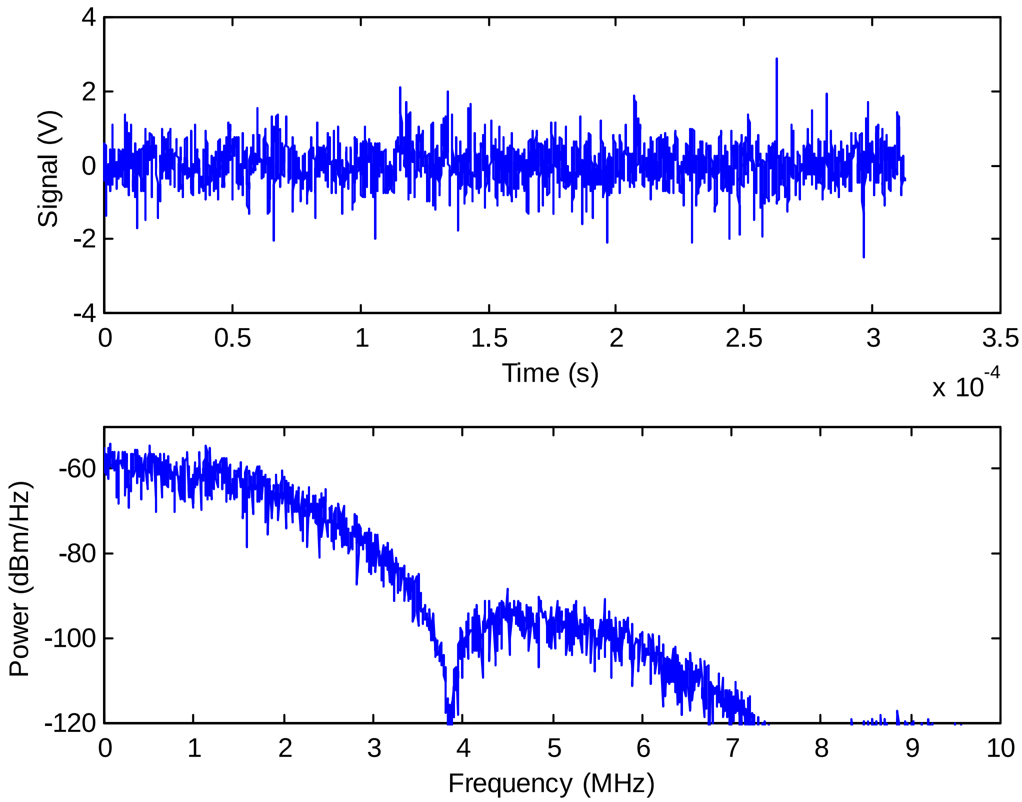

Figure 6: Signal 'Random 4' in time and frequency domain.

The difference in impact on the VDSL modem performance is shown in Figure 7. Obviously, by increasing the level of the disturbing signal, the pre-FEC BER grows. When the pre-FEC BER grows beyond approximately $2 \cdot 10^{-3}$, also the corrected signal starts to exhibit bit errors (as reported by the modems themselves). When increasing the disturbing signal even more, the reported values by the modems become unreliable: both the pre- and post-FEC BER become of the same order ($1.2 \cdot 10^{-3}$) and the modems start to lose sync.

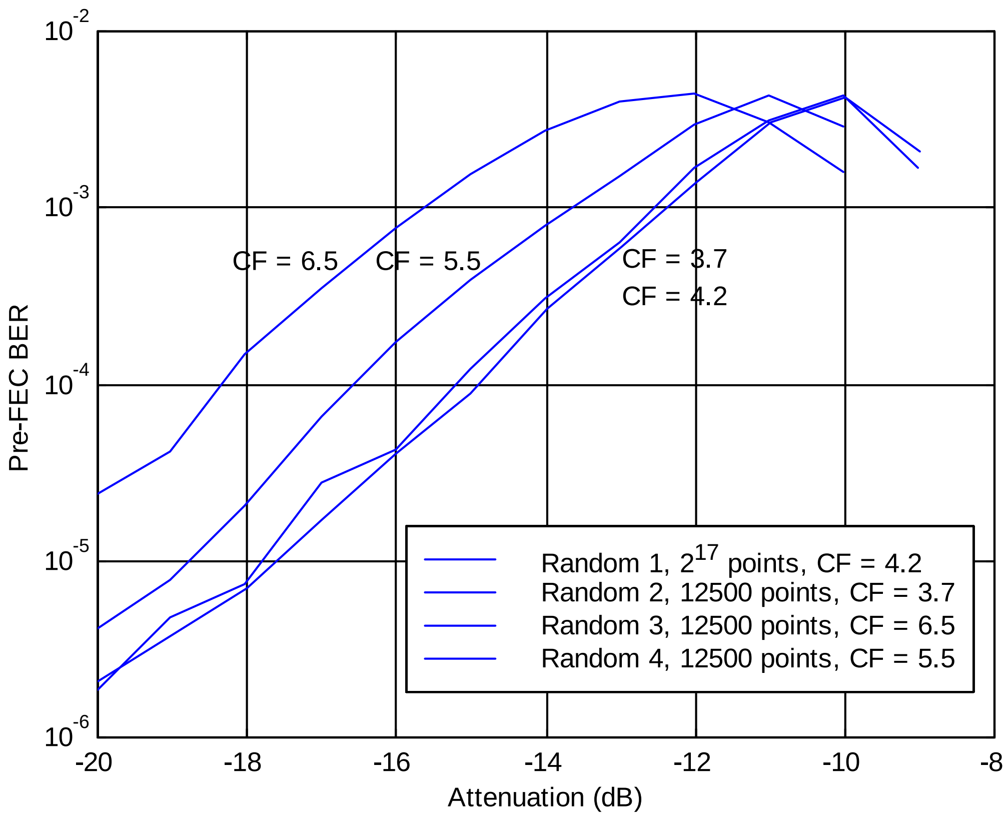

Figure 7: Influence of crest factor of a 2B1Q disturber on error performance. Although the PSDs of the disturbing signals are equal, their impact on the modem under test is different: the left-most curve (CF = 6.5) differs 3 dB from the curves on the right (CF ≈ 4).

In the range upto 10^{-3}, we can rely on the reported values. The difference between the curves for the signals 'Random 1' and 'Random 2' is of the order of a few tenths of a dB, which is smaller than the accuracy with which the BER is determined. The curves corresponding to the disturbers 'Random 3' and 'Random 4' differ significantly from the first two curves:

- measured at a BER of 10^{-3}, the impact of the 'Random 4' and 'Random 3' signals is respectively 1 and 3 dB higher in level than the impact of the signals 'Random 1' and 'Random 2'.
- measured at a BER of 10^{-4}, the impact of the 'Random 4' and 'Random 3' signals is respectively 1.5 and 3 dB higher in level than the impact of the signals 'Random 1' and 'Random 2'.

4.2 Disturber with G3.LT.B spectral envelope

The second set of signals (see Table 2) corresponded to the G3.LT.B spectrum as described in [1].

Signal	Number of points	Crest factor	Remarks
G3.LT.B 1	131072	4.3	
G3.LT.B 2	131072	8.2	
G3.LT.B 3	131072	5.2	
G3.LT.B 4	131072	6.1	
G3.LT.B 5	131072	7.3	
G3.LT.B 6	131072	6.1	Single spike added
G3.LT.B 7	131072	6.0	Many spikes added

Table 2: Crest factors of the different G3.LT.B signals.

The signals within this set differed by the crest factors, and also by the *number* of peaks in the signal that were emphasised in the process of enlarging the crest factor (see appendix).

The results of the measurements with these series of signals are depicted in Figure 8. The clear influence of the crest factor that was obvious in the previous measurement cannot be observed with these signals due to the measuring accuracy: all the curves are indistinguishable.

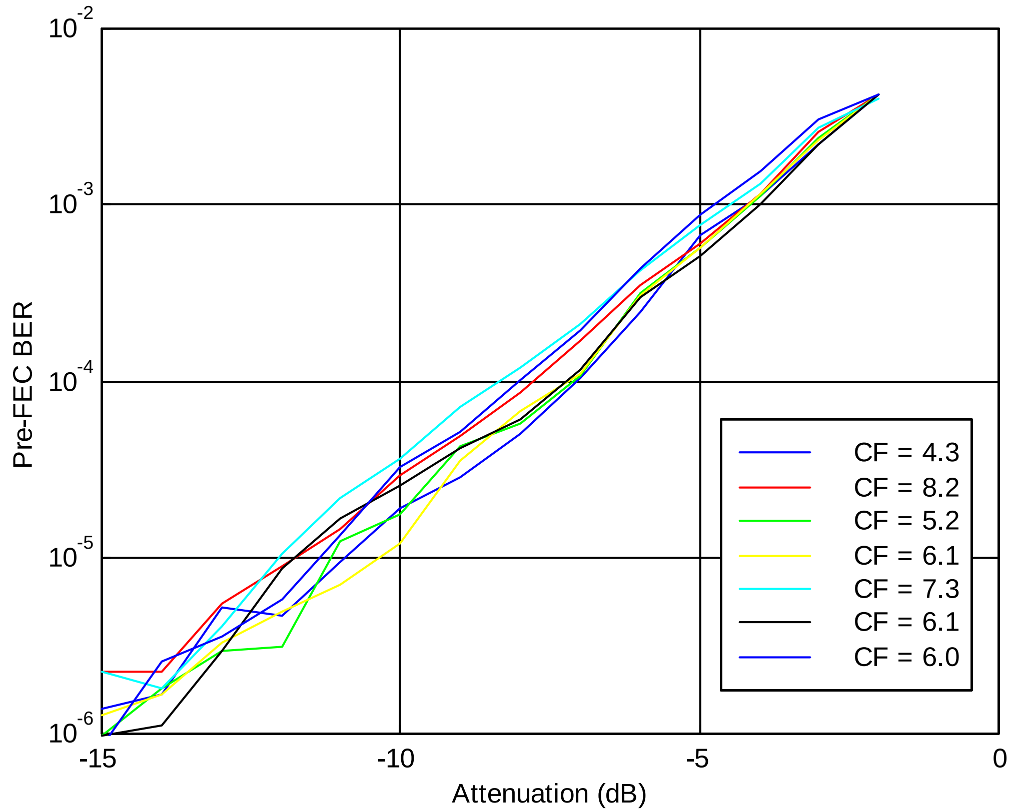

Figure 8: Influence of crest factor of a G3.LT.B disturber on error performance. In this case, no significant difference in the impact on the error performance can be observed due to the measuring accuracy.

5 Discussion & Conclusions

We clearly observed examples where signals with equal PSD but different crest factor had a large difference in their impact on the test modem. We also encountered situations where the crest factor of the disturbing signal could not be observed to have an impact on the error performance of the modem under test. More study is required to clarify this situation.

The fact that there are cases in which signals that differ only in their crest factor make such a different impact on the modem under test, clearly demands for a more complete characterisation of the noise signals. We expect that not just bounds on the crest factor (between 5 to 8 in the current version of [1]) should be given, but also other constraints on the noise signal in the time domain.

A concrete way to achieve this would be to prescribe a mask for the amplitude distribution function. Apart from representing realistic noise signals, this amplitude distribution should also be chosen such that even fairly short signals (with a limited number of samples, say, 1 million) can already be expected to reach the peak values of the distribution. The details of this amplitude distribution, including the value of the crest factor, are for further study.

6 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] Schmid Telecom AG, "Proposal for the modification of the HDSL test noise", ETSI TM6, TD11, April 20th - 24th, Antwerp, Belgium.

[3] 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.

7 Appendix: Algorithm for synthesis of noise signals.

We used the following algorithm (implemented in MATLAB) to construct signals with varying crest factors.

1. Start in the time domain with a white, gaussian noise signal. This was constructed by choosing normally distributed values for the signal at each sample time.
2. If desired, increase the crest factor of this signal by multiplying a number of the larger values in this signal.
3. Do a Fourier Transform to the frequency domain, and multiply the Fourier coefficients with the square root of the desired Power Spectral Density function.
4. Renormalise the obtained signal to the desired total output power.
5. Transform the signal back to the time domain.
6. Download the signal into the AWG.

Important note:
The crest factor of the final signal will *not* be equal to the crest factor of the signal that was obtained after step 2, due to the subsequent manipulations in the frequency domain. However, by starting step 3 with a signal that has a high crest factor, the final signal is very likely to also have a high crest factor. The various high crest factor signals described in this contribution were obtained by tuning the crest factor of the signal at step 2..