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Topic: Simulation of wire-lines for testing Broadband Access products – xDSL technology

What you need to know when Simulators of Physical layer are used to test Standard Compliance in terms of Interoperability, Functionalities and Performance of DSL technology.

This paper supposes that the reader has sound knowledge of transmission technologies like 2B1Q, TC-PAM, QAM and DMT used in different DSL flavours, to know:

- symmetric technology: Upstream = Downstream data-rate

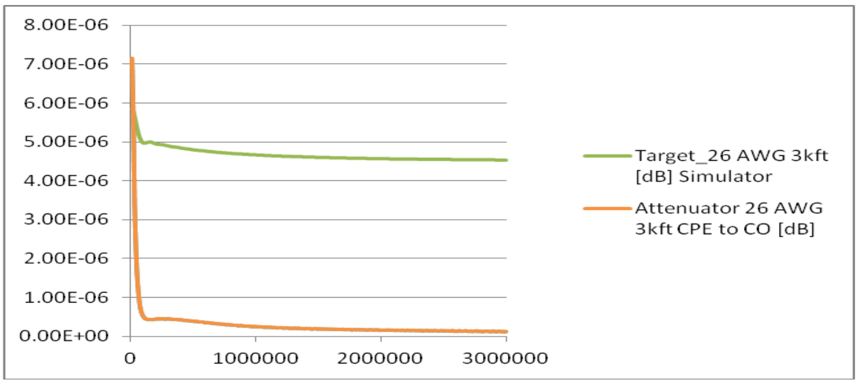
- a-symmetric technology: Upstream < Downstream data-rate

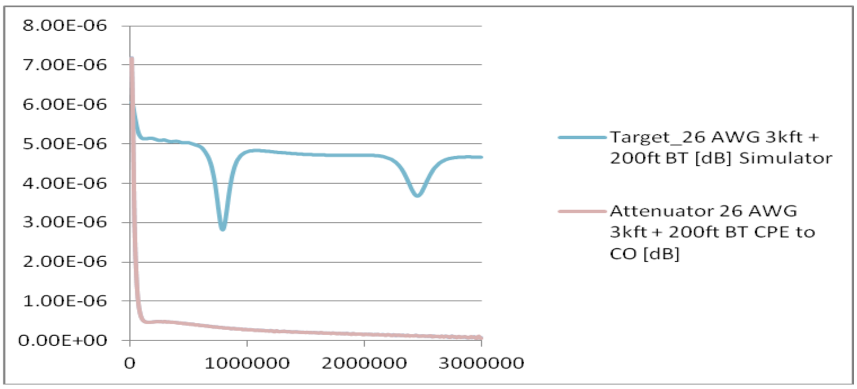
The text is applicable for all DSL technologies, to know SDSL, SHDSL, ADSL, ADSL2, ADSL 2plus, VDSL, VDSL2, VDSL35 Vectored DSL, G.fast 106, G.fast 212

Important !

G.fast is a new technology that is using TDD technology (duplexing in time-domain) and thus the 'propagation delay' caused by a wire-line is a determining factor and **should be implemented**.

This excludes the use of 'attenuator-based' test set-ups ! an attenuator is a filter that is built to create 'insertion loss' or 'attenuation' according a line type with a flat impedance ! an attenuator does not implement the delay caused by a cable. The delay of an attenuator = 0.





Introduction

Testing Broadband Access Products consider mainly 3 parts:

- the physical layer drivers
- the functionalities of the product
- the interfaces.

Standards

The 'Standard Recommendations' use more or less the same approach.

The ITU-T recommendations are specifying the PSD masks of each technology that needs to be tested.

ETSI (Europe) and ATIS (American) fall under ITU-T and will define specific test cases applicable for their region.

The BBF is a working-group where all players of the Broadband Industry agree on test topologies for different Broadband Technologies. They develop Test Recommendations ('TR') for 'annex a' (America) and 'annex b' (for Europe). Japanese specifications are formulated for some of these tests.

DSL Testing according Standards

- The BBF typically focuses on '*physical layer testing with performance requirements*' like TR-100 i3 (ADSL2plus) and TR-114 i2 (VDSL2).

- The so-called '*functionality tests of CPE – DSLAM*' are described in different documents like TR-105 or TR-115.

- The user interfaces at the customer premises are CPE specific and require appropriate testing like for 10/100base-T, Wireless WiFi, Router, Voice (Pots and VoIP) … and thus are not included in the test recommendations of BBF, unless they would have a direct impact on the access network between the CPE and the CO.

Testing CPE – DSLAM's are therefore focusing on

- 'functionality testing'
- 'physical layer performance testing'

The first objective is 'Interoperability' among products. This concerns the different features that are inherent to the technology that is used for realizing the transmission between devices. Many of these features are controlled with software and needs adaptation in order to match with the Standards. For such tests it is sufficient that there is a link between CPE and CO. The 'performance of device in terms of maximum speed and stability' is not the aim of these tests. That is why it is called 'FUNCTIONAL TESTS'. Simple attenuators can be used for such tests.

When systems are interoperable, than maximum performance is tested. This is called 'PERFORMANCE TESTS'. For such tests the use of 'full blown Line Simulators' is mandatory.

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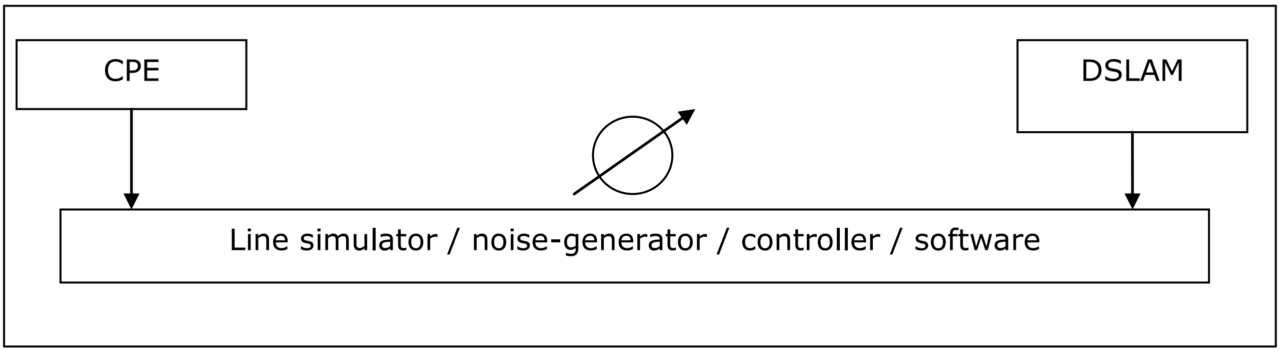
Physical Layer

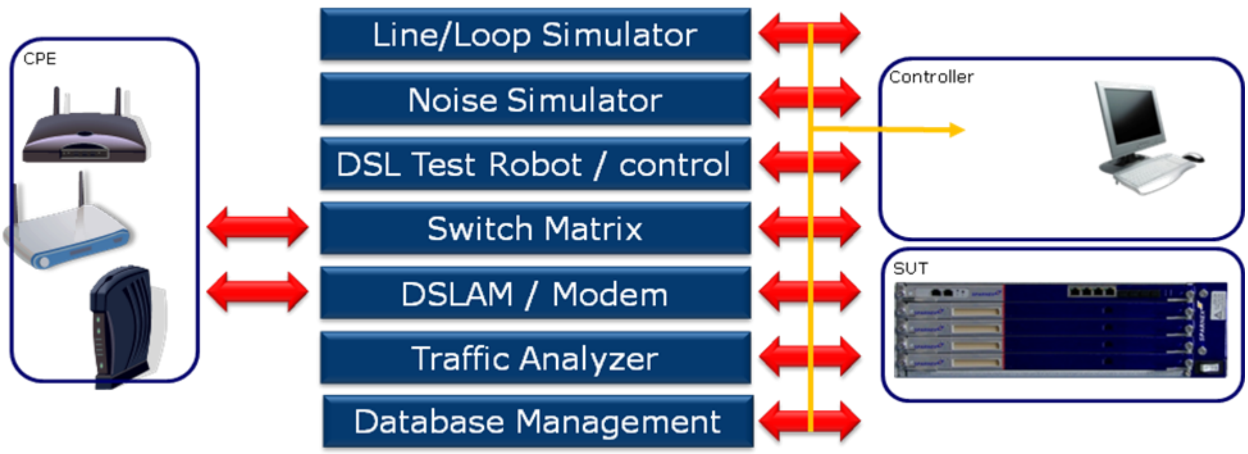
The physical layer tests are typically executed with a test set-up that represents the wire-line infrastructure of the Service Operator. There are 3 possible approaches:

- Using real wire-line cable
- Using a line simulator that simulates a 'Standard' wire-line definition (ITU-T, ATIS, ETSI, BBF ..)
- Using a programmable line simulator that simulates a 'Standard' line definition (ITU-T, ATIS, ETSI, BBF …) and that ultimately also can 'mimic' the cable that is used in the Country where the Access Products are deployed (like German, French, Dutch Telecom lines, Japanese lines ..)

A typical platform for testing CPE's and DSLAM has following minimum configuration:



An automated test setup has the following functions:



A fully automated test-platform might look like the following drawing (based on a document of Sparnex Instruments)

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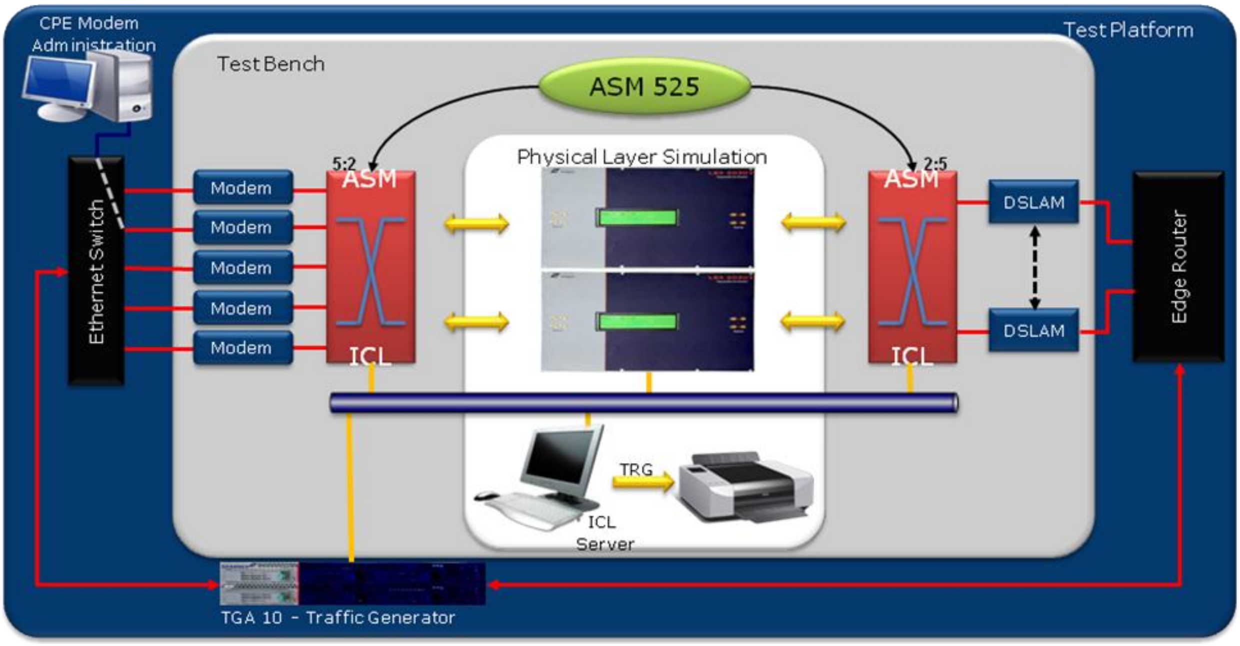

The Standard Recommendations are very strict(!) regarding the use of 'Line Simulators' or 'Loop simulators'

A cable (wire-line) is modeled in so-called 'primary parameters' known as R-L-C-G models which are the outcome of the 'physical characteristics' of a cable.

A modem or a DSLAM though is only coping with the 'electrical characteristics' of a cable. These form together the 'transfer function' of a cable. The characteristics are defined in 3 parameters, they are called the 'Secondary Parameters' of a loop

- **Attenuation in dB per Hz**
- **(Complex) Impedance of the cable**
- **Phase of the cable (delay)**

Each of these parameters are defined per type of cable and have to be simulated according the Standard Recommendations. The Standard gives a detailed description of the accuracy and calibration of line simulators and noise generators in order to guarantee that CPE's and DSLAM's are tested correctly. The test results in US and DS bit-rate under minimum Noise Margins depend on the accuracy of simulated secondary parameters.

CPE's that 'Pass' or 'Fail' on the benchmarks performance *have no value* when measured with at platform that is not within the calibration bounderies or when not all parameters are simulated.

1. Accuracy of loop simulators

1.1. Attenuation

North American Annex A testing

Loop Attenuation which corresponds to the insertion loss is expressed in dB is calculated from RLCG parameters using two-port ABCD modeling methodology as specified in [T1.417] Section B.3.1 (for both straight loops and loops with bridge taps).
The RLCG cable parameters are specified in [T1.417] Table B.2 "Cable model parameters for 26-AWG twisted pair cable" and Table B6 "Cable model parameters for 24-AWG twisted pair cable".

European Annex B testing

Loop Attenuation which corresponds to the Insertion Loss is expressed in dB is calculated from RLCG parameters using two-port ABCD modeling methodology as specified in ANSI T1.417 Section B.3.1. The line constants for PE.04mm and TP100 cables are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.13. The line constants for TP150 cable are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.14.

For the loop simulator used in testing, the simulated loop attenuation is measured over the frequency band [f1, f2], given by table Table 1 for the different annexes. At least one measurement is made per fdelta interval. The Mean Error (ME) and Mean Absolute Error (MAE) of the measured simulated loop attenuation values (in dB), relative to the theoretical loop attenuation values (in dB), are calculated.

Table 1: Loop calibration frequency boundaries for VDSL2

Profile	Band Plan	f1 (kHz) over POTS	f1 (kHz) over ISDN	f1 (kHz) over TCM-ISDN	f2 (MHz)	Fdelta (kHz)
8a, b, c, d	998	24	120	640	8.520	12
	997	24	120	N/A	8.844	12
12a	998	20	120	640	12.000	20
	997	20	120	N/A	12.000	20
12b	998	120	120	N/A	12.000	20
	997	120	120	N/A	12.000	20
17a	998	120	120	640	17.670	30
	997	120	120	N/A	17.670	30
30a	998	150	250	640	30.000	50
	997	150	250	N/A	30.000	50

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The maximum amplitude A_{max} for use in estimating MAE and ME for the loop simulator is used from the frequency dependent table 2.

Table 2: Maximum amplitude for loop simulator calibration

Frequency (MHz)	Level dB
0.025	90 dB
1.104	90 dB
1.622	85 dB
3.750	82 dB
5.200	82 dB
7.500	80 dB
15.00	80 dB
15.05	70 dB
30.00	70 dB

Mean Absolute Error (MAE) and Mean Error (ME) for loop X are given by:

Formula 1: Determining MAE

$$\mathrm{MAE}_{\mathrm{LoopX}} = \frac{1}{N_i} \sum_{i \in \{A_{Ti} \le A_{\max j}\}} \left| A_{Ri} - A_{Ti} \right| + \frac{1}{N_j} \sum_{j \in \left\{ \substack{A_{Tj} > A_{MAXj} \\ A_{Rj} - A_{MAXj} < -0.5} \right\}} \left| A_{Rj} - A_{MAX_j} \right|$$

Formula 2: Calculating ME

$$\mathrm{ME}_{\mathrm{LoopX}} = \frac{1}{N_i} \sum_{i \in \{A_{Ti} \le A_{\max j}\}} \left(A_{Ri} - A_{Ti} \right) + \frac{1}{N_j} \sum_{j \in \left\{ \substack{A_{Tj} > A_{MAXj} \\ A_{Rj} - A_{MAXj} < -0.5} \right\}} \left(A_{Rj} - A_{MAX_j} \right)$$

[positive error = too much attenuation]

A_{Ri} = Attenuation sample, in dB, of the measured loop X
A_{Ti} = Attenuation sample, in dB, of the theoretical loop X

The index "i" belongs to a set defined by the points necessary to measure the attenuation in steps of fdelta or less and taking into account only those points between f1 and f2 for which $A_T <= A_{Max}$ dB .
Ni is the number of elements in the above set.
The index "j" belongs to a set defined by the points necessary to measure the attenuation in steps of fdelta or less and taking into account only those points between f1 and f2 for which $A_T > A_{Max}$ dB and $A_R - A_{Max} < -0.5$ dB
Nj is the number of elements in the above set.

Defined MAE requirement: The loop simulator is compensated by adjusting the loop length by minimizing the MAE to be less than 0.5 dB. This accuracy requirement is applicable for all test loops.

Noise floor of line simulators:

The noise floor of the wireline simulator is not impacting injected White Guassian Noise of - 140dBm/Hz.

1.2. Impedance

Input impedance for North American Annex A testing

Input Impedance shall be calculated from RLCG parameters using two-port ABCD modeling methodology as specified in [T1.417] Section B.3.1 (for both straight loops and loops with bridge taps).
The RLCG cable parameters are specified in [T1.417] Table B.2 "Cable model parameters for 26-AWG twisted pair cable" and Table B6 "Cable model parameters for 24-AWG twisted pair cable"

Input impedance for European Annex B testing

Input Impedance shall be calculated from RLCG parameters using two-port ABCD modeling methodology as specified in ANSI T1.417 Section B.3.1. The line constants for PE.04mm and TP100 cables are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.13. The line constants for TP150 cable are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.14.

The impedance compensation is based on a difference in injected noise power (captures the impact on the datarate).
The difference in injected noise power due to the variance of the input impedance of the wireline simulator has a mean absolute error (MAE) of less than 0.5 dB from the injected noise power using the theoretical input impedance, measured with the same appropriate termination impedance in each case.

The difference in injected noise power is calculated in dB according to Formula 3.

Formula 3 (VDSL2)

$$\Delta p_i = 10 \cdot \log_{10}(p_{out}^{sim}) - 10 \cdot \log_{10}(p_{out}^{loop})$$
$$= 10 \cdot \log_{10}\left(\left|\frac{Z_{in,sim}^{R}(f_i) \cdot Z_L(f_i)}{Z_{in,sim}^{R}(f_i) + Z_L(f_i)}\right|^2\right) - 10 \cdot \log_{10}\left(\left|\frac{Z_{in,loop}^{R}(f_i) \cdot Z_L(f_i)}{Z_{in,loop}^{R}(f_i) + Z_L(f_i)}\right|^2\right) \text{ dB}$$

where f_i are the frequency bins.

The mean absolute error is defined in Formula 4.

Formula 4 (VDSL2)

$$MAE(\Delta p) = \frac{1}{N_{bins}} \sum_i |\Delta p_i|$$

and the sum is over those bins in the passband where the insertion loss is less than 90 dB

1.3. Phase

North American Region

Phase is calculated from RLCG parameters using two-port ABCD modeling methodology as specified in [T1.417[6] Section B.3.1 (for both straight loops and loops with bridge taps). The RLCG cable parameters is specified in T1.417[6] Table B.2 "Cable model parameters for 26-AWG twisted pair cable" and Table B6 "Cable model parameters for 24-AWG twisted pair cable"

European Region:

‘Phase’ is calculated from RLCG parameters using two-port ABCD modeling methodology as specified in ANSI T1.417 Section B.3.1. The line constants for PE.04mm and TP100 cables are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.13. The line constants for TP150 cable are specified in Annex ZA.2 of ETSI TS 101 271 (2008 DRAFT) table ZA.14..

Mean Average Percentage Error for Phase delay shall be defined as in formula 5.

Formula 5 (VDSL2)

$$\mathrm{MAPE(PD)} = 100 \cdot \frac{1}{\mathrm{N}} \cdot \left[\sum_{\mathrm{N}} \left(\left| \frac{\mathrm{PD}_{\mathrm{cable}} - \mathrm{PD}_{\mathrm{sim}}}{\mathrm{PD}_{\mathrm{cable}}} \right| \right) \right]$$

where
Phase Delay(f) = unwrapped(phase(f))/ (2*pi*f)
f is the frequency
PDcable is the Phase delay for a theoretical loop, and
PDsim is the measured Phase delay for the simulator,
N is the number of frequencies used in the averaging.

Mean Average Percentage Error for Group Delay shall be defined as in formula 6.

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Formula 6 (VDSL2)

$$\mathrm{MAPE(GD)} = 100 \cdot \frac{1}{N} \cdot \left[\sum_{N} \left(\left| \frac{GD_{cable} - GD_{sim}}{GD_{cable}} \right| \right) \right]$$

where
GDcable is the Group delay for a theoretical loop
GDsim is the measured Group delay for the simulator,
N is the number of frequencies used in the averaging.

Points where $|GD_{cable}|$ is <= 0.1 microseconds is not included in the sum and N shall be adjusted accordingly.

The maximum MAPE(PD) is 7%
The maximum MAPE(GD) is 7%

The measurement of the PD and GD used above is made over a frequency range of fdelta see table 1 starting at the lowest used channel frequency for the PDs in question and ending at the frequency below which EITHER the insertion loss exceeds Amax OR the frequency is the highest used frequency, whichever comes first.

The Group delay is defined using the formula 7.

Formula 7 (VDSL2)

$$GD_i = \frac{phase_{i-1} - phase_{i+1}}{2 \cdot \pi \cdot \left(f_{i+1} - f_{i-1}\right)}$$

Where phase is the unwrapped phase in radians
the difference in frequency between f_{i+1} and f_i is fdelta as per table 1

2. Accuracy of Noise Generators

Each noise is measured independently at the VTU terminal. This is done for one noise source at a time, using a zero-length loop with For North American cases both VTUs are replaced by an 100 Ohm (±1%) resistor. For European cases the methodology in [TS101388] section 5.1.4.1 is used. The measured noise is impacted by the noise generator tolerance, the coupling circuit tolerance, cabling tolerance and noise pick-up.

For the noise source used in testing, the simulated noise level is measured over the frequency band [f1, f2], given by table 3 for the different annexes. At least one measurement is made per 10 kHz interval. The Mean Error (ME) and Mean Absolute Error (MAE) of the measured simulated noise level values (in dBm/Hz), relative to the theoretical noise level values (in dBm/Hz), is calculated. The noise calibration frequency ranges f1 and f2 for testing of the various VDSL2 profiles are identical to the frequencies specified for loop calibration for the same tests (see Table 1).

Mean Absolute Error (MAE) and Mean Error (ME) for noise X are given by:

Formula 8: Noise MAE calculation

$$\mathrm{MAE}_{\ \mathrm{noise\ X}} = \frac{1}{M} \sum_{i \in \left\{ P_{Ti} \geq -TBD\, dBm/Hz \right\}} \left| P_{Ri} - P_{Ti} \right|$$

Formula 9: Noise ME calculation

$$\mathrm{ME}_{\ \mathrm{noise\ X}} = \frac{1}{M} \sum_{i \in \left\{ P_{Ti} \geq -TBD\, dBm/Hz \right\}} \left(P_{Ri} - P_{Ti} \right)$$

Positive error indicates excessive noise power

P_{Ri} = power sample, in dBm/Hz, of the generated noise X
P_{Ti} = power sample, in dBm/Hz, of the theoretical noise X

The index “i” belongs to a set defined by the points necessary to measure the noise power in steps of TBD kHz or less and taking into account only those points for which

$P_{Ti} \geq$ -TBD dBm/Hz.
N is the number of elements in the above set.

The noise generator is compensated such that the absolute value of ME is minimized while maintaining <u>an MAE less than 0.5 dB.</u>

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Noise Impairment: *Cumulative Amplitude Distribution*

North American Region:

Noise impairments used in this specification for Annex A (North America) comply with the following specifications. The theoretical noise level has a Gaussian amplitude distribution to 5 sigma. For a normalized Gaussian distribution with mean μ and sigma σ formula 10 is applicable:

Formula 10

$$p(a_i) = \frac{1}{\sqrt{2\pi}} e^{-\frac{a_i^2}{2}} \qquad a_i = \frac{x_i - \mu}{\sigma}$$

and define the following limits

Formula 11

$$\Delta\sigma = 0.5 \qquad \beta = 10^{\frac{\Delta\sigma}{20}} \qquad \varepsilon = 0.1$$

$$\mathrm{ULimit}_{\,\mathrm{i}} = (1+\varepsilon)\left\{1 - erf\left(\frac{a_i}{\sqrt{2}}\right)\right\} \qquad a_i \le 4$$

$$\mathrm{ULimit}_{\,\mathrm{i}} = 10^{(0.802-1.24 \cdot a_i)} \qquad 4 \le a_i \le 4.68$$

$$\mathrm{ULimit}_{\,\mathrm{i}} = \left\{1 - erf\left(\frac{a_i}{\beta\sqrt{2}}\right)\right\} \qquad a_i > 4.68$$

$$\mathrm{LLimit}_{\,\mathrm{i}} = (1-\varepsilon)\left\{1 - erf\left(\frac{a_i}{\sqrt{2}}\right)\right\} \qquad a_i \le 5$$

$$= 0 \qquad a_i > 5$$

European Region:

Noise impairments used in this specification for Annex B (Europe) comply with the following specifications which are based on section ZA1.3.4.2 of the Draft ETSI TS 101 271.
The amplitude distribution function F(a) of noise voltage in time domain u(t) is the fraction of the time that the absolute value of u(t) exceed the value "a".
The amplitude distribution of noise shall comfply with the boundaries indicated in the following table:

Table 3:
Upper and lower boundaries of the noise amplitude distribution function

ndary (σ☐= rms value of noise)	Interval		Parameter	/alue
$_{ower}(a)=(1-\varepsilon)\cdot\{1-erf((a/\sigma)/\sqrt{2}\}$ $F_{lower}(a)=0$	$\leq a/\sigma < CF$ $F \leq a/\sigma < \infty$		rest Factor aussian Gap	CF=5 =0.1 =3.9
$_{pper}(a)=(1+\varepsilon)\cdot\{1-erf((a/\sigma)/\sqrt{2}\}$ $F_{upper}(a)= (1+\varepsilon)\cdot\{1-erf(A/\sqrt{2}\}$	$\leq a/\sigma < A$ $\leq a/\sigma < \infty$			

Note: noise generated according to the above specification is not suited to give reproducible results for margin verification relative to a reference BER lower than 10-7 or for systems using uncoded modulation (i.e. having no coding gain)

The meaning of the parameters in Table 3 is as follows:

CF denotes the minimum crest factor of the noise. Crest factor is defined as the ratio between the absolute peak value and rms value
ε denotes the Gaussian gap that indicates how closely the 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 practical repetition length.

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3. Interpretation of the Recommendations regarding the specifications of line simulators

The new generation of DSL technology goes beyond 50 MHz: that is a 5th order magnitude difference than the analogue voice band for which the cable infrastructure was meant. G.fast goes even beyond 100 MHz.

To translate this in electrical terms:

0,5 dB @ 300 kHz (the reference frequency for ADSL) is equivalent to 35 meters or about 100 feet for a 0,4 mm cable or 26 AWG T.417.

This is 1,5 dB @ 2,2 MHz (ADSL2) and 7 dB@35 Mhz (VDSL2) **!**

<u>In other words 0,5 dB@30 MHz is equivalent to 3 meters.</u>

The consequence of this statement is that tolerance margins of less than 1 dB over the entire spectrum of xDSL is possible only if the simulator can be programmed in steps of less than 5 meter. If not, it is practical impossible to even ‘adjust’ the simulator for compensation of variations in terms of attenuation -apart from the discussion what is happening with propagation delay and impedance. As a matter of fact the impedance variation of a cable is not a function of delay (phase) nor it is a function of attenuation! Varying the attenuation will not automatically adjust the impedance nor the delay in the right way since these parameters are directly linked to the line type, and should be considered as an independent secondary parameter of the R-L-C-G model.

4. Line Simulating technologies

The ITU-T specifications are a complicated matter for anyone who wants to test compliance of modems and DSLAM's to Standards. Nobody is calibrating test system in his lab. Only few will investigate if a test platform is compliant to the Standards - apart from a single attenuation check test which is only 1 of the 3 parameters that need to be verified (attenuation, impedance, delay).

This reality is known as a 'complex' and 'time-consuming' verification that only can be executed by real analog experts who understand how systems should be measured and who can interprete the test results.

This is the playing field of test equipment vendors who claim 'Standard compliant test platforms' while the technology that is used for simulating the physical layer is in no-way compliant to the ITU-standard. They speculate that only a small group of technology experts know what is meant with 'Standard compliance test platforms'.
It opens the door for test vendors who claim 'Standard verification' while in reality the proposed simulation test platform is not simulating a real cable as specified by ITU-T!

A good example is the use of low cost 'line attenuation technology' as an alternative for 'line simulation technology'.

A 'line attenuator' is only attenuating the signal and does not take any other parameter into account: the impedance of such attenuator is often 'flat' (not complex) as well as the phase of a cable (delay) is not implemented at all.

What is the consequence of using 'line-attenuators' in stead of line simulators?

When testing the performance of CPE and DSLAM (cfr. Recommendations TR-100, TR-67, TR-60, TR-114, ..) it is mandatory to simulate the characteristics of a real cable. The performance of a modem is determined by its ability to transform an analogue signal into digital data. The better a CPE can cope with the analog signals before it turns into a digital data-stream where data is recovered with sophisticated algorithms, the higher the performance potential of a modem.

Reflexions of transmission signals in the line such as unbalanced pairs, line disturbers, single ended lines bridge taps, bad termination of pairs or intermittent interruptions ... have a direct impact on the modem performance!

It is impossible to test a modem on these important and ever present line disturbers when the 'phase' effect of the cable is not present in the test platform - which is the case with a 'line attenuator' that is not simulating the phase characteristics of a real cable.

In that respect a line-attenuator is to be considered as a 'filter characteristic' rather than a 'real cable characteristic'. The outcome of testing with line attenuators is a theoretical data-rate performance that is not representative for the performance of the modem or DSLAM once deployed in the real network.

Certification on CPE's and DSLAM from respected vendors and Independent Test Labs *are always executed with test platforms equipped with line simulators*. It is not permitted to issue Certificates with test platforms based on line-attenuators.

Conclusion

A test platform based on 'Line attenuators' in stead of 'Line simulators' whereas line attenuators act as a 'frequency filter' that does not take into account the delay of lines and thus consequently not simulate the reflections of a real cable with a direct impact on injected noise, is only acceptable for interoperability and functionality compliance tests where such effects are less important. They can not be used for Performance Testing.

The new G.fast technology which is a time duplexing technology turns the technical minimum requirement of the presence of the delay even more stringent as G.fast performance can simply not be tested without delay.

A test platform can not be evaluated based on rate-reach bitstreams results!

Performance test results are the purpose of the test platform in order to test in an objective way the performance of the modems as they will perform on real cables. If one of the parameters of the cable is not simulated than the test results are not reliable and not correct. An attenuator is cheating on some vital effects of real cable and may 'pass' modems that will not work well on real cables in a deployed network which might cause a lot of problems for the equipment manufacturer of modems and DSLAM and the Telecom Operator as they think they have passed the tests while in reality the modems were not tested correctly.

That is the reason why nowadays the BBF is asking to mention in the test report the used test platform, the date of calibration and thus the guarantee that the pass/fail tests of modems and DSLAM's/DPU's are executed with 'compliant' test platforms.

When it comes to define performance of the DSL technology *'under different noise conditions'*, it is mandatory to use a fully implemented 'line simulator' that simulates attenuation, impedance and phase of a real cable, whatever cable is defined. (country specific cables or cable-types defined in the Standard).

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Test equipment vendors: market information

The market for testing DSL technology is split in 3 submarkets:

1. The *'laboratory grade testing'*: engineers will use 'Performance test platforms' based on fully implemented line-simulators for testing the performance chipsets, DSLAM's, CPE's ... in different shapes like symmetric and asymmetric DSL, Bonded DSL, retransmission schemes, Vectoring DSL with different disturbers like FB noises, REIN, PEIN, SHINE, A-B (tip-ring) micro-interrupts, RFI-noises ... They might also use more cost-effective 'line-attenuators' when tests are not performance related, like interoperability tests and software tests.

2. The *'functionality testing'*: these engineers and technicians are not testing performance of DSL technology. They basically are running regression tests to test CPE's and DSLAM's on their backwards compatibility with legacy products. The tests where a line is required can be executed with Line-attenuators as well as with Line-simulators.

3. The *'production-grade testing'* is a matter of qualification of CPE's and DSLAM ports in production. Tests requirements are about multi-channel testing in order to run as many tests in shortest time possible. Such application does not require line-simulators. Simple line-attenuators with longer step-sizes will perfectly address the testing requirements.

There are 3 test equipment vendors worldwide who make products for one of these markets as shown in the table 4.

Table 4:
Test Equipment vendors for different DSL technologies

Spirent communication	**Lab-grade test platforms**	**Functionality test platform**	**Production-grade test platform**
Type of test	Performance	Functional	Production
Line Simulator	Yes	-	-
Line Attenuator	-	Yes	Yes
Step size	10 meter	25 meter	100 meter
Line Type	Fixed (Standards)	Fixed	Fixed
Certification	Yes	Yes	-
Automated Scripts	No	No	No

Sparnex Instruments	**Lab-grade test platforms**	**Functionality test platform**	**Production-grade test platform**
Type of test	Performance	Functional	Production
Line Simulator	Yes	Yes	-
Line Attenuator	-	Yes	Yes
Step size	1 meter	50 meter	50 meter
Line type	Programmable Several line types	0,4 mm, 0,5 mm 24AWG - 26AWG	0,4 mm - 26 AWG
Certification	Yes	Yes	-
Automated Scripts	Yes	Yes	Yes

Telebyte	Lab-grade test-platform	Functionality test-platform	Production-grade test-platform
Type of test	Performance	Functional	Production
Line Simulator	-	-	-
Line Attenuator	-	Yes	Yes
Step Size	-	10 meter	25 meter
Line type	-	Multiple	Multiple
Certification	No	Yes	-
Automated Scripts	-	Yes	Yes

It classifies Spirent Communication and Sparnex Instruments as the two vendors used for Certification of CPE's and DSLAM's in terms of performance and functionality tests according Standards. Sparnex Instruments has an automated Certification platform that can do all DSL flavors in one system whereas Spirent Communication is focusing on Line Simulators and Noise Generators with different hardware systems per DSL Standard.
Telebyte can be used for Certification of TR-105 and TR-115 and all other non-performance related test cases of TR-100 and TR-114.
Telebyte can be used for 95 % of the non-performance related '*interoperability*' that are mostly 'functional and software test' related.
Telebyte can not be used for all 'performance related tests' like in TR-100 and TR-114, ID-337, Vectoring performance tests, ...

Noise Generators

There are many arbitrary noise generators in the market. If they match the accuracy requirement of the BBF, they can be used.

In DSL market, only Spirent, Sparnex Instruments and Telebyte have compliant noise generators as of the specific request to use baluns for high-impedance noise injection @ 100 Ohm in stead of classic unbalanced 50 Ohm output of general purpose noise generators.

The trend in DSL is going towards more and more complicated noise generation files and noise test scenario's as of the more complicated transmission technologies, the fact that new transmission has to cope with the legacy network deployment, and the many new features to increase speed and improve stability.

Even the most complex well calibrated and accurate noise generator is *of only reduced importance* if the noise generator is connected to a wire-line simulator that is not simulating the reflections and delay as present with real cable networks.
Tests with noises - apart from flat AWG noise - are only correct when used with full-blown line simulators that simulate all parameters of a real cable.

Micro-interrupts, other impairments ..

The reason for micro-interrupt tests is exactly to simulate the reflections present in real cable networks and the capability of modems to recover fast synchronisation or even should keep showtime. Interruptions with attenuators have a reduced effect and only interrupt the data-stream. The reflections and associated delay are not simulated with attenuators.