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SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

Single-ended line testing for digital subscriber lines (DSL)

Recommendation ITU-T G.996.2

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Recommendation ITU-T G.996.2

Single-ended line testing for digital subscriber lines (DSL)

Summary

Recommendation ITU-T G.996.2 specifies line testing for xDSL transceivers in the form of single-ended line testing (SELT), dual-ended line testing (DELT) and metallic line testing (MELT).

Source

Recommendation ITU-T G.996.2 was approved on 22 May 2009 by ITU-T Study Group 15 (2009-2012) under Recommendation ITU-T A.8 procedures.

FOREWORD

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Recommendation ITU-T G.996.2

Single-ended line testing for digital subscriber lines (DSL)

1 Scope

This Recommendation specifies line testing for use on xDSL lines. This Recommendation contains annexes that describe specifications for single-ended line testing (SELT), dual-ended line testing (DELT) and metallic line testing (MELT). Separate annexes describe physical medium dependent (PMD) and processing functions for SELT, DELT and MELT. An informative appendix is also included describing SELT application models. In this Recommendation, one or more of the line testing (LT) functional blocks may, but are not required to, be the same as the xDSL transceiver unit (xTU) functional block.

2 References

This Recommendation does not contain any references to external documents.

3 Definitions

None.

4 Abbreviations

This Recommendation uses the following abbreviations:

ACS	Automatic Configuration System
ADC	Analogue-to-Digital Conversion
AFE	Analogue Front End
AGC	Automatic Gain Control
CO	Central Office
CPE	Customer Premises Equipment
DELT	Dual-Ended Line Test
DSLAM	DSL Access Multiplexer
DSP-FE	Digital Signal Processor – Front End
HPF	High-Pass Filter
LPF	Low-Pass Filter
LT	Line Test
ME	Management Entity
MELT	Metallic Line Test
MIB	Management Information Base
NSC	Number of SubCarriers
OSS	Operations Support System
PGA	Programmable Gain Amplifier
PMD	Physical Medium Dependent



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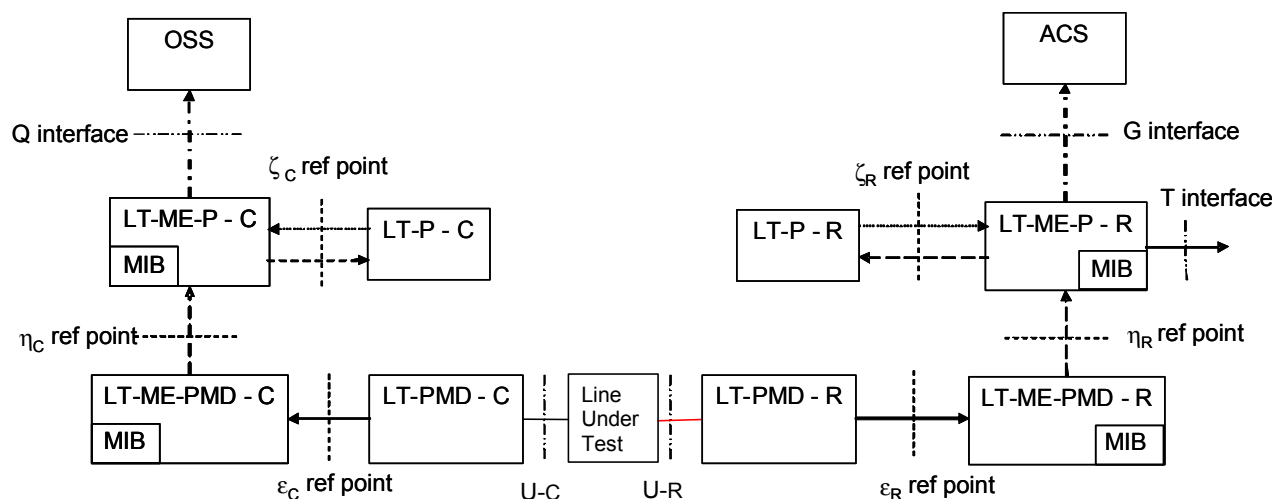
POTS	Plain Old Telephone Service
PSD	Power Spectral Density
QLN	Quiet Line Noise
Rx	Receive
SELT	Single-Ended Line Testing
Tx	Transmit
UER	Uncalibrated Echo Response
xDSL	Any DSL
xTU-C xDSL	Transceiver Unit at the Central side
xTU-R xDSL	Transceiver Unit at the Remote side (e.g., subscriber at the end of the loop)

5 Overview

Line testing involves the measurement of electrical signals on a line, with or without a stimulus applied to the near end or the far end of the loop. These measurements are used to determine measurement parameters which are the basic parameters that characterize the loop and its noise environment. Derived parameters are derived from the measurement parameters and provide specific features of the loop and the noise environment.

5.1 Line test reference model

In order to produce the parameters to be delivered to the management system from observations of the loop connected at one termination side to the U-C interface and at the other side to the U-R interface, a number of distinctive functions can be identified. Each of these functions is represented by a functional block (rectangle) in the functional reference model. Reference points are introduced into the model. Some reference points correspond to functional interfaces. Figure 5-1 depicts the functional reference model.



NOTE – Arrows show flow of data elements only; flow of control elements are bidirectional (not shown)

Figure 5-1 – Functional reference model

There are four functional blocks at each end of a line. The following general descriptions of the functionality of each block apply at both ends of the line but the detail of their functionality may be different at each end.

The first functional block is called the LT-PMD (line test – Physical medium dependent). The LT-PMD function performs measurements on the physical medium to which the line test device is connected. The result of a measurement is a quantity represented as a parameter (one or more dimensional, discrete or continuous). From these parameters, measurement parameters are derived, usually through multiple measurements.

The fact that the functional block is connected to the physical medium motivates calling it "PMD". The prefix LT indicates that this functional block is specific to line testing. However, in some instantiations, this may be the same as, or nearly the same as, instantiations of an xTU-PMD functional block.

The second functional block is called the LT-P (LT – Processing). The LT-P function transforms the measurement parameters into derived parameters. These derived parameters directly reflect the characteristics of the loop under test.

The third functional block is denoted LT-ME-P (LT – Management entity – P) and has the following functionalities:

- a) Data plane:
 - to provide an interface point to the OSS, ACS or user for access to both derived and measurement parameters across the Q, G or T interfaces, respectively;
 - to access the measurement parameters in the LT-ME-PMD across the η reference point.
- b) Management plane:
 - to manage the LT-P-MIB;
 - to control the functionality of the LT-P across the ζ reference point;
 - to communicate with the far end LT-ME-P across the U interface to coordinate testing and exchange derived and measurement parameters.

The fourth functional block is denoted LT-ME-PMD (LT – Management entity – PMD) and has the following functionalities:

- a) Data-plane:
 - to provide to the LT-ME-P access to measurement parameters.
- b) Management plane:
 - to manage the LT-PMD-MIB;
 - to control the measurements performed by the LT-PMD across the ε reference point.

The term "LT" in the line test reference model refers to all forms of line test (i.e., SELT, DELT and MELT). In Annexes A and B, which contain SELT requirements, the term "SELT" is used in place of the term "LT". In Annexes C and D, which contain DELT requirements, the term "DELT" is used in place of the term "LT". In Annexes E and F, which contain MELT requirements, the term "MELT" is used in place of the term "LT".

5.2 Test measurements

The test measurements are fundamental electrical measurements. Three types of measurements can be distinguished:

- 1) Measurements at the near end that are associated with an excitation of the physical medium from the PMD block at the near end.
- 2) Measurements at the near end that are associated with an excitation of the physical medium from the PMD block at the far end.
- 3) Measurements that do not require any excitation.

A sequence of measurements of the first two measurement types is defined as the measurements associated with a sequence of corresponding excitations. For the third measurement type, the PMD blocks at either end shall not inject any signal on to the line.

6 Test management and communications

Test management and communications are for further study.

Annex A

Specific requirements of a SELT-PMD

(This annex forms an integral part of this Recommendation)

A.1 SELT-PMD functions

A.1.1 SELT-PMD measurement functions

A.1.1.1 Measurement of uncalibrated echo response

The uncalibrated echo response function $UER(f)$ is defined as the estimated mean value of the voltage ratio $V(f)/E(f)$ measured inside the SELT-PMD.

$$UER(f) = Estimated\_Mean(X(f)) \quad \text{with} \quad X(f) = \left(\frac{V(f)}{E(f)} \right)$$

where $E(f)$ is the excitation signal and $V(f)$ the measured signal at frequency f .

$E(f)$ is the voltage of a 0 ohm voltage source applied to the SELT-PMD transmitter front end, which transmits a voltage waveform $V1+$ on the SELT-PMD U-interface. The U-interface is connected to the one-port network (line) under test, that will generate a reflected voltage wave $V1-$. A linear combination of the voltage waveform $V1+$ and the reflected voltage wave $V1-$ is transformed by the SELT-PMD receiver front end into a voltage $V(f)$ measured with a high impedance voltage measurement unit.

The schematic representation of the SELT-PMD unit is shown in Figure A.1.

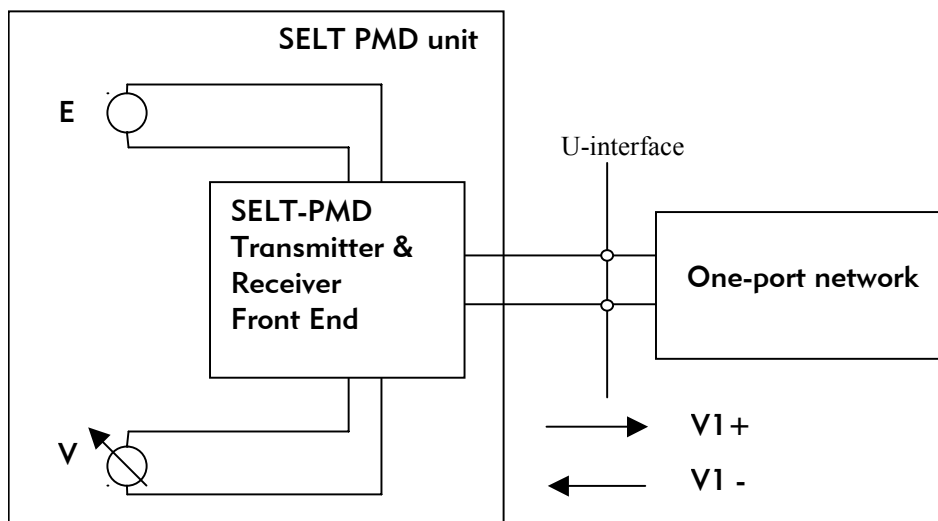


Figure A.1 – SELT-PMD during measurement of "uncalibrated echo response"

The transmit and receive parts of the front end includes all signal conditioning and processing until the U interface (linear time invariant networks, DSP-FE, amplifiers, filters, hybrid, POTS splitters, relays, connectors, protection circuitry, etc.). The SELT-PMD transmitter and receiver front end as a black box shall behave equivalently to a linear time invariant network. As a consequence, the $UER(f)$ shall be independent of the analogue and digital gains used to perform the measurement. However, the $UER(f)$ is the echo response measured without compensation of the time invariant effects of TX and RX AFE linear distortion.

The measurement and estimation duration shall be limited according to the configured SELT UER maximum measurement duration (see clause A.2.1.1). The actual physical line data acquisition time shall increase when the SELT UER maximum measurement duration is increased. This increase may have a step-wise character.

NOTE 1 – SELT-PMD units usually have some freedom when configuring their front ends. However, because calibration arrays are often computed and stored outside of the SELT-PMD, the response of the SELT-PMD should be consistent over time in order for the calibration arrays to be valid. Therefore, it is recommended that the SELT-PMD use the same analogue and digital front-end configurations for all data collection.

NOTE 2 – The requirement that the SELT-PMD transmitter and receiver front end (as a black box) shall behave equivalently to a linear time invariant network may be realized by using fixed settings for the transmit front end and for the receive front end. Alternatively, inside the black box, an implementation may use time/channel dependent analogue gains in the transmitter and/or receiver. It should be noted that in this case it is the responsibility of the UER PMD implementation to compensate these analogue gains in such a way that the external characteristics of the black box are made equivalent to a linear time invariant network to satisfy the accuracy requirements. Digital scaling is inherently linear (except for increased quantization noise). Analogue gain scaling could introduce tolerances and frequency-dependent behaviour that depends on the analogue gain (e.g., gain of the transmit power amplifier, gain of the receive programmable-gain amplifiers (PGAs)). Transmit power amplifiers and receive path PGAs should be set so as to maximize the UER accuracy without incurring into significant non-linear distortion.

NOTE 3 – The SELT-PMD unit should select settings that minimize the attenuation and dispersion through its analogue and digital front ends. Any filters (e.g., high-pass, low-pass, band-pass, notch, and compensation filters) in either the transmit or receive path, that cause the response to deviate from a linear-phase all-pass characteristic, should be disabled if possible.

NOTE 4 – Digital echo cancellers should be turned off. Analogue echo cancellers should not be allowed to adapt during data collection because adaptation invalidates port calibrations and might cancel the desired echo.

A.1.1.2 Measurement of SELT quiet line noise

The quiet line noise SELTQLN(f) is the power spectral density (PSD), referred to a 100 ohm impedance, of the noise present on the line at frequency f when no near-end and far-end transmit signals are present on the line.

The quiet line SELTQLN(f) per sub-carrier shall be measured by the near-end receive PMD function.

The measured SELTQLN(f) shall reflect the actual PSD at the near-end U-interface related with the receive PMD. This means that the receive PMD function shall compensate for any used amplifier gains in the receiver and shall perform a best effort attempt to remove any impact of the near-end receiver filter characteristics.

The quiet line noise SELTQLN(f) shall be measured over a time interval complying to the configured SELT quiet line noise maximum measurement duration (see clause A.2.1.2). The actual physical line data acquisition time shall increase when the SELT QLN maximum measurement duration is increased. This increase may have a step-wise character.

Accuracy of SELT quiet line noise is for further study.

A.1.1.3 Measurement of impulse noise

Measurement of impulse noise is for further study.

A.1.1.4 Estimation of uncalibrated echo response variance

Noise during the measurement process of the echo response can lead to variation of the reported parameter UER(f). The uncalibrated echo response variance characterizes this variation.

NOTE – The variance parameter can be used to estimate the precision of UER(f).

To define the uncalibrated echo response variance, the echo measurement is considered to be a random process $X(f)$ with expected value or mean value $UER(f)$ as defined in clause A.1.1.1. The quantity $UER(f)$ is derived using a vendor discretionary algorithm.

$UER(f)$ can also be written as:

$$UER(f) = E[X(f)] \quad \text{where } E[\] \text{ is the mathematical expectation operator.}$$

The variation of UER is characterized by the relative variance of the uncalibrated echo response $REL\_VAR\_UER(f)$ defined by:

$$REL\_VAR\_UER(f) = 10 \log_{10} \left(\frac{VAR\_UER(f)}{|UER(f)|^2} \right)$$

where $VAR\_UER(f)$ is defined as

$$VAR\_UER(f) = E[|X(f) - UER(f)|^2] = E[|X(f) - E[X(f)]|^2]$$

and $|x|$ denotes the absolute value of a complex valued number x .

The above definition of $REL\_VAR\_UER(f)$ is an exact definition. The SELT-PMD entity shall report an estimate of this $REL\_VAR\_UER(f)$. The exact algorithm to estimate the value of $VAR\_UER(f)$ estimation process is vendor discretionary.

The estimation of the uncalibrated echo response variance shall be performed within the same time period as the measurement of the uncalibrated echo response (see clause A.1.1.1).

A.2 SELT-PMD management entity

A.2.1 SELT-PMD configuration parameters

A.2.1.1 SELT UER maximum measurement duration

This parameter is the maximum allowed time for SELT uncalibrated echo response measurement, between the time of the start command written by the SELT-PMD-ME, and the time the result is available for read operation by SELT-PMD-ME.

NOTE – The above duration includes internal pre- and post-processing.

It is configurable between 5 seconds and 240 seconds, in steps of 1 second.

A.2.1.2 SELT quiet line noise maximum measurement duration

This parameter is the maximum allowed time for SELT quiet line noise measurement, between the time of the start command written by the SELT-PMD-ME, and the time the result is available for read operation by SELT-PMD-ME.

NOTE – The above duration includes internal pre- and post-processing.

It is configurable between 1 second and 240 seconds, in steps of 1 second.

A.2.2 SELT-PMD measurement parameters

A.2.2.1 SELT uncalibrated echo response

The uncalibrated echo response, $UER(i * UER\_G * Df)$, shall be represented in linear format by a scale factor and a normalized complex number $a(i) + j * b(i)$, where i is a frequency index i ranging from 0 to $NSC - 1$, the subcarrier spacing, $Df = 4.3125$ kHz, and $(NSC - 1) \times UER\_G \times Df$ is the highest frequency supported by the SELT-PMD functionality. The UER granularity parameter, UER_G , has two valid values: 1 and 2, indicating whether the measurements were performed using a tone spacing of 4.3125 kHz or of 8.625 kHz. If the uncalibrated echo response is being reported

over a frequency range of 17.664 MHz or lower, UER_G shall be set to 1. If the uncalibrated echo response is being reported over a frequency range that is greater than 17.664 MHz, UER_G shall be set to 2.

The scale factor shall be coded as a 32-bit unsigned integer. Both $a(i)$ and $b(i)$ shall be coded as 32-bit 2's complement signed integers. The value of $UER(i \times UER\_G \times Df)$ shall be defined as: $UER(i \times UER\_G \times Df) = (scale/2^{31}) \times (a(i) + j \times b(i))/2^{31}$. In order to maximize precision, the scale factor shall be chosen such that $\max(|a(i)|, |b(i)|)$ over all i is equal to $2^{31}-1$.

NOTE – This data format supports an $UER(f)$ granularity of 2^{-31} and an $UER(f)$ dynamic range of approximately +6 dB to –186 dB, however it does not imply any future accuracy requirements.

An $UER(i \times UER\_G \times Df)$ value indicated as $a(i) = b(i) = -2^{31}$ is a special value. It indicates that no measurement could be done for this subcarrier either because it is not supported by the SELT-PMD function, or that the value is out of range to be represented.

A.2.2.2 SELT variance of uncalibrated echo response

The $REL\_VAR\_UER(f)$ provides the relative variance of the uncalibrated echo response by the SELT-PMD function for each frequency $i \times UER\_G \times Df$, where i ranges from 0 to $NSC-1$, $Df = 4.3125$ kHz, and $(NSC-1) \times UER\_G \times Df$ is the highest frequency supported by the SELT-PMD functionality.

The relative variance of the uncalibrated echo response $REL\_VAR\_UER(i \times UER\_G \times Df)$ shall be represented as an 8-bit unsigned integer $v(i)$, where i is the subcarrier index $i = 0$ to $NSC-1$. The value of $REL\_VAR\_UER(i \times UER\_G \times Df)$ shall be defined as $REL\_VAR\_UER(i \times UER\_G \times Df) = 3 - v(i)/2$ dB. The number $v(i)$ is an 8-bit unsigned integer in the range 0 to 254. This data format supports a $REL\_VAR\_UER(i)$ over a range from –124 dB to +3 dB for each carrier with a granularity from 0.5 dB. Out of range values shall be clamped to the closest range bound. The special value $v(i) = 255$ indicates that no measurement is available for that carrier.

A.2.2.3 SELT quiet line noise

The SELT quiet line noise provides the quiet line noise PSD as measured by the SELT-PMD function (see clause A.1.1.2) for each sub-carrier frequency $i \times SELTQLN\_G \times Df$ where i ranges from 0 to $NSC-1$, $Df = 4.3125$ kHz, and $(NSC-1) \times SELTQLN\_G \times Df$ is the highest frequency supported by the SELT-PMD functionality. $SELTQLN\_G$ has two valid values: 1 and 2, indicating whether the measurements were performed using a tone spacing of 4.3125 kHz or of 8.625 kHz. If the SELT quiet line noise is being reported over a frequency range of 17.664 MHz or lower, $SELTQLN\_G$ shall be set to 1. If the SELT quiet line noise is being reported over a frequency range that is greater than 17.664 MHz, $SELTQLN\_G$ shall be set to 2.

SELT quiet line noise $SELTQLN(i \times SELTQLN\_G \times Df)$ shall be represented as an 8-bit unsigned integer $n(i)$, where i is the subcarrier index $i = 0$ to $NSC-1$. The value of $SELTQLN(i \times SELTQLN\_G \times Df)$ shall be defined as $SELTQLN(i \times SELTQLN\_G \times Df) = -23 - (n(i)/2)$ dBm/Hz. This data format supports a $SELTQLN(f)$ granularity of 0.5 dB and an $SELTQLN(f)$ dynamic range of –150 to –23 dBm/Hz.

A.2.2.4 SELT impulse noise parameters

Impulse noise parameters are for further study.

A.2.3 SELT control parameters

A.2.3.1 SELT UER measurement enable C (SELT-UME-C)

This parameter is a binary variable, where "1" triggers the CO SELT PMD to start a UER measurement.