TECHNICAL REPORT

TR-347
CPE SELT Calibration

Issue 1
Issue Date: June 2018

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Issue History

Issue Number	Approval Date	Publication Date	Issue Editor	Changes
1	13 June 2018	1 July 2018	Ken Kerpez, ASSIA	Issue 1

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Executive Summary

This Technical Report gives a brief overview of a method for calibrating CPE SELT based on multiple measurements of the Uncalibrated Echo Response (UER).

1 Purpose and Scope

1.1 Purpose

Single-End Line Testing (SELT) defined in ITU-T Recommendation G.996.2 [1] can help diagnose the underlying copper transmission properties of digital subscriber lines for connectivity, faults, and performance. This Recommendation defines the physical medium dependent measurement parameters and functions for additional processing of collected measurement data. SELT provides echo response measurements indicating the transmission channel, as well as noise measurements, that builds a foundation for loop make-up indication, including bridge tap length and location particularly near the customer end.

It is noted that ITU-T Recommendation G.996.2 [1] does not define requirements for SELT management. If supported at a CPE, the Broadband Forum's TR-356 [3] alternate management path for broadband can be used in conjunction with SELT diagnostics.

1.2 Scope

This Technical Report gives a brief overview of a method for calibrating CPE SELT based on multiple measurements of the Uncalibrated Echo Response (UER).

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [2].

SHALL	This word, or the term “REQUIRED”, means that the definition is an absolute requirement of the specification.
SHALL NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term “RECOMMENDED”, means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term “OPTIONAL”, means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 Normative References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.
A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document	Title	Source	Year
[1] G.996.2 Amd 5	*Single-ended line testing for digital subscriber lines (DSL)*	ITU-T	2017
[2] RFC 2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997

2.3 Informative References

Document		Title	Source	Year
[3]	TR-356	*Alternate Management Path for Broadband*	BBF	2016

2.4 Abbreviations

This Technical Report uses the following abbreviations:

AFE	Analog Front End
CPE	Customer Premises Equipment
DSL	Digital Subscriber Line
PMD	Physical Medium Dependent
SELT	Single-Ended Line Test
SELT-P	SELT-Processing
SELT-PMD	SELT- Physical Medium Dependent
UER	Uncalibrated Echo Response

3 Technical Report Impact

3.1 Energy Efficiency

TR-347 has no impact on energy efficiency.

3.2 Security

TR-347 has no impact on security.

3.3 Privacy

Any issues regarding privacy are not affected by TR-347.

4 Introduction

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 or processed parameters are derived from the measurement parameters and provide specific features of the loop and the noise environment.

ITU-T G.996.2 [1] defines Single-Ended Line Testing (SELT) for digital subscriber lines, with parameters and reporting formats defined at both the network end and the CPE end of a line. SELT can be performed by the CPE on a line that is not yet provisioned, or is inoperable. CPE side SELT diagnostics can facilitate customer self-install, troubleshooting of installation in general, and lower the number of truck rolls for connectivity problems. SELT- PMD (Physical Medium Dependent) measurements includes among other parameters, the Uncalibrated Echo Response (UER). The CPE echo response can be processed to indicate loop make-up, including bridge tap length and location particularly near the customer end.

This Technical Report describes a procedure showing how multiple measurements of the SELT UER can be used to convert SELT UER into calibrated values.

5 Calibrating CPE SELT based on multiple measurements of Uncalibrated Echo Response (UER)

ITU-T G.996.2 [1] defines the Uncalibrated Echo Response (UER) object; this is a reported parameter by the SELT-PMD. For the SELT-P functional block to process the UER data, it needs to have calibration data to remove the effects of the analog front end (AFE) and accommodate differences in line impedance. Per the reference model in ITU-T G.996.2 [1], it is inferred that this calibration data is made available to the SELT-P functional block to enable processing of the received UER data to obtain the SELT-P derived parameters. The way of making calibration data available and use of it are SELT-vendor discretionary.

This section presents one way of calibrating CPE SELT based on several measurements of the SELT-PMD Uncalibrated Echo Response (SELT-UER-R in [1]).

Figure 1 shows the reference model for SELT measurements and data processing, based on which a method for CPE SELT calibration is described.

The SELT-PMD block performs measurement of the Uncalibrated Echo Response UER(f). The measured UER is forwarded to a SELT-P block for processing and computation of all derived parameters. The SELT-P block is expected to remove the effects of the analog front-end circuit in the SELT-PMD measurement device. The reference SELT-PMD unit defined in ITU-T G.996.2 [1] assumes that the SELT-P block has calibration data provided to the SELT-PMD in a vendor discretionary manner.

It is noted that no objects and corresponding file formats, as well as SELT-PMD management, are defined in ITU-T G.996.2 [1] for the CPE SELT calibration.

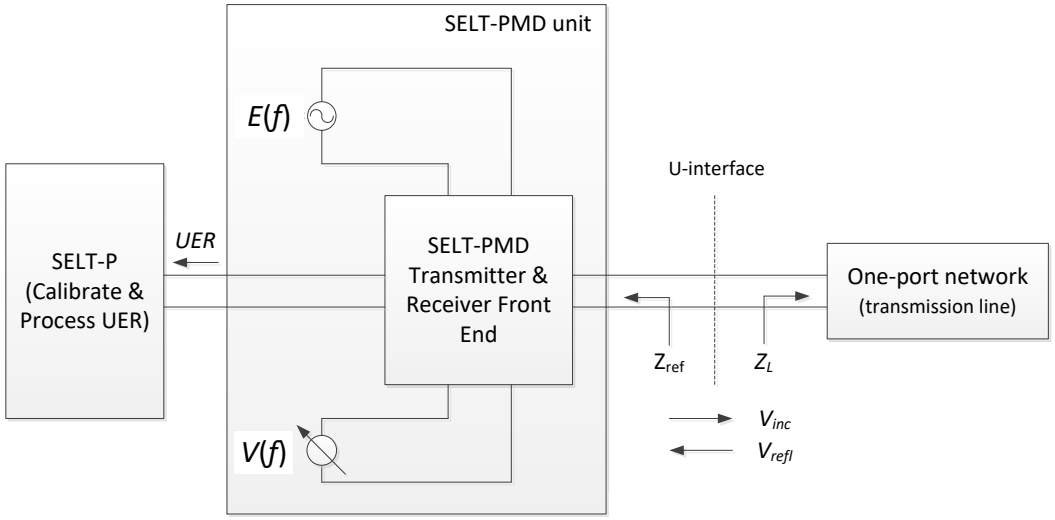

Figure 1: SELT Reference Model for calibrating CPE SELT

5.1 CPE-SELT calibration data objects

The following CPE-SELT calibration data objects are used in this document for computation of the calibrated echo response (CER(*f*)):

- $UER_{R1}(f)$: UER(*f*) with the U-interface terminated in a resistance *R*1
- $UER_{R2}(f)$: UER(*f*) with the U-interface terminated in a resistance *R*2
- $UER_{R3}(f)$: UER(*f*) with the U-interface terminated in a resistance *R*3
- *R1*: Resistance of value R1
- *R2*: Resistance of value R2
- *R3*: Resistance of value R3

All of the above *UER* data objects are complex-valued functions of frequency.

All of the above *R* data objects are real values independent of frequency.

The following are to be used for the values of resistances *R*1, *R*2, and *R*3:

- R1: reference impedance Z_{ref} of 100Ω, purely resistive
- R2: open circuit
- R3: short circuit, or very low resistance

The above *UER* data objects could be obtained by performing SELT-PMD UER measurements with the appropriate termination. The measurements could be done on a reference design, production sample, or on-site equipment.

5.2 Computation of the CER

The method of calibrating UER is now shown; this uses the CPE-SELT calibration data objects defined in the previous section. The example calculates the S_{11} parameter based on measurements of the Uncalibrated Echo Response. The calibrated S_{11} parameter could be further used by SELT-P to compute some of the derived parameters (e.g., loop topology) listed in ITU-T G.996.2 [1].

The parameter that characterizes the one-port network (transmission line) is the S_{11} scattering parameter, which measures the input reflection coefficient. The SELT-PMD measures the Uncalibrated Echo Response UER(f) as the ratio of the estimated mean value of the voltage ratio *V(f)*/E*(f),* where *E(f)* is the vendor discretionary excitation signal and *V(f)* is the measured signal at frequency *f*.

The method uses following impedances to generate calibration data:

- R1: reference impedance Zref of 100 Ohms purely resistive
- R2: open circuit
- R3: short circuit, or very low resistance

The S_{11} parameter of the line under test can be written as a function of the measured UER(f), namely

$$S_{11}(f)\big|_{Zref} = \frac{C1(f) + UER(f)}{C2(f) + C3(f) \cdot UER(f)} \tag{1}$$

where $S_{11}(f)\big|_{Zref}$ is the one port scattering parameter of the one-port network in reference impedance (Z_{ref}) and *C*1(*f*), *C*2(*f*) and *C*3(*f*) are coefficient values as a function of frequency derived from the calibration data described in the previous section. One can determine *C*1(*f*), *C*2(*f*), and *C*3(*f*) from the set of three calibration data mentioned above as follows:

$$\begin{aligned} C1 &= -UER_{R1}(f) \\ C2 &= \frac{\left(2 \times UER_{R2}(f) \times UER_{R3}(f) - UER_{R1}(f) \times \left(UER_{R2}(f) + UER_{R3}(f)\right)\right)}{\left(UER_{R3}(f) - UER_{R2}(f)\right)} \\ C3 &= \frac{\left(UER_{R2}(f) + UER_{R3}(f) - 2 \times UER_{R1}(f)\right)}{\left(UER_{R2}(f) - UER_{R3}(f)\right)} \end{aligned} \tag{2}$$

Based on *C*1, *C*2, and *C*3 and the measurement of UER for the one-port network at each measurement frequency, one can calculate the calibrated S_{11} values for this load by using equation (1), namely

$$S_{11}(f)\big|_{Zref} = \frac{C1(f) + UER(f)}{C2(f) + C3(f) \cdot UER(f)}.$$

And $S_{11}(f)$ = CER(*f*).

End of Broadband Forum Technical Report TR-347