IEC 61746-2

Edition 1.0 2010-06

INTERNATIONAL STANDARD

Calibration of optical time-domain reflectometers (OTDR) –
Part 2: OTDR for multimode fibres

IEC 61746-2:2010(E)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **X**

ICS 33.180.01

ISBN 978-2-88912-026-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALIBRATION OF OPTICAL TIME-DOMAIN REFLECTOMETERS (OTDR) –

Part 2: OTDR for multimode fibres

FOREWORD

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International Standard IEC 61746-2 has been prepared by IEC technical committee 86: Fibre optics.

The text of this standard is based on the following documents:

CDV	Report on voting
86/336/CDV	86/359/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of IEC 61746 series, under the general title *Calibration of optical time-domain reflectometers (OTDR)*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

In order for an optical time-domain reflectometer (OTDR) to qualify as a candidate for complete calibration using this standard, it must be equipped with the following minimum feature set:

a) the ability to measure type A1a or A1b IEC 60793-2-10 fibres;

b) a programmable index of refraction, or equivalent parameter;

c) the ability to present a display of a trace representation, with a logarithmic power scale and a linear distance scale;

d) two markers/cursors, which display the loss and distance between any two points on a trace display;

e) the ability to measure absolute distance (location) from the OTDR's zero-distance reference;

f) the ability to measure the displayed power level relative to a reference level (for example, the clipping level).

Calibration methods described in this standard may look similar to those provided in Part 1 of this series. However, there are differences: mix of different fibre types, use of mode conditioner or different arrangement of the fibres. This leads to different calibration processes as well as different uncertainties analysis.

CALIBRATION OF OPTICAL TIME-DOMAIN REFLECTOMETERS (OTDR) –

Part 2: OTDR for multimode fibres

1 Scope

This part of IEC 61746 provides procedures for calibrating multimode optical time domain reflectometers (OTDR). It covers OTDR measurement errors and uncertainties. The test of the laser(s) source modal condition is included as an optional measurement.

This standard does not cover correction of the OTDR response.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-2-10, *Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres*

IEC 60793-2-50, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 61280-1-4, *Fibre optic communication subsystem test procedures – Part 1-4: General communication subsystems – Light source encircled flux measurement method*

IEC 61280-4-1, *Fibre optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement*

IEC 61745, *End-face image analysis procedure for the calibration of optical fibre geometry test sets*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions and symbols

For the purposes of this document, the following terms, definitions and symbols apply.

NOTE For more precise definitions, the references to IEC 60050-731 should be consulted.

3.1
attenuation
A
loss

optical power decrease in decibels (dB)

NOTE If P_{in} (watts) is the power entering one end of a segment of fibre and P_{out} (watts) is the power leaving the other end, then the attenuation of the segment is

$$A = 10\log_{10}\left(\frac{P_{in}}{P_{out}}\right) \text{ dB} \quad (1)$$

[IEV 731-01-48, modified]

3.2
attenuation coefficient
α
attenuation (3.1) of a fibre per unit length

[IEV 731-03-42, modified]

3.3
attenuation dead zone
for a reflective or attenuating event, the region after the event where the displayed trace deviates from the undisturbed backscatter trace by more than a given vertical distance ΔF

NOTE The attenuation dead zone (see Figure 1 below) will depend on the following event parameters: reflectance, loss, displayed power level and location. It may also depend on any fibre optic component in front of the event.

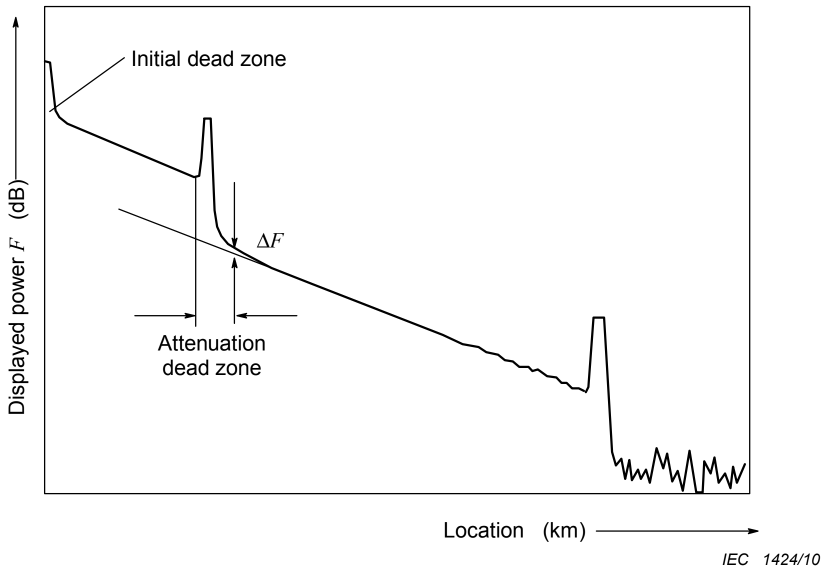


Figure 1 – Definition of attenuation dead zone

3.4
calibration
set of operations which establish, under specified conditions, the relationship between the values indicated by the measuring instrument and the corresponding known values of that quantity

NOTE See ISO *Guide International vocabulary of basic and general terms in metrology.*

3.5
centroidal wavelength
λ_{avg}
power-weighted mean wavelength of a light source in vacuum

[IEC 61280-1-3, definition 2.1.4]

3.6
displayed power level
F
level displayed on the OTDR's power scale

NOTE 1 Unless otherwise specified, F is defined in relation to the clipping level (see Figure 8).

NOTE 2 Usually, the OTDR power scale displays five times the logarithm of the received power, plus a constant offset.

3.7
distance
D
spacing between two features

NOTE Usually expressed in metres.

3.8
distance sampling error
$\boldsymbol{\Delta L_{\mathrm{sample}}}$
maximum distance (3.7) error attributable to the distance between successive sample points

NOTE 1 Usually expressed in metres.

NOTE 2 The distance sampling error is repetitive in nature; therefore, one way of quantifying this error is by its amplitude.

3.9
distance scale deviation
$\boldsymbol{\Delta S_{\mathrm{L}}}$
difference between the average displayed distance (3.7) $< D_{\mathrm{otdr}} >$ and the correspondent reference distance (3.27) D_{ref} divided by the reference distance (3.27)

NOTE 1 Usually expressed in m/m.

NOTE 2 ΔS_{L} is given by the following formula

$$\Delta S_{\mathrm{L}} = \frac{< D_{\mathrm{otdr}} > - D_{\mathrm{ref}}}{D_{\mathrm{ref}}} = \frac{< D_{\mathrm{otdr}} >}{D_{\mathrm{ref}}} - 1 \qquad (2)$$

where $< D_{\mathrm{otdr}} >$ is the displayed distance on a fibre averaged over at least one sample spacing.

3.10
distance scale factor
$\boldsymbol{S_{\mathrm{L}}}$
average displayed distance (3.7) divided by the correspondent reference distance (3.27)

NOTE 1 S_{L} is given by the following formula

$$\mathrm{S}_{L} = \frac{< D_{\mathrm{otdr}} >}{D_{\mathrm{ref}}} \qquad (3)$$

where $< D_{\mathrm{otdr}} >$ is the displayed distance between two features on a fibre (actual or simulated) averaged over at least one sample spacing.

3.11
distance scale uncertainty
$\boldsymbol{u_{\Delta \mathrm{SL}}}$
uncertainty of the distance scale deviation (3.9)

NOTE 1 Usually expressed in m/m.

NOTE 2 $u_{\Delta SL}$ is given by the following formula

$$u_{\Delta SL} = u\left(\frac{< D_{otdr} >}{D_{ref}} - 1\right) = u\left(\frac{< D_{otdr} >}{D_{ref}}\right) \quad (4)$$

NOTE 3 In the above formula, $u()$ is understood as the standard uncertainty of ().

3.12
dynamic range at 98 % (one-way)
amount of fibre attenuation (3.1) that causes the backscatter signal to equal the noise level at 98 % (3.24)

NOTE It can be represented by the difference between the extrapolated point of the backscattered trace (taken at the intercept with the power axis) and the noise level expressed in decibels, using a standard category A fibre (see IEC 60793-2-10).

3.13
encircled flux
EF
fraction of cumulative near field power to total output power as a function of radial distance from the centre of the core

3.14
group index
N
factor by which the speed of light in vacuum has to be divided to yield the propagation velocity of light pulses in the fibre

3.15
location
L
spacing between the front panel of the OTDR and a feature in a fibre

NOTE Usually expressed in metres

3.16
location deviation
ΔL
displayed location (3.15) of a feature L_{otdr} minus the reference location (3.28) L_{ref}

NOTE 1 Usually expressed in metres.

NOTE 2 This deviation is a function of the location.

3.17
location offset
ΔL_0
constant term of the **location deviation** (3.16) model

NOTE 1 Usually expressed in metres.

NOTE 2 This is approximately equivalent to the location of the OTDR front panel connector on the instrument's distance scale.

NOTE 3 For a perfect OTDR, the location offset is zero.

3.18
location offset uncertainty
$u_{\Delta L0}$
uncertainty of the location offset (3.17)

3.19
location readout uncertainty
u_{Lreadout}
uncertainty of the location (3.15) measurement samples caused by both the distance sampling error (3.8) and the uncertainty type A of the measurement samples

3.20
loss deviation
ΔA
difference between the displayed loss of a fibre component A_{otdr} and the reference loss (3.29) A_{ref}, in dB

NOTE 1 ΔA is given by the following formula

$$\Delta A = A_{\mathrm{otdr}} - A_{\mathrm{ref}} \tag{5}$$

NOTE 2 The loss deviation usually depends on the displayed power level, F.

3.21
loss uncertainty
$u_{\Delta \mathrm{A}}$
uncertainty of the loss deviation (3.20), in dB

3.22
loss scale deviation
ΔS_{A}
difference between the displayed loss of a fibre component A_{otdr} and the reference loss (3.29) A_{ref}, divided by the reference loss (3.29), in dB/dB

NOTE 1 ΔS_{A} is given by the following formula

$$\Delta S_{\mathrm{A}} = \frac{A_{\mathrm{otdr}} - A_{\mathrm{ref}}}{A_{\mathrm{ref}}} \tag{6}$$

NOTE 2 Refer to 7.1 for more details.

3.23
mode conditioner
a fibre set that converts any power distribution submitted at its input to an output power distribution that fully comply with encircled flux limits

NOTE For the purposes of this standard, the encircled flux limits are defined by the IEC 61280-4-1.

3.24
noise level at 98 %
upper limit of a range which contains at least 98 % of all noise data points

3.25
non-linearity
NL_{loss}
difference between the maximum and minimum values of the loss deviation (3.20) ΔA for a given range of power levels, in dB

NOTE 1 This is the non-linearity of a logarithmic power scale.

NOTE 2 Non-linearity is one contribution to loss deviation; it usually depends on the displayed power level and the location.

3.26
received power level
P
power received by the OTDR's optical port

3.27
reference distance
D_{ref}
distance (3.7) precisely determined by measuring equipment with calibration traceable to international or national standards

NOTE Usually expressed in metres.

3.28
reference location
L_{ref}
location (3.15) precisely determined by measuring equipment with calibration traceable to international or national standards

NOTE Usually expressed in metres.

3.29
reference loss
A_{ref}
loss of a fibre optic component precisely determined by measuring equipment with calibration traceable to international or national standards

3.30
rms dynamic range (one-way)
amount of fibre attenuation (3.1) that causes the backscatter signal to equal the rms noise level (3.31)

NOTE Assuming a Gaussian distribution of noise, the rms dynamic range can be calculated adding 1,56 dB to the one way dynamic range. See 3.31.

3.31
rms noise level
the quadratic mean of the noise

NOTE 1 On a general basis, the rms noise level cannot be read or extracted from the logarithm data of the OTDR. This is because the linear to logarithm conversion used to display the power level on a dB scale removes the negative part of the noise.

NOTE 2 Assuming a Gaussian distribution of noise, a relation between the noise level and the RMS noise level can be found using the following formula

$$Noise_{98} - Noise_{\mathrm{rms}} = 5 \times \log_{10}(2{,}05375) = 1{,}56 \ \text{dB} \qquad (7)$$

where $Noise_{98}$ is the noise level at 98 %, e.g. in dB;

$Noise_{\mathrm{rms}}$ is the rms noise level, e.g. in dB;

2,05375 is the value of the reverse standard normal distribution for 98 %.

3.32
sample spacing
distance of consecutive data points digitized by the OTDR

NOTE 1 Usually expressed in metres.

NOTE 2 Sample spacing may be obtainable from instrument set-up information. Sample spacing may depend on the measurement span and other OTDR instrument settings.

3.33
spectral width
$\Delta\lambda_{FWHM}$
full-width half-maximum (FWHM) spectral width of the source

[IEC 61280-1-3, definition 3.2.3 modified]

4 Preparation for calibration

4.1 Organization

The calibration laboratory should satisfy requirements of ISO/IEC 17025.

There should be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used.

4.2 Traceability

The requirements of ISO/IEC 17025 should be met.

All standards used in the calibration process shall be calibrated according to a documented program with traceability to national standards laboratories or to accredited calibration laboratories. It is advisable to maintain more than one standard on each hierarchical level, so that the performance of the standard can be verified by comparisons on the same level. Make sure that any other test equipment which has a significant influence on the calibration results is calibrated. Upon request, specify this test equipment and its traceability chain(s). The re-calibration period(s) shall be defined and documented.

4.3 Preparation

Perform all tests at an ambient room temperature of 23 °C ± 3 °C, unless otherwise specified. Give the test equipment a minimum of 2 h prior to testing to reach equilibrium with its environment. Allow the OTDR a warm-up period according to the manufacturer's instruction.

4.4 Test conditions

The test conditions usually include the following OTDR external conditions: date, temperature, connector-adapter combination and use of a lead-in fibre.

Perform the calibration in accordance with the manufacturer's specifications and operating procedures. Where practical, select a range of test conditions and parameters so as to emulate the actual field operating conditions of the OTDR under test. Choose these parameters so as to optimize the OTDR's accuracy and resolution capabilities (for example, view windows, zoom features, etc.), as specified by the manufacturer's operating procedures.

The test conditions usually include the following OTDR parameters: averaging time, pulse width, sample spacing, centre wavelength. Unless otherwise specified, set the OTDR group index to exactly 1,46.

NOTE 1 The calibration results only apply to the set of test conditions used in the calibration process.

NOTE 2 Because of the potential for hazardous radiation, be sure to establish and maintain conditions of laser safety. Refer to IEC 60825-1 and IEC 60825-2.

4.5 Documentation

Calibration certificates shall include the following data and their uncertainties:

a) the location offset ΔL_0 and its uncertainty $\pm$ 2 $u_{\Delta L0}$ as well as the distance scale deviation ΔS_L and its uncertainty $\pm$ 2 $u_{\Delta SL}$, or the location deviations ΔL_i and their uncertainties $\pm$ 2 $u_{\Delta Li}$;

b) the non-linearity NL_{loss} ;

c) the instrument configuration (pulse with, measurement span, wavelength, averaging time, etc.) used during calibration;

d) other appropriate calibration data and other calibration certificate requirement as per ISO/IEC 17025.

5 Distance calibration – General

5.1 General

The objective of distance calibration is to determine deviations (errors) between the measured and actual distances between points on a fibre, and to characterize the uncertainties of these deviations.

An OTDR measures the location L of a feature from the point where a fibre is connected to the instrument, by measuring the round-trip transit time T for a light pulse to reach the feature and return. L is calculated from T using the speed of light in vacuum c (2,997 924 58 $\times$ 10^8 m/s) and the group index N of the fibre:

$$L = \frac{cT}{2N} \tag{8}$$

Errors in measuring L will result from scale errors, from offsets in the timebase of the OTDR and from errors in locating a feature relative to the timebase. Placing a marker in order to measure the location may be done manually or automatically by the instrument. The error will, generally, depend on both the marker placement method and the type of feature (for example, a point loss, a large reflection that saturates the receiver or a small reflection that does not).

Even larger errors in measuring L may result from the uncertainty in determining the multimode fibre's group index N and taking into account the differential mode delay. The determination of N and the analysis of the consequences of the differential mode delay are beyond the scope of this standard. Consequently, the calibration procedures below only discuss the OTDR's ability to measure T correctly. For the purposes of this standard, a default value N = 1,46 is used and the uncertainty of N is considered to be 0. Also the calibration methods are built to limit uncertainties due to the differential mode delay.

5.2 Location deviation model

In order to characterize location deviations, a specific model will be assumed that describes the behaviour of most OTDRs. Let L_{ref} be the reference location of a feature from the front panel connector of the OTDR and let L_{otdr} be the displayed location. It is assumed that the displayed location L_{otdr}, using OTDR averaging to eliminate noise, depends functionally on the reference location L_{ref} in the following way

$$L_{otdr} = S_L \cdot L_{ref} + \Delta L_0 + f(L_{ref}) \tag{9}$$

where

S_L is the scale factor, which ideally should be 1;

ΔL_0 is the location offset, which ideally should be 0;

$f(L_{ref})$ represents the distance sampling error, which is also ideally 0. The distance sampling error is a periodic function with a mean of zero and a period equal to the distance interval between sampled points on the OTDR. As an example, if the location of a large reflection is measured by placing a marker on the first digitized point that shows an increase in signal and the position of the reflection is incremented in fine steps, then $f(L_{\mathrm{ref}})$ may be shaped like a periodic ramp waveform.

Equation (9) is meant to characterize known errors in location measurements, but there may still be an additive uncertainty type A. This will affect both the distance measurements and the accuracy with which parameters describing the errors can be determined by the procedures below.

S_{L} and ΔL_0 may be determined by measuring L_{otdr} for different values of L_{ref}, then fitting a straight line to the data by the least squares method. S_{L} and ΔL_0 are the slope and intercept, respectively.

Equivalently, a line may be fitted to the location deviation function, that is the difference between L_{otdr} and L_{ref}

$$\Delta L = L_{\mathrm{otdr}} - L_{\mathrm{ref}} = \Delta S_{\mathrm{L}} \cdot L_{\mathrm{ref}} + \Delta L_0 + f\left(L_{\mathrm{ref}}\right) \tag{10}$$

where

ΔS_{L} is the slope, and

ΔL_0 is still the intercept, as illustrated in Figure 2.

After finding the linear approximation, the distance sampling error $f(L_{\mathrm{ref}})$ respectively its half-amplitude $\Delta L_{\mathrm{readout}}$ may be determined by measuring departures from the line for different values of L_{ref}. The distance sampling error amplitude $\Delta L_{\mathrm{sample}}$ is taken as half the amplitude of $f(L_{\mathrm{ref}})$.

In this standard, the distance sampling error amplitude $\Delta L_{\mathrm{sample}}$ is treated as part of the location readout uncertainty type A. The stated uncertainty result thus ignores the repetitive nature of the sampling error, that is it does not distinguish between the relative contributions of the sampling error and the uncertainty type A.

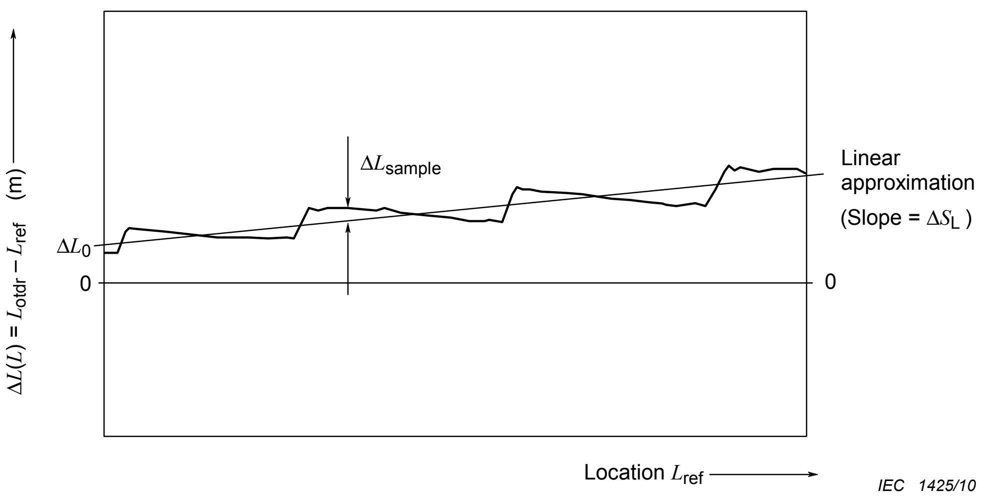


Figure 2 – Representation of the location deviation $\Delta L(L)$

Therefore, the result of the distance calibration shall be stated by the following parameters:

ΔS_{L}, $u_{\Delta \mathrm{SL}}$ is the distance scale deviation and its uncertainty;

ΔL_0, $u_{\Delta \mathrm{L0}}$ is the location offset and its uncertainty;

u_{Lreadout} is the location readout uncertainty, that is the combined uncertainty due to the distance sampling error and the uncertainty type A of the measurement samples, in the form of a standard deviation.

In compliance with the "mathematical basis," divide the largest excursions from the least-squares approximation by the square root of 3 for stating u_{Lreadout}. Note that the uncertainty will depend on the distance, the displayed power level and the instrument settings.

NOTE $\Delta L_{\mathrm{sample}}$ represents the physical sampling error of the instrument. This error is accessible for the user as u_{Lreadout} that includes distance calculation and displaying errors.

5.3 Using the calibration results

The error in the location of a feature $\Delta L = L_{\mathrm{otdr}} - L_{\mathrm{ref}}$ can be calculated from the calibration results:

$$\Delta L = \Delta L_0 + L_{\mathrm{ref}} \Delta S_{\mathrm{L}} \tag{11}$$

with the uncertainty in ΔL given by the following formula, in which the recommended confidence level of 95 % is used:

$$\pm 2u_{\Delta\mathrm{L}} = \pm 2\left(u_{\Delta\mathrm{L0}}{}^2 + L_{\mathrm{ref}}{}^2 u_{\Delta\mathrm{SL}}{}^2 + u_{\mathrm{Lreadout}}{}^2\right)^{1/2} \tag{11a}$$

where the displayed location L_{otdr} can be used instead of the reference location L_{ref} without serious consequences.

Similarly, the error in the distance between two features ΔD and its uncertainty can be calculated from the following formula:

$$\Delta D = D_{\mathrm{ref}} \Delta S_{\mathrm{L}} \tag{12}$$

with uncertainty in ΔD given by the following formula:

$$\pm 2u_{\Delta\mathrm{D}} = \pm 2\left(D_{\mathrm{ref}}{}^2 u_{\Delta\mathrm{SL}}{}^2 + 2u_{\mathrm{Lreadout}}{}^2\right)^{1/2} \tag{12a}$$

where the displayed distance D_{otdr} can be used instead of the reference distance D_{ref}.

NOTE The 2 in front of $u_{\mathrm{Lreadout}}{}^2$ is due to combining two uncorrelated uncertainties.

Differential mode delay may create additional uncertainties on long fibres measurement. Such uncertainties should be negligible for distance given in Table 1.

Table 1 – Additional distance uncertainty

Wavelength nm	**Length of fibre causing additional distance uncertainty**			
	IEC 60793-2-10 A1a.1	**IEC 60793-2-10 A1a.2**	**IEC 60793-2-10 A1b**	**IEC 60793-2-10 A1d**
850	1 000 m	7 500 m	500 m	50 m
1 300	1 000 m	2 500 m	1 000 m	500 m

Additional uncertainties may have to be taken into account if the type of feature is different from the feature used in the calibration. Specify the type of feature as part of the calibration result.

5.4 Measuring fibre length

As indicated above, one of the methods of OTDR distance calibration is to measure fibres of known length with the OTDR. In several instances in this standard, it is required that fibre length be determined using the fibre's transit time, in contrast to a mechanical length measurement. This method is directly compatible with the measurement principle of the OTDR itself. In addition, the transit time can usually be measured with better accuracy than its mechanical length, particularly when the fibre is long. Therefore, in this standard, it is suggested that fibre transit time instead of fibre length be used whenever accuracy is important.

Measure the transit time of the fibre T_{transit} with the help, for example, of a pulse generator, a triggerable laser source, an optical-to-electrical converter (O/E converter) and a time interval counter. It is important that the laser source has approximately the same centre wavelength λ_{centre} as the test OTDR, because a difference in wavelength may result in a difference of transit time due to the chromatic dispersion of the fibre. An alternative to the laser source is using the OTDR itself to produce optical pulses; in this case, the centre wavelengths automatically coincide. Record the transit time as the difference between the arrival times with and without the fibre inserted between the laser source and the O/E converter.

When this fibre is used for OTDR distance calibrations, then the reference distance D_{ref} can be calculated by

$$D_{\text{ref}} = \frac{cT_{\text{transit}}}{N} \quad \text{m} \tag{13}$$

In this equation, use a group index N which is identical with the OTDR's group index setting. The time measurement principle makes it possible to use D_{ref} as the reference distance.

6 Distance calibration methods

6.1 General

Each of the calibration methods described below is capable of determining all of the necessary calibration results: location offset, distance scale deviation, and their uncertainties.

6.2 External source method

6.2.1 Short description and advantage

The external source method uses a calibrated time-delay generator to simulate the time delay in a fibre and an optical source to simulate the reflected or scattered signal from a fibre.

Each time it is possible (e.g. when operation at 1 300 nm), IEC 60793-2-50 single mode fibres are used instead of multimode fibres for the interconnections, in order to reduce uncertainties caused by differential mode delay.

The method is well suited to automated laboratory testing under computer control. For simplicity, only reflective features are discussed in this standard. To calibrate the OTDR for features other than reflection, the pulsed E/O converter described below should be replaced by an optical source that simulates the appropriate feature.

6.2.2 Equipment

In addition to the OTDR, the measurement equipment includes, as shown in Figure 3:

a) a mode conditioner;

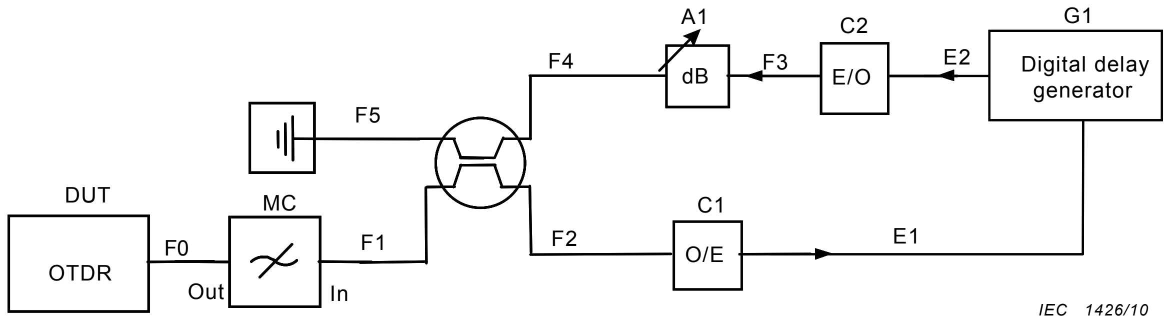
b) an single mode optical coupler;

c) an optical-to-electrical converter;

d) a digital delay generator with pulse capability;

e) an electrical to optical converter;

f) a variable optical attenuator, for reduction of the pulse amplitude to just below the clipping level.



Key

F0	multimode fibre
F1, F2, F3, F4 and F5	single mode fibres
MC	mode conditioner
E1 and E2	electric cables
E/O	electrical-to-optical converter
O/E	optical-to-electrical converter
A1	variable attenuator

Figure 3 – Equipment for calibration of the distance scale – External source method

The OTDR is connected to the coupler through the mode conditioning multimode to single mode adapter. The coupler routes the OTDR signal to the O/E converter (detector). The detector triggers the delay generator, which, after a known time delay, causes an optical pulse to be generated. This pulse is then coupled back to the OTDR.

The E/O converter can be a simple pulsed laser that simulates a reflection. Constant pulse amplitude and pulse width are considered adequate to calibrate the distance scale for reflective features. However, the attenuator makes it possible to adjust the pulse amplitude based on the distance of the reflection from the front panel of the OTDR, in order to simulate the change of reflection amplitude caused by the attenuation of the fibre.

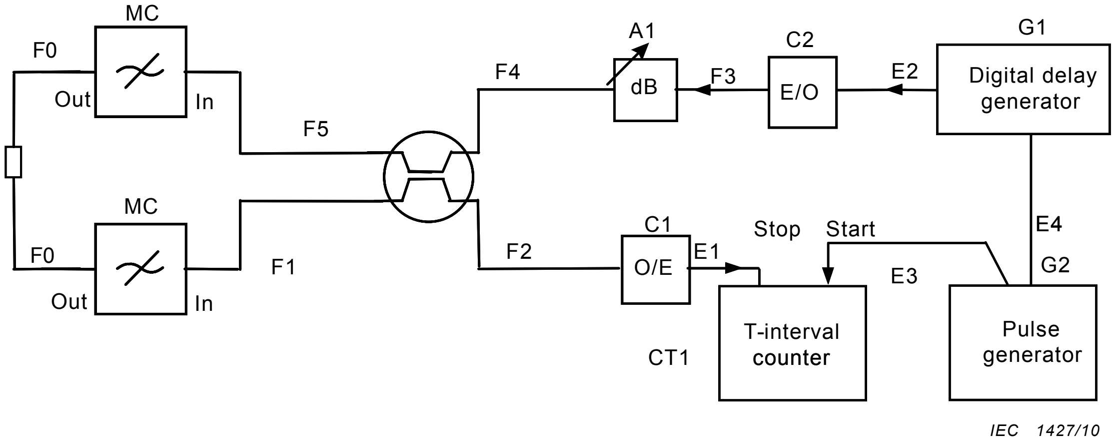
To allow accurate calibration of the set-up, fibres F1 and F5 should have the same length (see below). Fibre F5 is terminated to absorb reflections.

NOTE 1 The mode conditioner is needed to make sure the OTDR receives proper launch conditions from the electrical to optical converter. Therefore fibre F0 should be connected to the output of the mode conditioner while fibre F1 should be connected to the input.

NOTE 2 The attenuation of the optical path between the connector of the OTDR and the optical to electrical converter may be high. This is acceptable as the output power of the OTDR is generally sufficient.

6.2.3 Calibration of the equipment

Before using the "external source" equipment, it shall be properly calibrated. It is assumed that the digital delay generator is regularly calibrated. For computing the location offset ΔL_0 from the measured data, it is also necessary to determine the insertion delay T_{delay} of the apparatus. This can be accomplished by adding a pulse generator and a calibrated time interval counter to the equipment, as shown in Figure 4.



Key

F0	multimode fibre (two during calibration)
MC	mode conditioner (two during calibration)
F1, F2, F3, F4 and F5	fibres
E1, E2, E3 and E4	electric cables
C2	electrical-to-optical converter
C1	optical-to-electrical converter
A1	variable attenuator

Figure 4 – Set-up for calibrating the system insertion delay

To properly measure the propagation delay of the mode conditioner it is recommended to include within the optical path, a second identical mode conditioner.

To calibrate the insertion delay T_{delay}, proceed as follows.

Set the pulse generator to square wave, with a repetition period more than twice as long as the delay time to be measured. Use the output pulse of the pulse generator as the start pulse on the time interval counter, and to externally trigger the delay generator. Set the digital delay generator for external triggering and zero delay for the leading edge of the pulse generator signal. Set the trigger levels of the delay generator and the counter.

The external source will then generate an optical square wave which, after re-conversion to an electrical pulse, will stop the time interval counter. To ensure lowest uncertainty, the electrical cables E3 and E4 should have equal length. Also, fibres F1 and F5 should have equal lengths. The two modes conditioner and the two fibres F0 should have the same length. Note that identical cable numbers in Figures 3 and 4 mean the same physical cables. Adjust the optical attenuator for best triggering of the time interval counter. Record the displayed time interval (between start and stop) as the insertion delay T_{delay}.

6.2.4 Measurement procedure

6.2.4.1 Preparation

Select the technique (automatic or manual) for locating the feature on the OTDR. Program the attenuator to generate the desired pulse amplitude(s). Select the pulse width on the digital delay generator, for example 1 µs.

Choose the time settings of the delay generator T_i so that the samples are distributed over a wide distance range with some randomness, to accomplish averaging over the OTDR's distance sampling interval. The first time setting should be chosen so that the pulse appears close to the front panel of the OTDR, but sufficiently out of the initial dead zone for good measurements. If the testing laboratory does not determine and analytically justify a different distance sampling scheme, one of the two schemes below shall be chosen.

a) In the first scheme, evaluate the sample spacing D_{sample} (for the appropriate OTDR instrument setting), for example by zooming into the OTDR trace. Then calculate the corresponding delay difference of the delay generator T_{sample} using

$$T_{\text{sample}} = \frac{2ND_{\text{sample}}}{c} \tag{14}$$

where N is the OTDR's group index setting and c is the speed of light in vacuum.

Then calculate a total number of i delay generator settings, grouped in k clusters of n settings each ($i = k\ n$), where each cluster uniformly covers one sample spacing. Each cluster shall have the form:

$$T_K, T_K + {}^{T_{\text{sample}}}\!/_{n}, T_K + 2\,{}^{T_{\text{sample}}}\!/_{n}, ...T_K + (n^{-1})\,{}^{T_{\text{sample}}}\!/_{n} \tag{15}$$

where the number of settings in each cluster n is at least four and is the same for every cluster. The centres of the clusters are uniformly spaced, from just beyond the initial dead zone to a large distance over which the instrument is to be calibrated. The number of clusters k may be as small as two.

b) In the second scheme, there are no clusters, and the sample spacing D_{sample} does not need to be known except very approximately. Calculate T_{sample} from Equation (14). Choose the time settings so that they are uniformly spaced between the initial dead zone and a large distance and each has a random time interval added. The random intervals should have a uniform probability density in the interval – T_1 to T_1, where T_1 is at least 20 T_{sample} but less than 10 % of the longest time delay for the tests. The number of measurements i (that is, different settings) should be at least 20.

Alternatively, prior knowledge of the magnitude of the uncertainty type A and the tolerable uncertainty in the measurements may lead the testing laboratory to select a different systematic or random distance sampling scheme.

6.2.4.2 Taking the measurement results

Select the first time setting of the time T_i of the series T_1 as defined above. Record the time T_1 of the delay generator and the measured location $L_{\text{otdr},1}$ of the event on the OTDR. Proceed with the time settings as selected in 6.2.4.1. Always record the time T_i and the measured location $L_{\text{otdr},i}$. Continue until all time settings are completed.

6.2.5 Calculations and results

Following the concept of Clause 4, use the time settings to calculate i reference locations $L_{\text{ref},i}$

$$L_{\text{ref,i}} = \frac{c\left(T_{\text{i}} + T_{\text{delay}}\right)}{2N} \tag{16}$$

where

N is the group index setting of the OTDR;

T_{i} are the time settings defined in 6.2.3;

T_{delay} is the calibrated insertion delay of the test equipment (see 6.2.2).

Then, use the reference locations and the displayed locations $L_{\text{otdr,i}}$ to calculate the set of i location deviations ΔL_{i}

$$\Delta L_{\text{i}} = L_{\text{otdr,i}} - L_{\text{ref,i}} \tag{17}$$

To determine the location offset ΔL_0 and the distance scale deviation ΔS_{L}, fit the location deviation data to the simplified location deviation model (in which the distance sampling error is momentarily neglected):

$$\Delta L_{\text{i, model}} = \Delta S_{\text{L}}\, L_{\text{ref,i}} + \Delta L_0 \tag{18}$$

Specifically, minimize the difference between the model and the data using the least-squares criterion that is, choose ΔS_{L} and ΔL_0 so that the summation

$$\sum_{\text{i}} \left(\Delta L_{\text{i}} - \Delta S_{\text{L}}\, L_{\text{ref,i}} - \Delta L_0\right)^2 \tag{19}$$

is minimized. Record ΔL_0 and ΔS_{L} obtained from the approximation.

As in Figure 2, the slope of the linear approximation represents the distance scale deviation ΔS_{L}. The intercept with the vertical axis represents the location offset ΔL_0. Record ΔS_{L} and ΔL_0 obtained from the calculation.

6.2.6 Uncertainties

6.2.6.1 General

A general discussion of the distance uncertainties can be found in Clause 5.

Note that the following list of uncertainties may not be complete. Additional contributions may have to be taken into account, depending on the measurement set-up and procedure. The mathematical basis given in Annex B should be used to calculate and state the uncertainties.

6.2.6.2 Distance scale uncertainty

The least-squares approximation outlined in 6.2.5 effectively uses the displayed distances between the measurement samples to calculate the distance scale deviation. It is assumed that the measurement samples near L = 0 and near the farthest location $L = L_{\text{max}}$ have the strongest influence on the distance scale deviation because the samples in the middle of the range have less influence on the slope of the distance error model.

Applying the standard formula for the propagation of errors to Equation (4) yields the distance scale uncertainty $u_{\Delta\text{SL}}$ in which $\langle D_{\text{otdr}}\rangle \cong D_{\text{ref}}$ was used.

$$u_{\Delta SL} \cong \left[\left(\frac{u_{<\mathrm{Dotdr}>}}{< D_{\mathrm{otdr}} >} \right)^2 + \left(\frac{u_{\mathrm{Dref}}}{D_{\mathrm{ref}}} \right)^2 \right]^{1/2} \text{ m/km} \tag{20}$$

where

D_{otdr} is $D_{\mathrm{ref}} \approx L_{\mathrm{ref}}$ (for the long distances discussed here);

$u_{<\mathrm{Dotdr}>}$ is the standard deviation expressing the uncertainty of the distance samples (on the basis of the location samples);

$u_{<\mathrm{Dotdr}>}/<D_{\mathrm{otdr}}>$ represents the slope uncertainty due to inaccurate distance readout; it is equivalent to the standard deviation of the slope, ΔS_{L} in the location model of Equation (10) which includes the marker placement uncertainty and the distance sampling error; the least-squares algorithm used for the determination of ΔS_{L} can be used to determine $u_{<\mathrm{Dotdr}>}$; if applicable, ΔL_{i} may be averaged over the corresponding sampling interval;

u_{Dref} is the uncertainty of the reference distances;

$u_{\mathrm{Dref}}/D_{\mathrm{ref}}$ represents the slope uncertainty caused by the digital delay generator and is equal to the relative timing uncertainty of the delay generator.

6.2.6.3 Location offset uncertainty

The location offset ΔL_0 is equal to the intercept of the least-squares approximation with the vertical axis. This intercept mostly depends on the first few samples, that is those samples which are closest to the location L = 0, and on the accuracy of the insertion delay T_{delay}.

The location offset uncertainty $u_{\Delta \mathrm{L0}}$ can be calculated by using the standard formula for the propagation of errors

$$u_{\Delta \mathrm{L0}} = \left[u_{\Delta \mathrm{L}}{}^2 + \left(\frac{c}{2N} \right)^2 u_{\mathrm{Tdelay}}^2 \right]^{1/2} \tag{21}$$

where

$u_{\Delta L}$ is the uncertainty of the differences between ΔL_{i} and the least-squares approximation near L = 0, which includes the marker placement uncertainty and the distance sampling error; it is equivalent to the standard deviation of ($\Delta L_{\mathrm{i}} - \Delta L_{\mathrm{i,\ model}}$) near L = 0; if applicable, ΔL_{i} may be averaged over the correspondent sampling interval; the least-squares algorithm used for the determination of ΔL_0 can be used to determine $u_{\Delta \mathrm{L}}$.

u_{Tdelay} is the uncertainty of the system insertion delay that also includes the difference between the two mode conditioning adapters used during calibration; the assumption is that the first measurement setting will be very short or even zero, reducing the delay generator uncertainty to one of the insertion delays only.

6.2.6.4 Location readout uncertainty

As outlined in Clause 5, determine the largest difference between the location deviation samples ΔL_{k} and the least-squares approximation near L = 0. Then calculate the location readout uncertainty u_{Lreadout} (which includes the distance sampling error) by dividing the largest difference by the square root of 3. Alternatively, u_{Lreadout} can be determined either with the least-squares algorithm used for the determination of ΔS_{L} and ΔL_0 or with the following formula

$$u_{\mathrm{Lreadout}} = \left[\frac{1}{n-1} \sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\Delta L_{\mathrm{i}} - \Delta L_{\mathrm{i,\ model}} \right)^2 \right]^{1/2} \tag{22}$$

6.3 Concatenated fibre method (using multimode fibres)

6.3.1 Short description and advantages

This method uses multimode calibrated fibres with transit times precisely measured at the wavelength of the OTDR under test to calibrate the distance scale.

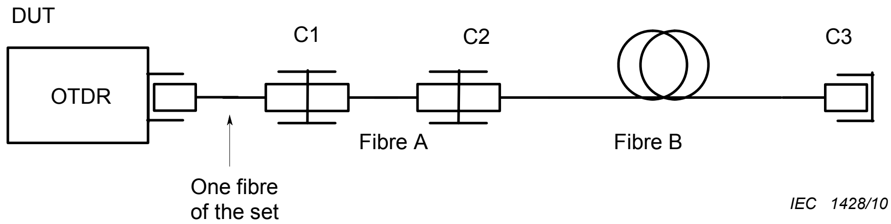
The method requires only connectorized lengths of fibre, and is thus both inexpensive and well suited to testing in locations where equipment such as that used in 6.2 cannot be carried. It may be viewed as a manual test method because it requires connecting and disconnecting short lengths of fibre a number of times to vary the locations of reflections. However, this process can be automated with optical switches, if desired.

This method using multimode fibres is applicable at both 850 nm and 1 300 nm and does not require any mode conditioner. However, the differential mode delay (DMD) of the calibrated fibre B (see Figure 5) has to be taken into account as an uncertainty.

6.3.2 Equipment

In addition to the test OTDR, the equipment includes, as shown in Figure 5,

a) fibre A, to determine the location offset;
b) fibre B, to determine the distance scale deviation;
c) a set of incremental fibres, to determine the distance sampling error.



Key

C1, C2 and C3 optical connectors

Figure 5 – Concatenated fibres used for calibration of the distance scale

Normally, these fibres will be cabled or packaged in some way for protection and connectorized for easy connection and disconnection.

The requirements on these fibres are indicated below.

a) Fibre A is a simple multimode fibre with an end reflection (generated by a non-angled connection). Its length, much shorter than fibre B, is not very important, as long as it puts the end reflection to be measured on a backscatter trace which is essentially undisturbed from the initial reflection(s) near the OTDR port.

   Fibre A can also be used as a lead-in fibre for measuring the distance scale deviation with the help of fibre B.

b) Fibre B shall have reflective ends, for example by using the reflections from its connectors. Because the uncertainty is reduced by making this fibre longer, it is recommended that fibre B be a few hundreds of metres long.

   To calibrate the fibre, measure its optical transit time T_b as described in Clause 5.

   Caution: for a correct distance calibration, the reflections from the two ends of fibre B (connectors C2 and C3) should be approximately equal. For example, if one end produces a reflection that saturates the OTDR and the other end does not, then the difference in waveforms can lead to inaccurate distance measurements. The effect of this difference on the measured distance scale deviation will be small if the fibre is long, however.

c) When the sampling interval is not precisely known from the manufacturer and expected to be large, the set of incremental fibres will be used to vary the locations of the two reflections of the long fibre B by amounts less than the distance sampling interval of the OTDR (if practical). Their lengths should be selected in order to generate at least four distance increments which are evenly spaced over the distance sampling interval. As an example, if the distance sampling interval is 10 m, this can be accomplished with two fibres of lengths 2,5 m and 5 m. Separately and in combination, these can produce increments of 0 m (no fibre), 2,5 m, 5 m, and 7,5 m (both fibres). More generally, the fibres should generate length increments of

$$0, D_{\mathrm{x}}, 2D_{\mathrm{x}}, \ldots..(n-1)D_{\mathrm{x}} \tag{23}$$

where

$n \geq 4$, and

$n\ D_{\mathrm{x}}$ equals the distance sampling interval of the OTDR under the conditions to be tested.

Except in unusual cases, calibrating the transit time of these fibres according to Clause 5 is unnecessary. Instead, their physical lengths should be measured. The difference between the true group index and the OTDR group index setting will be negligible on such short fibres.

6.3.3 Measurement procedures

6.3.3.1 General

The contribution of random noise to location deviation is usually small except when the displayed power level comes close to the noise limit of the instrument. Longer OTDR averaging is recommended in this case.

6.3.3.2 Preparation

Establish the technique (automatic or manual) for placing the markers on the reflection of fibre A and the reflective ends of fibre B.

Connect fibre A to the front of the OTDR, so that the end reflection of the fibre can be seen on the OTDR. Connect fibre B to the far end of fibre A, so that the reflections from both ends of fibre B may be seen on the OTDR.

6.3.3.3 Taking the measurements

Measure the location of the reflection of fibre A with the OTDR. Record this first measured location as $L_{\mathrm{otdr,1.}}$ Measure the length of fibre B with the OTDR, using the two reflections generated by this fibre. Record this first measured distance as $D_{\mathrm{otdr,1}}$.

Insert the shortest of the incremental fibres between the OTDR and the beginning of fibre A. Measure the location $L_{\mathrm{otdr,2}}$ and the distance $D_{\mathrm{otdr,2}}$.

Continue inserting successively increasing length combinations of the incremental fibres. Measure the location $L_{\mathrm{otdr,i}}$ and the distance $D_{\mathrm{otdr,i}}$ until $i = n$ and the total length of the incremental fibres is $(n - 1)\ D_{\mathrm{x}}$.

6.3.4 Calculations and results

6.3.4.1 Distance scale deviation

Compute the distance $< D_{\mathrm{otdr}} >$ (the length of fibre B) as the average of the n values of $D_{\mathrm{otdr,i.}}$ Then compute the distance scale deviation as

$$\Delta S_L = \frac{< D_{otdr} >}{D_{ref}} - 1 = \frac{N < D_{otdr} >}{c T_b} - 1 \tag{24}$$

where

D_{ref} is the reference distance;

N is the group index setting of the OTDR;

T_b is the one-way transit time for fibre B, as measured according to Clause 5.

6.3.4.2 Location offset

Let < L_{otdr} > be the average of all n values of $L_{otdr,i}$. Compute the location offset on the basis of Equation (10).

$$\Delta L_0 = < L_{otdr} > - (1 + \Delta S_L) < L_{ref} > \tag{25}$$

$$\Delta L_0 = < L_{otdr} > - (1 + \Delta S_L)\left(\frac{c T_a}{N} + \frac{(n-1) D_x}{2}\right) \tag{26}$$

where

< L_{ref} > is the average reference location corresponding to the first reflection, to be calculated with the help of the average length of the incremental fibres;

N is the group index setting of the OTDR;

T_a is the one-way transit time for fibre A, as measured according to Clause 5;

ΔS_L is the distance scale deviation as determined by Equation (10); if fibre A is sufficiently short, then the ΔS_L term can be disregarded.

6.3.5 Uncertainties

6.3.5.1 General

A general discussion of the distance uncertainties is given in Clause 5. Note that the following list of uncertainties may not be complete. Additional contributions may have to be taken into account, depending on the measurement set-up and procedure.

The mathematical basis given in Annex B should be used to calculate and state the uncertainties.

6.3.5.2 Distance scale uncertainty

The distance scale uncertainty $u_{\Delta SL}$ should be calculated with the following formula which is derived from Equation (10)

$$u_{\Delta SL} = \left[\left(\frac{u_{Dotdr}}{D_{otdr}}\right)^2 + \left(\frac{u_{Tb}}{T_b}\right)^2\right]^{1/2} \quad \text{m/km} \tag{27}$$

where u_{Dotdr} is the uncertainty of the displayed length of fibre B, for example, as caused by the marker placement uncertainty and the distance sampling error.

The transit time uncertainty of fibre B u_{Tb} should itself be calculated by root-sum-squaring:

$u_{Tb,counter}$ is the transit time uncertainty of fibre B, due to the time interval counter;

$u_{Tb,\lambda}$ is the transit time uncertainty of fibre B, due to a difference between the wavelength used in determining the transit time and the OTDR wavelength;

$u_{\text{Tb},\Theta}$ is the transit time uncertainty of fibre B, due to its temperature coefficient; typical value: 1 cm/(km °C);

$u_{\text{Tb,DMD}}$ is the transit time uncertainty of fibre B, due to the differential mode delay; Table 1 gives some indications for different multimode fibres.

6.3.5.3 Location offset uncertainty

The location offset uncertainty $u_{\Delta\text{L0}}$ should be calculated from the following formula which is derived from Equation (25), by neglecting the ΔS_{L} and the $(n-1)\ D_{\text{x}}/2$ terms:

$$u_{\Delta\text{L0}} = \left[u_{\text{Lotdr}}^2 + \left(\frac{c}{N} \right)^2 u_{\text{Ta}}^2 \right]^{1/2} \tag{28}$$

where u_{Lotdr} is the uncertainty of measuring the location of the end reflection of fibre A, that is mainly the uncertainty of the marker placement; it is assumed that the distance sampling error is effectively removed by averaging over one sampling interval.

The transit time uncertainty of fibre A u_{Ta} should itself be calculated by root-sum-squaring:

$u_{\text{Ta,counter}}$ is the transit time uncertainty of fibre A, due to the time interval counter;

$u_{\text{Ta},\lambda}$ is the transit time uncertainty of fibre A, due to a difference between the wavelength used in determining the transit time and the OTDR wavelength;

$u_{\text{Ta},\Theta}$ is the transit time uncertainty of fibre A, due to its temperature coefficient; typical value: 1 cm/(km °C);

$u_{\text{Ta,DMD}}$ is the transit time uncertainty of fibre A, due to the differential mode delay in fibre A (can be estimated based on the length ratio of the different type of fibres; should be negligible if fibre A is much shorter than fibre B).

6.3.5.4 Location readout uncertainty

Calculate the following two sets of data, one for the location deviation and one for the distance error, using the measurement samples given in 6.3.3.

$$L_{\text{otdr, i}} - L_{\text{ref, i}} = L_{\text{otdr, i}} - \left(\frac{cT_{\text{a}}}{N} + iD_{\text{x}} \right) \quad i = 0 \text{ to } n-1 \tag{29}$$

and

$$\text{D}_{otdr,\text{i}} - \text{D}_{ref,\text{i}} = \text{D}_{otdr,\text{i}} - \frac{\text{cT}_b}{\text{N}} \quad i = 0 \text{ to } n-1 \tag{30}$$

It is recommended that half the difference between the largest and the smallest value of the L set or the D set, whichever is the larger, be divided by the square root of 3 to calculate the location readout uncertainty u_{Lreadout}.

6.4 Recirculating delay line method

6.4.1 Short description and advantages

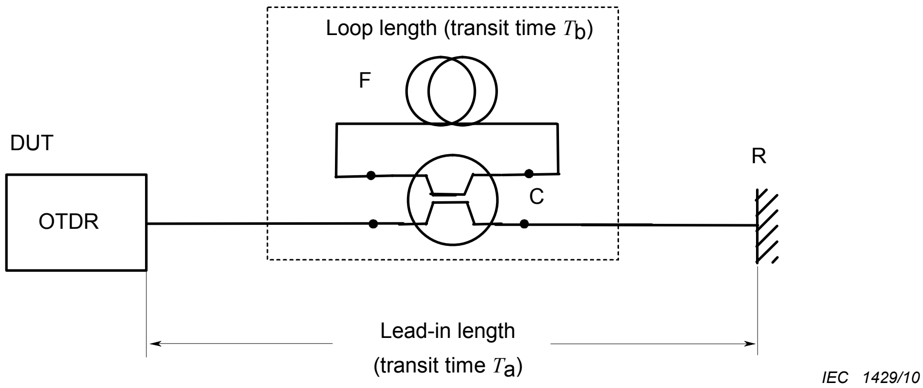
The recirculating delay line method uses a calibrated loop of multimode fibre, made with a coupler and a reflector, to generate periodic reflections.

The method is similar to the concatenated fibre method: a fibre artifact is used, and there is no need for electronic equipment. The artifact generates many calibrated distance samples; this has the potential of reducing type A uncertainties affecting the distance scale deviation.

The measurements of location offset are limited to the reflective features generated by the recirculating delay line.

6.4.2 Equipment

In addition to the test OTDR, the measurement equipment only includes a multimode recirculating delay line manufactured and calibrated according to Annex A, as shown in Figure 6.



Key

F	fibre in the loop
C	four-port coupler
R	reflection

Figure 6 – Distance calibration with a recirculating delay line

The recirculating delay line places a number of reflective features on the OTDR display, as shown in Figure 7. The first feature is the one obtained from the optical pulse travelling direct to the mirror, then back direct to the OTDR. The second feature is generated by the optical pulse travelling once through the loop, then to the mirror, then back direct to the OTDR (this pulse coincides with the pulse travelling direct to the mirror, then back through the loop, then back to the OTDR). The third pulse travels through the loop twice, etc.

Accordingly, the ideal displayed locations would be

$$\begin{aligned} L_{\text{otdr},0} &= L_a \\ L_{\text{otdr},1} &= L_a + L_b/2 \\ L_{\text{otdr},2} &= L_a + L_b \rightarrow \text{etc} \end{aligned} \tag{31}$$

where L_a is the length of the lead-in fibre and L_b is the length of the fibre loop.

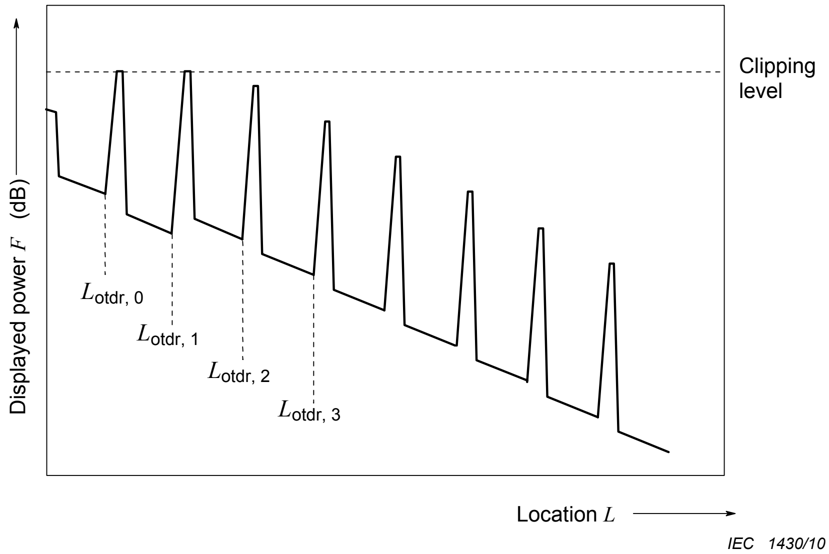


Figure 7 – OTDR trace produced by recirculating delay line

As an optional addition to the measurement set-up, it may be advantageous to use one or more incremental fibres as in 6.3.3. The need for this is reduced because the multiple reflections from the delay line are likely to generate averaging over the distance sampling interval. However, this averaging effect is not controlled and systematic control may be preferred. Using the notation of 6.3.3, it may be sufficient to let n = 2, so there is just one incremental fibre with length equal to half of the distance sampling interval.

6.4.3 Measurement procedure

6.4.3.1 General

The procedure assumes that no incremental fibres are used. If they are used, this simply increases the number of distance samples that are recorded, and it is straightforward to modify the notation and computations. The method then becomes very similar to that of 6.3, with the lead-in fibre being equivalent to fibre A and the loop length equivalent to fibre B.

6.4.3.2 Preparation

Establish the technique (automatic or manual) of placing the markers at the leading edges of the reflections from the recirculating delay line, following the manufacturer's recommendations.

Connect the recirculating delay line assembly directly to the OTDR so that the reflective features can be seen on the OTDR.

6.4.3.3 Taking the measurement results

Measure the locations of successive reflections from the recirculating delay line with the OTDR. Record these as $L_{otdr,i}$, where the index i goes from 0 to k and represents the number of passes through the loop. A large number k will presumably increase the accuracy of the result, but it will be limited by loss and the noise floor of the OTDR.

6.4.4 Calculations and results

Using the calibration data of the recirculating delay line T_a and T_b the series of reference locations is

$$i = 1:\ L_{\text{ref},1} = \frac{c(T_a + T_b/2)}{N} \quad (32)$$

$$i = 2:\ L_{\text{ref},2} = \frac{c(T_a + T_b)}{N} \qquad \text{etc.}$$

where N is the group index setting of the OTDR.

Then use the displayed locations $L_{\text{otdr,i}}$ and the reference locations to calculate the series of location deviations ΔL_i:

$$\Delta L_i = L_{\text{otdr,i}} - L_{\text{ref,i}} = \Delta S_L L_{\text{ref,i}} + \Delta L_0 + f(L_{\text{ref.i}}) \quad (33)$$

To determine the location offset ΔL_0 and the distance scale deviation ΔS_L, fit the location deviation data to the simplified location deviation model (in which the location readout uncertainty is momentarily neglected):

$$\Delta L_{\text{i,model}} = \Delta S_L L_{\text{ref},0} + \Delta L_0 \quad (34)$$

Specifically, minimize the difference between the model and the data using the least-squares criterion, that is choose ΔS_L and ΔL_0 so that the summation:

$$\sum_i \left(\Delta L_i - \Delta S_L L_{\text{ref,i}} - \Delta L_0\right)^2 \quad (35)$$

is minimized. Record ΔL_0 and ΔS_L obtained from the approximation.

6.4.5 Uncertainties

6.4.5.1 General

A general discussion of the distance uncertainties is given in Clause 5.

Note that the following list of uncertainties may not be complete. Additional contributions may have to be taken into account, depending on the measurement set-up and procedure. The mathematical basis given in Annex B should be used to calculate and state the uncertainties.

6.4.5.2 Distance scale uncertainty

The least-squares approximation outlined in 6.4.4 effectively uses the displayed distances between the measurement samples to calculate the distance scale deviation. It is assumed that the group of measurement samples near L = 0 and the one near the farthest location $L = L_{\text{max}}$ have the strongest influence on the distance scale deviation because the samples in the middle of the range have less influence on the slope of the distance error model.

Applying the standard formula for the propagation of errors to Equation (4) yields the distance scale uncertainty $u_{\Delta SL}$ in which $< D_{\text{otdr}} > \cong D_{\text{ref}}$ was used.

$$u_{\Delta SL} \cong \left[\left(\frac{u_{<\text{Dotdr}>}}{< D_{\text{otdr}} >}\right)^2 + \left(\frac{u_{\text{Dref}}}{D_{\text{ref}}}\right)^2\right]^{1/2} \text{ m/km} \quad (36)$$

where

D_{otdr} is $D_{\text{ref}} \approx L_{\text{ref}}$ (for the long distances discussed here);

$u_{<Dotdr>}$ is the standard deviation expressing the uncertainty of the distance samples (on the basis of the location samples); this is equivalent to the standard deviation of the slope, ΔS_L in the location model of Equation (10) which includes the marker placement uncertainty and the distance sampling error; the least squares algorithm used for the determination of ΔS_L can be used to determine $u_{<Dotdr>}$; if incremental fibres are used, then ΔL_i may be averaged over the correspondent sampling interval;

u_{Dref} is the uncertainty of the reference distances; it can be calculated from the formula $u_{Dref}/D_{ref} = u_{Tb}/T_b$, where u_{Tb} is the uncertainty of the loop transit time, as documented in the calibration certificate of the recirculating delay line (see Annex A).

6.4.5.3 Location offset uncertainty

The location offset ΔL_0 is equal to the intercept of the least-squares approximation with the vertical axis. This intercept mostly depends on the first few samples, that is those which are closest to the location L = 0, and on the accuracy of the transit time T_a.

The location offset uncertainty $u_{\Delta L0}$ can be calculated by applying the standard formula for the propagation of errors to Equation (34)

$$u_{\Delta L0} = \left[u_{\Delta L}^2 + \left(\frac{c}{N} \right)^2 u_{Ta}^2 \right]^{1/2} \tag{37}$$

where

$u_{\Delta L}$ is the uncertainty of the differences between ΔL_i and the least squares approximation near L = 0; this includes the marker placement uncertainty and the distance sampling error; this is equivalent to the standard deviation of ($\Delta L_i - \Delta L_{i,\ model}$) near L = 0; the least squares algorithm used for the determination of ΔL_0 can be used to determine $u_{\Delta L}$; if incremental fibres are used, then ΔL_i may be averaged over the correspondent sampling interval;

u_{Ta} is the documented uncertainty of the delay time of the lead-in fibre of the recirculating delay line (see Annex A);

$u_{Ta,\Theta}$ is the uncertainty of the delay time of the lead-in fibre due to the temperature coefficient of the fibre; typical value: 1 cm/(km °C).

6.4.5.4 Location readout uncertainty

The principle of determining the location readout uncertainty is shown in Figure 2. With the recirculating delay line, it is expected that not enough data are produced to show the repetitive nature of the measurement samples. Nevertheless, it is recommended that the largest differences between the location deviations ΔL_i (L_{ref}) and the least-squares approximation be determined. Then divide this difference by the square root of 3 to obtain the location readout uncertainty $u_{Lreadout}$ (which includes the distance sampling error).

7 Vertical scale calibration – General

7.1 General

The vertical scale calibration process of an OTDR for multimode fibres is divided in two parts.

The first one is mostly related to the receiver part of the OTDR. It is called loss difference calibration. This part of the calibration process only considers the ability of the OTDR to properly measure the backscattered power received from the fibre.

The second part is the measurement of the launch conditions created by the laser source of the OTDR. The objective is to characterize the near field of the OTDR source in order to demonstrate that the backscatter signal is generated appropriately.

The characterization of the OTDR source can be carried out using a near field analysis (see IEC 61280-1-4).

The following subclauses outline the principles of the backscattered power calibration and the near field analysis.

7.2 Loss difference calibration

7.2.1 Determination of the displayed power level *F*

For each measured loss, determine the displayed power level or an equivalent parameter that can be used to reproduce the vertical position of a measurement sample. This level is termed F.

Unless otherwise specified, use the OTDR's clipping level, determined at the front panel connector location, as the (default) reference point for determining F: F_{ref} = 0 dB. State all values of F in relation to this reference point (for example, if the displayed power level is x dB below the clipping level, then $F = -x$ dB). The clipping level can be found by introducing a sufficiently large reflection into a length of fibre, as indicated in Figure 8.

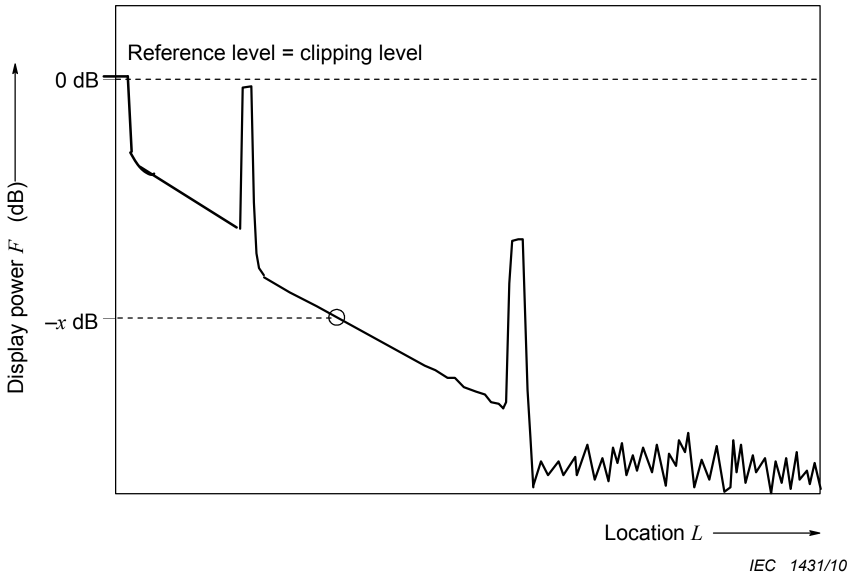


Figure 8 – Determining the reference level and the displayed power level

Alternative solutions may be to state the value of F in dB, relatively to a fixed level, if the OTDR provides the capability of reading out the displayed power in dB, or to use the start level of the backscatter trace from a specified type of fibre, at a specified pulse width, as the reference level. Note that, in the latter case, the reproducibility of the reference level is usually affected by the non-reproducibility of the connection to the OTDR port.

7.2.2 Development of a test plan

The loss samples may depend not only on the power level, but also on the distance and the history of the signal (that is, the shape of the fibre's OTDR signature) prior to the feature that is being measured. In particular, the detector and electronics may be affected by recovery from the initial firing of the laser and from signals due either to scattering or reflections in the fibre. The calibration will apply only to the distance and signal conditions for which it is performed.

This standard does not require specific conditions of signal history. For an aid in describing power levels and distance, this standard defines an OTDR display region A as an approximation to the region where the user normally takes measurements. For the purpose of this standard, region A is defined by four quantities, as illustrated in Figure 9: the extrapolated start of the backscatter trace for the specific pulse width used F_0, a lowest and a highest attenuation as defined in the table below, and 3 dB margins on both sides.

Table 2 – Attenuation coefficients defining region A

Wavelength nm	**Fibre attenuation coefficients**	
	Lowest (α_{min}) dB/km	**Highest (α_{max})** dB/km
850	1,5	3,5
1 300	0,3	1,5

On the same basis, attenuation coefficient values for other wavelengths may be chosen to represent typical multimode fibres. An analytical description of region A is given by

$$\begin{aligned} F_{max}(L) &= F_0 - \alpha_{min} L + 3 \text{ dB} \\ F_{min}(L) &= F_0 - \alpha_{max} L - 3 \text{ dB} \end{aligned} \tag{38}$$

F_{max} should not exceed an upper limit of 1 dB below the clipping level, unless otherwise specified by the OTDR manufacturer. The loss calibration points F should lie inside region A. Calibration data in regions B and C can be provided on a voluntary basis. Region B is applicable when the fibre path includes components with high loss. Region C is applicable when the fibre path includes components with strong reflection.

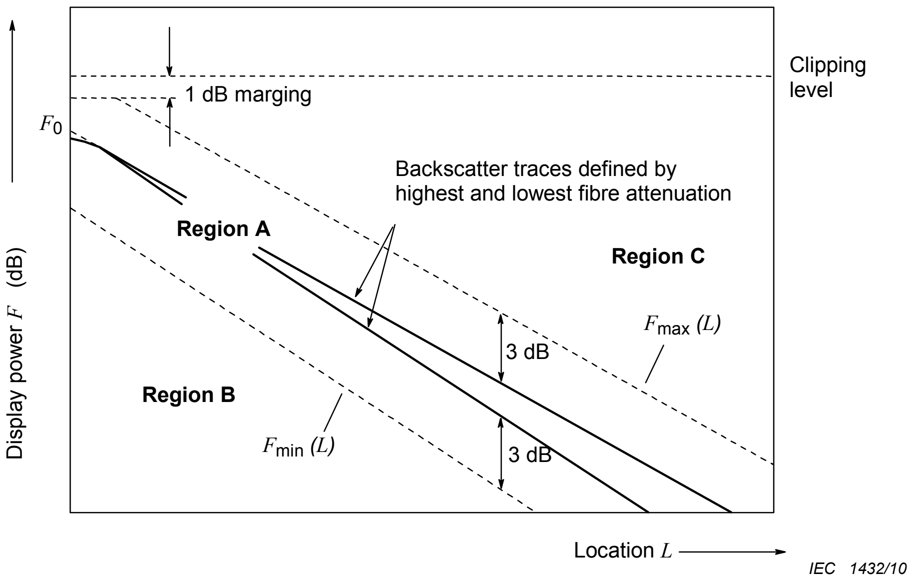


Figure 9 – Region A, the recommended region for loss measurement samples

For each of the methods outlined below, develop a test plan of sample placements, each of which is a combination of location and displayed power level. The goal is a vertical sample spacing of 0,5 dB to 1 dB, and not more than the reference loss A_{ref}. An attenuation range from F_0 down to the noise level and an even distribution of samples inside region A should be chosen. Overlapping measurement samples, that is samples at the same displayed power level but at different locations, are desirable, as indicated in Figure 10.

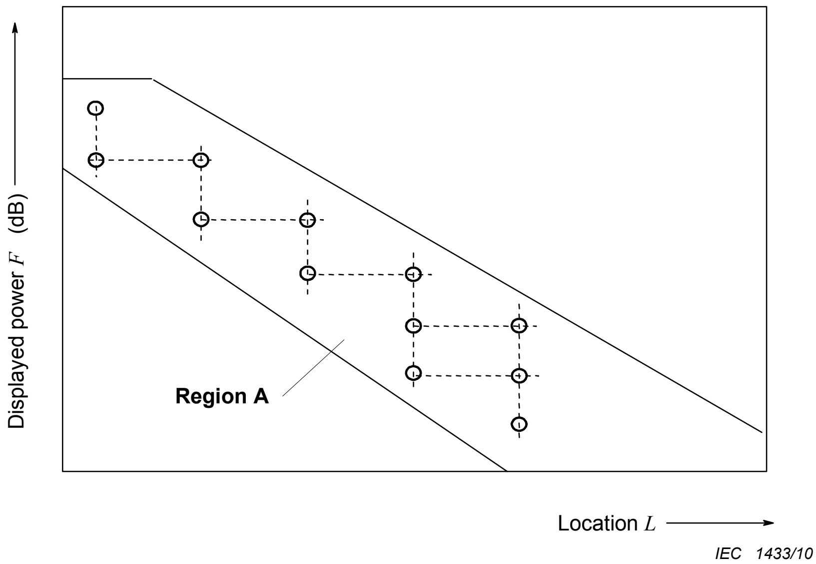


Figure 10 – Possible placement of sample points within region A

7.3 Characterization of the OTDR source near field

7.3.1 Objectives and references

The objective is to determine the encircle flux function *EF(r)* from the near field measurement of the light coming from the end of the test cord; and to compare it to the radial bound requirements.

$$EF(r) = \frac{\int_0^r xI(x)dx}{\int_0^R xI(x)dx} \tag{39}$$

The encircle flux limits are defined in the IEC 61280-4-1.

The requirements for the measurement and the process details are defined by the IEC 61280-1-4. The calibration procedure is given by the IEC 61745.

7.3.2 Procedure

In order to be consistent with the requirements of the IEC 61280-4-1, the OTDR source near field is measured at the end connector of the test cord.

Connect the end of the OTDR test cord to the near field measurement set up.

Measure the encircle flux function as defined per the reference documents.

Plot the measured function, the encircled flux lower bound and the encircled flux upper bound on the same diagram. The measured encircled flux curve should lie between the two bound curves.

8 Loss difference calibration method

8.1 General

Calibration methods that could provide loss calibration against known reference values are not available.

For the following method the loss reference is not supposed to be known; it is only supposed to be constant. Therefore the results only represent variations. Alternatively, if the attenuation is known with an appropriate level of uncertainty the measurement results can be reported differently (see 8.2.4).

8.2 Long fibre method

8.2.1 Short description

The long fibre method describes the measurement of the linearity of the OTDR power scale with the help of a long multimode optical fibre. This reference loss is not known; it is only supposed to be constant.

8.2.2 Equipment

8.2.2.1 General

In addition to the test OTDR, the measurement equipment includes

a) a long multimode fibre type A1a or A1b fibres (see IEC 60793-2-10);

b) a set of multimode lead-in fibres, these shall be type A1a or A1b fibres (see IEC 60793-2-10) able to create a minimum of 1 dB attenuation;

c) a variable attenuator for multimode fibre;

d) mode conditioner;

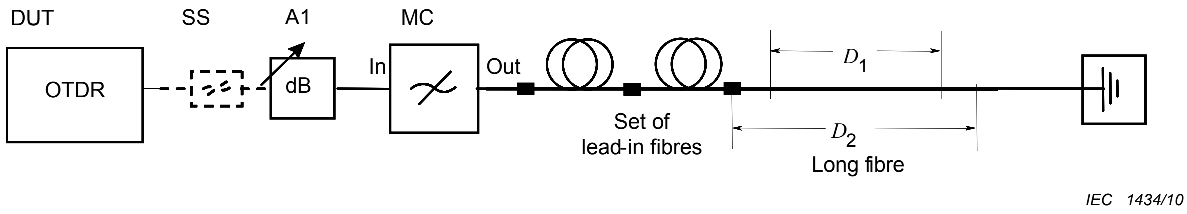
e) speckle scrambler optional.

The purpose of the attenuator and lead-in fibres is to place the fibre standard at a number of different locations within region A (see Clause 7) of the OTDR display. Example: the displayed power level can be varied within a 14 dB range with 2 dB steps by a proper combination of three lead-in fibres with attenuation values of 2 dB, 4 dB and 8 dB.

These fibres should be equipped with reference type connectors; the attenuation numbers include the typical connector losses. In order to obtain the recommended (finer) sample spacing of 0,5 dB, the attenuator will have to be varied between 0 dB and 1,5 dB in 0,5 dB steps.

It should be noted that the attenuator is not necessary if the recommended steps of 0,5 dB are generated with a larger number of lead-in fibres.

The purpose of the mode conditioner is to comply with the launch condition requirements and to ensure that any changes in modal condition as the attenuator is adjusted do not propagate through to the fibre. As an option the speckle scrambler can be used to improve repeatability.



Key

A1 variable attenuator

MC mode conditioner

SS speckle scrambler (optional)

Figure 11 – Linearity measurement with a long fibre

8.2.2.2 Determination of the initial loss

The objective of this part of the procedure is to properly define reference points on the fibre to be used to always measure the same loss.

Measure the total length D_2 of the long fibre according to the OTDR manufacturer's instructions for length measurement. Using the OTDR markers, select a section of the fibre, of length D_1, outside the attenuation dead zone caused primarily by any connectors in front of the fibre standard (see Figure 12). Choose the beginning of the section so that the difference between the actual backscatter trace and its linear extrapolation ΔF_{max} is sufficiently small at that point (a lead-in fibre may be necessary to accomplish this). Measure the length of the section D_1.

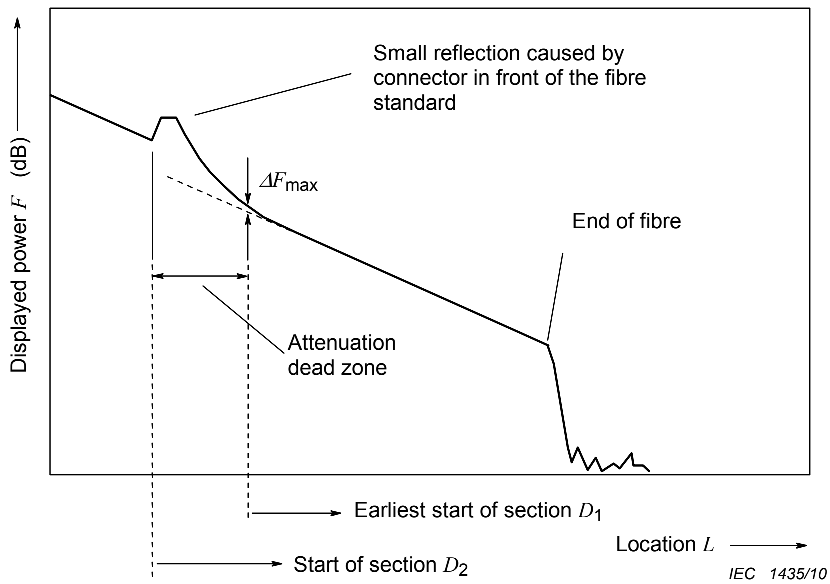


Figure 12 – Placing the beginning of section D_1 outside the attenuation dead zone

A length D_1 that corresponds to an initial loss of about 1 dB is recommended. Back reflections from the fibre standard's far end should be carefully avoided, because they can influence the preceding backscatter trace.

8.2.3 Measurement procedure

8.2.3.1 Preparation

First, develop a test plan of fibre/attenuator settings so that a vertical sample spacing of approximately 0,5 dB is achieved and all measurement samples fall within the region A of the OTDR display; an example is described in 7.2.2.

8.2.3.2 Taking the measurement results

For each displayed power level F_i, measure the loss value $A_{otdr,i}$. In order to reduce the uncertainty, it is recommended to average around the markers or over the entire length D_1, instead of using single power levels. Longer OTDR averaging may be advisable at low displayed power levels in order to reduce the uncertainty type A; all applied averaging times should be reported in this case. Record all $A_{otdr,i}$ displayed power levels F_i and locations L_i.

8.2.4 Calculation and results

Calculate the non-linearity NL_{loss} using Equation (40)

$$NL_{loss} = \pm \max \left| A_{otdr,i} - A_{otdr,0} \right| \quad \text{dB} \tag{40}$$

where $A_{otdr,0}$ is the initial loss.

Alternatively, if the attenuation of the fibre A_{ref} is known with an appropriate level of uncertainty, calculate the loss deviation samples ΔA_i using Equation (41)

$$\Delta A_i = A_{otdr,i} - A_{ref} \quad \text{dB} \tag{41}$$

Or report the loss scale deviation using Equation (42)

$$\Delta S_{A,i} = \frac{A_{otdr,i} - A_{ref}}{A_{ref}} \quad \text{dB/dB} \tag{42}$$

Annex A
(normative)

Multimode recirculating delay line for distance calibration

A.0 Introduction

In this annex, a fibre-type recirculating delay line to be used as calibration artefact for multimode OTDR distance calibration is described.

A.1 Construction

As illustrated in Figure A.1, the device is constructed from the following:

a) a multimode four-port coupler, with a long fibre (the length of which depends on the distance range to be calibrated) fusion spliced between a pair of input and output ports. The fibre core diameter may be either 50 µm or 62,5 µm, independently of the OTDR fibre type. Identical fibre core diameters allow keeping the insertion loss at a minimum and should be used for measurements over very long distances. The length of the long fiber shouldn't exceed one kilometre in order to keep the intermodal dispersion to an acceptable level, independently of the fibre type and of the launching condition;

b) an input fibre (typically around 250 m) which is spliced to the second input port with the input equipped with a connector;

c) an output fibre which is spliced to the second output port of the coupler and which is terminated with a low back-reflection connector. The length of this fibre piece is kept short, for example <1 m;

d) a device with a high reflectance which can be used to create a reflection at the end of the output fibre.

The length of the lead-in fibre is defined by the input fibre, one branch of the coupler and the output fibre. The length of the loop is defined by the long fibre specified in item a) and the second half of the coupler.

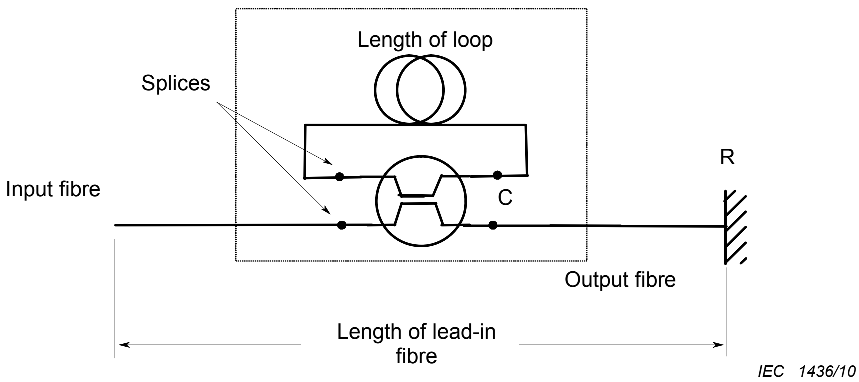


Figure A.1 – Recirculating delay line

A.2 Calibration

A.2.1 General

The objective is to calibrate a recirculating delay line for two parameters: the transit time of the fibre in the loop T_b and the transit time of the input length T_a. The latter is the sum of the transit times of the input fibre, the coupler pigtails and output fibre.

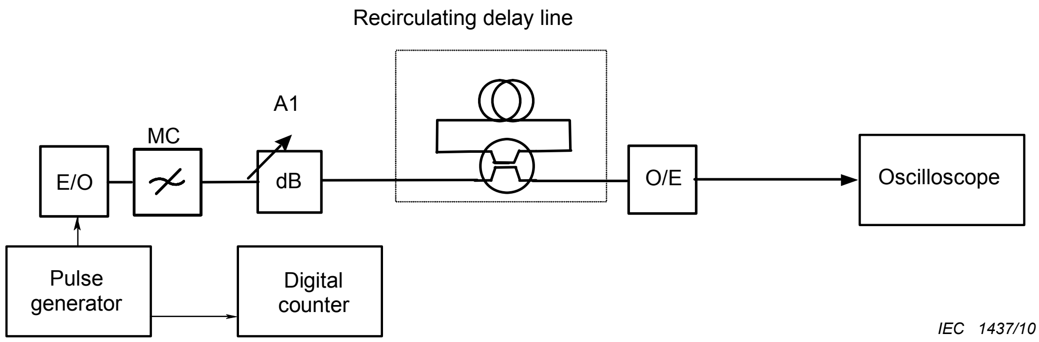
A.2.2 Measurement equipment

The equipment consists of a pulse generator with variable rate and delay, a digital counter, E/O and O/E converters, an oscilloscope and an optical attenuator. The centre wavelength of the E/O converter shall be known.

A.2.3 Procedure

A.2.3.1 Loop transit time measurement

To determine the loop transit time, set up the system shown in Figure A.2. A mode conditioner (MC) will be used either to establish a launch condition similar to the one produced by the OTDR or to generate an overfill. Set the pulse generator to give pulses of suitable width, and the attenuator to generate a suitable amplitude for the E/O converter. Set the pulse repetition rate, in kilohertz, to $200/L_b$, where L_b is the approximate length of the fibre in the loop in kilometres. View the output pulses from the O/E converter on the oscilloscope and then adjust the repetition rate until the following two pulses are superimposed on the oscilloscope trace: first, the optical pulse which has been transmitted directly from the E/O converter to the O/E converter without going round the loop, and second, the fraction of the preceding optical pulse which has travelled once round the loop are detected together. Record the repetition period with the digital counter. This is the loop transit time T_b. Estimate the uncertainty $u_{Tb,adjust}$ by introducing small changes to the repetition rate.



Key

MC mode conditioner

E/O electrical-to-optical converter

O/E optical-to-electrical converter

A1 variable attenuator

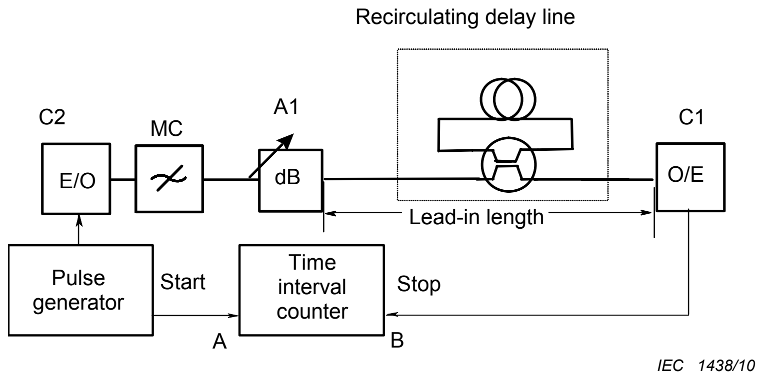
Figure A.2 – Measurement set-up for loop transit time T_b

A.2.3.2 Lead-in transit time measurement

To calibrate the transit time of the lead-in fibres, set up the system shown in Figure A.3. A mode conditioner (MC) will be used either to establish a launch condition similar to the one produced by the OTDR or to generate an overfill. Adjust the pulse width, amplitude and repetition rate (approximately 1 kHz is suggested) of the pulse generator to suitable values and provide a trigger signal for the digital counter. It may be necessary to delay the output pulse to the E/O converter with respect to this trigger pulse as some counters have a "dead time" between start and stop trigger. Adjust the trigger level of channel B of the counter so that it is just reliably triggered by the output of the O/E converter; this is to prevent the counter being triggered by smaller pulses which have made one or more circuits of the loop. Record the transit time T_1 displayed by the counter. Temporarily disconnect the O/E converter from the counter, connect to an oscilloscope, view the directly transmitted pulses and note their amplitude.

Then remove the recirculating delay line and connect the O/E converter directly to the attenuator. Again view the pulses on the oscilloscope. Adjust the attenuator to give pulses of the same amplitude as before. Reconnect the O/E converter to the counter and measure the transit time T_2. The transit time of the lead-in fibre T_a is then given by

$$T_a = T_1 - T_2 \tag{A.1}$$



Key

MC mode conditioner

E/O electrical-to-optical converter

O/E optical-to-electrical converter

A1 variable attenuator

Figure A.3 – Calibration set-up for lead-in transit time T_a

A.3 Uncertainties

The guidelines of the mathematical basis given in Annex B should be used to calculate and state the uncertainties.

The uncertainty of the loop transit time u_{Tb} should be accumulated, by root-sum-squaring, from the following contributions:

$u_{Tb,counter}$ the time uncertainty, in seconds, due to the digital counter, as caused by clock frequency uncertainty and time interval resolution;

$u_{Tb,adjust}$ the time uncertainty, in seconds, due to adjusting the repetition rate with the help of the oscilloscope;

$u_{Tb,\lambda}$ the time uncertainty, in seconds, due to the uncertainty of the E/O converter's centre wavelength; it can be calculated by multiplying the wavelength uncertainty by the fibre length L_a and the chromatic dispersion;

$u_{Tb,\Theta}$ the time uncertainty due to the fibre's temperature coefficient; typical value: 1 cm/(km °C) within the allowable temperature range;

$u_{\mathrm{Tb,MD}}$ the time uncertainty due to the modal dispersion at the applied launch condition.

The uncertainty of the lead-in transit time u_{Ta} should be accumulated, by root-sum-squaring, from the following contributions:

$u_{\mathrm{Ta,counter}}$ the time uncertainty, in seconds, due to the digital counter, as caused by clock frequency uncertainty, time interval resolution and setting the trigger amplitude;

$u_{\mathrm{Ta,type\ A}}$ the time uncertainty type A, in seconds, for example as caused by timing jitter; it can be obtained from a series of successive counter readings;

$u_{\mathrm{Ta},\lambda}$ the time uncertainty, in seconds, due to the uncertainty of the E/O converter's centre wavelength; it can be calculated by multiplying the wavelength uncertainty by the fibre length L_{a} and the chromatic dispersion;

$u_{\mathrm{Ta},\Theta}$ the time uncertainty due to the fibre's temperature coefficient; typical value: 1 cm/(km °C) within the allowable temperature range;

$u_{\mathrm{Ta,MD}}$ the time uncertainty due to the modal dispersion at the applied launch condition.

Additional contributions may have to be taken into account, depending on the measurement set-up and procedure.

A.4 Documentation

The following calibration results shall be supplied with the recirculating delay line

a) approximate lengths of lead-in fibre and loop;

b) measured transit times of lead-in fibre and loop;

c) centroidal wavelength of the E/O converter;

d) time uncertainties ±2 u_{Ta} and ±2 u_{Tb} as calculated according to Clause A.3.

Annex B
(normative)

Mathematical basis

B.0 Introduction

This annex summaries the form of evaluating, combining and reporting the uncertainty of measurement. It is based on the "Guide to the expression of uncertainty in measurement” (ISO/IEC Guide 98-3(GUM). It does not relieve the need to consult this guide for more advice.

This standard distinguishes two types of evaluation of uncertainty of measurement. Type A is the method of evaluation of uncertainty by the statistical analysis of a series of measurements on the same measurand. Type B is the method of evaluation of uncertainty based on other knowledge.

B.1 Type A evaluation of uncertainty

The type A evaluation of standard uncertainty can be applied when several independent observations have been made for a quantity under the same conditions of measurement.

For a quantity X estimated from n independent repeated observations X_{k}, the arithmetic mean is

$$\overline{X} = \frac{1}{n}\sum_{k=1}^{n} X_{\mathrm{k}} \tag{B.1}$$

This mean is used as the estimate of the quantity, that is $x = \overline{X}$. The experimental standard deviation of the observations is given by

$$s(X) = \left[\frac{1}{n-1}\sum_{k=1}^{n}\left(X_{\mathrm{k}} - \overline{X}\right)^2\right]^{1/2} \tag{B.2}$$

where

$\overline{X}$ is the arithmetic mean of the observed values;

X_{k} are the measurement samples of a series of measurements;

n is the number of measurements; it is assumed to be large, for example, $n \geq 10$.

The type A standard uncertainty $u_{\mathrm{typeA}}(x)$ associated with the estimate x is the experimental standard deviation of the mean

$$u_{\mathrm{typeA}}(x) = s(\overline{X}) = \frac{s(X)}{\sqrt{n}} \tag{B.3}$$

B.2 Type B evaluation of uncertainty

The type B evaluation of standard uncertainty is the method of evaluating the uncertainty by means other than the statistical analysis of a series of observations. It is evaluated by scientific judgement based on all available information on the variability of the quantity.

If the estimate x of a quantity X is taken from a manufacturer's specification, calibration certificate, handbook, or other source and its quoted uncertainty $U(x)$ is stated to be a multiple k of a standard deviation, the standard uncertainty $u(x)$ is simply the quoted value divided by the multiplier.

$$u(x) = U(x) / k \tag{B.4}$$

If only upper and lower limit X_{max} and X_{min} can be estimated for the value of the quantity X (for example a manufacturer's specifications or a temperature range), a rectangular probability distribution is assumed, the estimated value is

$$x = \frac{1}{2}(X_{max} + X_{min}) \tag{B.5}$$

and the standard uncertainty is

$$u(x) = \frac{1}{2\sqrt{3}}(X_{max} - X_{min}) \tag{B.6}$$

The contribution to the standard uncertainty associated with the output estimate y resulting from the standard uncertainty associated with the input estimate x is

$$u(y) = c \times u(x) \tag{B.7}$$

where c is the sensitivity coefficient associated with the input estimate x, that is the partial derivative of the model function $y(x)$, evaluated at the input estimate x.

$$c = \frac{\partial y}{\partial x} \tag{B.8}$$

The sensitivity coefficient c describes the extent to which the output estimate y is influenced by variations of the input estimate x. It can be evaluated by Equation (B.8) or by using numerical methods, that is by calculating the change in the output estimate y due to a change in the input estimate x from a model function. Sometimes, it may be more appropriate to find the change in the output estimate y due to the change of x from an experiment.

B.3 Determining the combined standard measurement uncertainty

The combined standard measurement uncertainty is used to collect a number of individual uncertainties into a single number. The combined standard measurement uncertainty is based on statistical independence of the individual uncertainties, it is calculated by root-sum-squaring all standard uncertainties obtained from type A and type B evaluation

$$u_c(y) = \sqrt{\sum_{i=1}^{n} u_i^2(y)} \tag{B.9}$$

where

i is the current number of individual contribution;

$u_i(y)$ are the standard uncertainty contributions;

n is the number of uncertainties.

NOTE It is acceptable to neglect uncertainty contributions to this equation that are smaller than 1/10 of the largest contribution, because squaring them will reduce their significance to 1/100 of the largest contribution.

When the quantities above are to be used as the basis for further uncertainty computations, then the combined standard measurement uncertainty, u_c, can be re-inserted into Equation (B.9). Despite its partially type A origin, u_c should be considered as describing an uncertainty of type B.

B.4 Reporting

In calibration reports and technical data sheets, combined standard measurement uncertainties shall be reported in the form of expanded measurement uncertainties, together with the applicable level of confidence. Correction factors or deviations shall be reported. The expanded measurement uncertainty U is obtained by multiplying the standard uncertainty $u_c(y)$ by a coverage factor k:

$$U = k \times u_c(y) \tag{B.10}$$

For a coverage probability of approximately 95 %, the default level, then $k = 2$. If a level of confidence of approximately 99 % is chosen, then $k = 3$. The above values for k are valid under some conditions, see ISO/IEC Guide 98-3 (GUM); if these conditions are not met, larger coverage factors are to be used to reach these levels of confidence.

Bibliography

[1] IEC 60050-731:1991, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication*

[2] IEC 60793-1-1, *Optical Fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

[3] IEC 60793-1-40, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

[4] IEC 60794-1-2, *Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures*

[5] IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

[6] IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

[7] IEC 61280-1-3, *Fibre optic communication subsystem test procedures – Part 1-3: General communication subsystems – Central wavelength and spectral width measurement*

[8] IEC 61280-2-10, *Fibre optic communication subsystem test procedures – Part 2-10: Digital systems – Time-resolved chirp and alpha-factor measurement of laser transmitters*

[9] IEC 61300-3-6, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss*

[10] IEC/TR 61930:1998, *Fibre optic graphical symbology*

[11] IEC/TR 61931, *Fibre optic – Terminology*

[12] VIM: 1993, *International vocabulary of basic and general terms in metrology*

[13] ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM)*

[14] DANIELSON, DL. *Backscatter measurements on optical fibers*, NBS Technical Note 1034, US Department of Commerce, 1981

[15] KAPRON, FP. et al. *Fiber-optic reflection measurements using OCWR and OTDR techniques*. Journal of Lightwave Technology. Vol 7, No 8, August 1989

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