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Edition 2.0 2024-06
COMMENTED VERSION

INTERNATIONAL STANDARD

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Optical fibres –
Part 1-22: Measurement methods and test procedures – Length measurement

IEC 60793-1-22:2024-06 CMV(en)

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Part 1-22: Measurement methods and test procedures – Length measurement

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OPTICAL FIBRES –

Part 1-22: Measurement methods and test procedures – Length measurement

FOREWORD

This commented version (CMV) of the official standard IEC 60793-1-22:2024 edition 2.0 allows the user to identify the changes made to the previous IEC 60793-1-22:2001 edition 1.0. Furthermore, comments from IEC SC 86A experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

IEC 60793-1-22 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This second edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Inclusion of category C single mode fibres in Table 1;
b) Inclusion of a new informative Annex F on Brillouin frequency shift test method to determine the tensile strain applied to a fibre.

The text of this International Standard is based on the following documents:

Draft	Report on voting
86A/2456/FDIS	86A/2474/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60793 series, published under the general title *Optical fibres*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Publications in the IEC 60793-1 series concern measurement methods and test procedures as they apply to optical fibres.

Within the same series several different areas are grouped, as follows:

- ~~parts 1-10 to 1-19: General~~
- IEC 60793-1-20 to IEC 60793-1-29: *Measurement methods and test procedures for dimensions*
- IEC 60793-1-30 to IEC 60793-1-39: *Measurement methods and test procedures for mechanical characteristics*
- IEC 60793-1-40 to IEC 60793-1-49: *Measurement methods and test procedures for transmission and optical characteristics*
- IEC 60793-1-50 to IEC 60793-1-59: *Measurement methods and test procedures for environmental characteristics.*
- IEC 60793-1-60 to IEC 60793-1-69: *Measurement methods and test procedures for polarization-maintaining fibres.*

IEC 60793-1-2X consists of the following parts, under the general title: Optical fibres:

- Part 1-20: Measurement methods and test procedures – Fibre geometry
- Part 1-21: Measurement methods and test procedures – Coating geometry
- Part 1-22: Measurement methods and test procedures – Length measurement

OPTICAL FIBRES –

Part 1-22: Measurement methods and test procedures – Length measurement

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the length and elongation of optical fibre (typically within cable).

The length of an optical fibre is ~~one of the most~~ a fundamental value~~s and shall be known~~ for the evaluation of transmission characteristics such as losses and bandwidths.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60793-1-40, *Optical fibres – Part 1-40: Attenuation measurement methods~~ and test procedures – Attenuation~~*

IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

~~IEC 60794-1-1, *Optical fibre cables – Part 1-1: Generic specification – General*~~

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

BOTDA Brillouin optical time domain analysis
BOTDR Brillouin optical time domain reflectometry
FWHM full-width half-maximum
OTDR optical time domain reflectometer
RMSW root-mean-squared width
RTM reference test method

4 Overview of method

4.1 General

This document gives five methods for measuring length, which are presented in Table 1.

Table 1 – Measurement methods

Method		Characteristics covered	Fibre categories covered	~~Former designation~~
A	Delay measuring	Length	All A1, B, and ~~all B~~ C 1	~~IEC 60793-1-A6~~
B	Backscattering	Length	All A1, B, and ~~all B~~ C	~~IEC 60793-1-C1C~~
C	Fibre elongation [a]	Fibre elongation [c]	A1, B1 [b], and C	~~IEC 60793-1-A7~~
D	Mechanical	Length	All	~~IEC 60793-1-A5~~
E	Phase shift	Length	All A1, B, and ~~all B~~ C	~~IEC 60793-1-A8~~

[a] The measurement of fibre elongation~~, method C,~~ is ~~part of several measurement methods for fibres and fibre optic cables, such as those~~ used in IEC 60794-1-1.

[b] This measurement is applicable unreservedly to type B single-mode fibres. For type A1 multimode fibres, take particular care when interpreting the results because the results of this measurement ~~may~~ can be influenced by interfering modal effects, for example, due to the occurrence of non-longitudinal stresses on the fibre. Application of the measurement to A2 to A4 multimode fibres is under consideration.

[c] Informative Annex F has been added to determine the tensile strain applied to a fibre. It uses Brillouin reflectometry (BOTDR) or so-called Brillouin analysis (BOTDA), which are single-sided and double-sided methods respectively.

Information common to all measurements is contained in Clause 2 to Clause 8. Information on specific application appears in Annex A, Annex B, Annex C, Annex D, and Annex E for methods A, B, C, D and E, respectively.

4.2 Method A – Delay measuring

The delay measuring method applies to measurements of the fibre length by the measurement of the propagation time of an optical pulse or a pulse train based on a known value of the group index of the fibre.

Alternatively, this method is suitable for measuring the group index of a fibre of known length. Therefore, in practice this fibre length measurement method is calibrated against a known length of fibre of the same type.

4.3 Method B – Backscattering

The backscattering method, which is a single-sided measurement, uses an optical time domain reflectometer (OTDR), and measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

4.4 Method C – Fibre elongation

This measurement method describes a procedure for determining the fibre elongation. It does not measure absolute strain, but instead measures the changes in strain from one loading condition to another.

4.5 Method D – Mechanical length

This measurement method describes a procedure for determining the fibre length by winding a fibre around a fixed diameter calibrated wheel that rotates. The length is determined by the number of revolutions of the wheel.

4.6 Method E – Phase shift

The phase shift method describes a procedure for determining the fibre length. The length is determined from the phase shift that occurs when a predetermined modulation frequency f_{max} is applied.

4.7 Reference test method

The reference test method (RTM), which shall be the one used to settle disputes, varies depending on whether the fibre is cabled or not, such as

- uncabled fibre: method D;
- length of fibre within cable: method B;
- elongation of fibre within cable: method C;
- elongation of uncabled fibre: method C.

5 Apparatus

Annex A, Annex B, Annex C, Annex D, and Annex E include layout drawings and other equipment requirements for each of the methods A, B, C, D and E, respectively.

6 Sampling ~~and specimens~~ 2

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements. General requirements follow.

Prepare a flat end face, perpendicular to the fibre axis, at the input and output ends of each ~~specimen~~ sample for measurements based on optical delay measurements.

7 Procedure

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements.

8 Calculations

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements.

9 Results

The following information shall be provided with each measurement:

- date and title of measurement;
- identification and description of ~~specimen~~ sample, including whether fibre or cable;
- ~~specimen~~ sample length, or elongation;
- measurement method used: A, B, C, D or E;

– other results, as required by the appropriate Annex A, Annex B, Annex C, Annex D or Annex E.

The following information shall be available upon request:

– description of measurement apparatus arrangement;
– type and wavelength of measurement source;
– launch conditions;
– details of computation technique;
– date of latest calibration of equipment.

See Annex A, Annex B, Annex C, Annex D and Annex E for any additional information that shall be available upon request.

10 Specification information

The detail specification shall specify the following information:

– type of fibre (or cable) to be measured;
– failure or acceptance criteria;
– information to be reported;
– deviations to the procedure that apply.

Annex A
(normative)

Requirements specific to method A – Delay measuring

A.1 General

Use this method to measure the length of optical fibre by itself or installed in cable. If the ~~specimen~~ sample is a fibre in a cable, determine the value of group index N under conditions applicable to the ~~specimen~~ sample under measurement (for example, tension, temperature). This is done by inverting Formula (A.1) and the measurements on a ~~specimen~~ sample with a known length.

A.2 Principle

An optical pulse travelling through an optical fibre with length L and average group index N experiences a ~~travelling/delay time~~ time delay, Δt:

$$\Delta t = \frac{NL}{C} \tag{A.1}$$

where

Δt is the time delay;

N is the average group index;

C is the velocity of light in vacuum.

If N is known, the measurement of Δt gives L. On the other hand, the measurement of Δt gives the value of N when L is known.

A.3 Apparatus

A.3.1 Two techniques

There are two techniques for measuring the propagation time of an optical pulse:

– time measurement of the transmitted pulse (Δt measured);

– time measurement of the reflected pulse ($2\Delta t$ measured).

See Figure A.1 and Figure A.2 for two different arrangements corresponding to the two techniques applying a sampling oscilloscope.

Instead of the sampling oscilloscope, backscattering equipment, or a counter with separate start-stop gate and averaging capability (e.g. at least 10^4 counts), can be used.

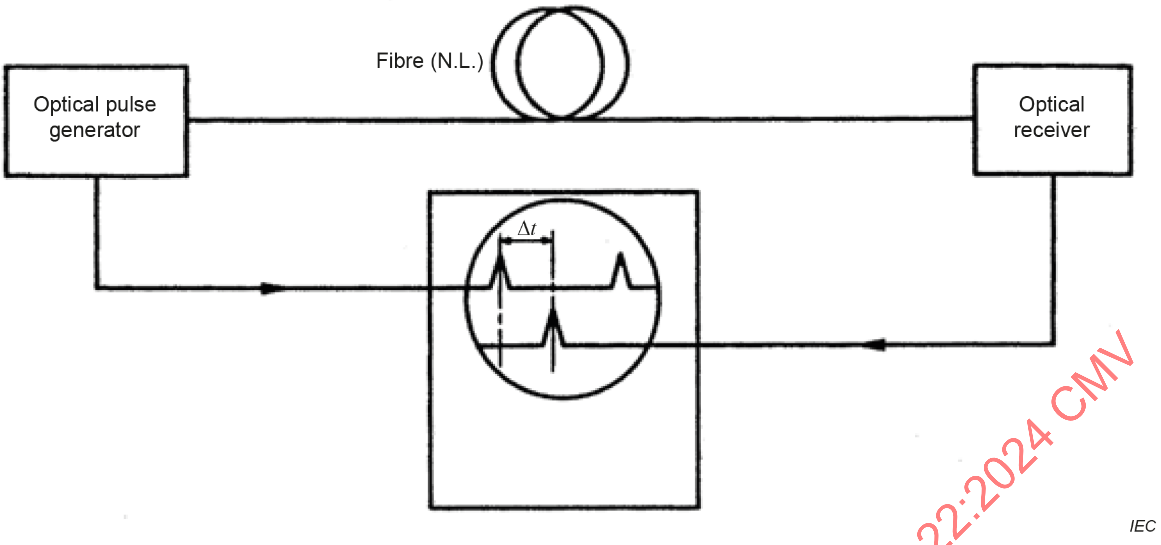


Figure A.1 – Time measurement of the transmitted pulse

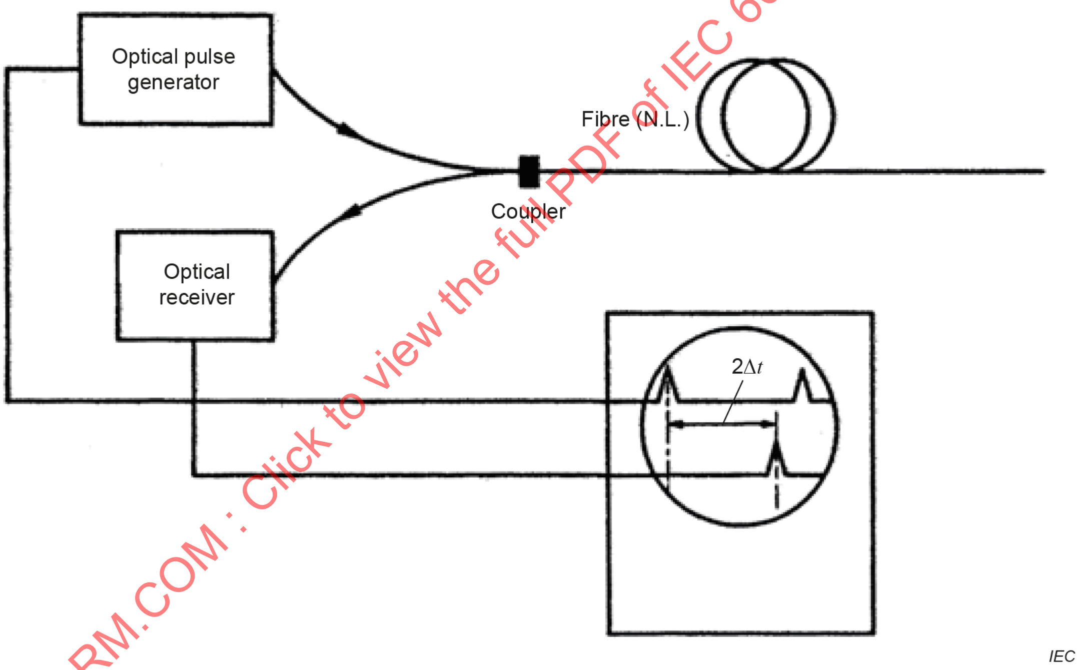


Figure A.2 – Time measurement of the reflected pulse

A.3.2 Optical source

A.3.2.1 Measurement with the sampling oscilloscope

An optical pulse generator shall ~~preferably~~ be a high-power laser diode, excited by an electrical pulse train generator, tunable in frequency and width. Record the wavelength and the spectral width.

A.3.2.2 Measurement with a counter or a backscattering apparatus

An optical pulse generator shall ~~preferably~~ be a high-power laser diode, excited by an electrical pulse train generator, tunable in width. The time between two pulses shall be longer than the travelling time of the transmitted pulse (Δt, with counter) or the reflected pulse ($2\Delta t$, with backscattering equipment). Record the wavelength and the spectral width of the laser diode.

A.3.3 Optical detector

The receiver shall ~~preferably~~ be a high-speed avalanche photodiode. The sensitivity of the optical detector ~~shall be sufficient~~ at the measuring wavelength, and its bandwidth shall ~~be large enough so as not to~~ not influence the shape of the pulse.

A.4 Procedure

A.4.1 Calibration

Measure the delay time of the optical source to the launching point (this is the delay time of the measurement apparatus itself).

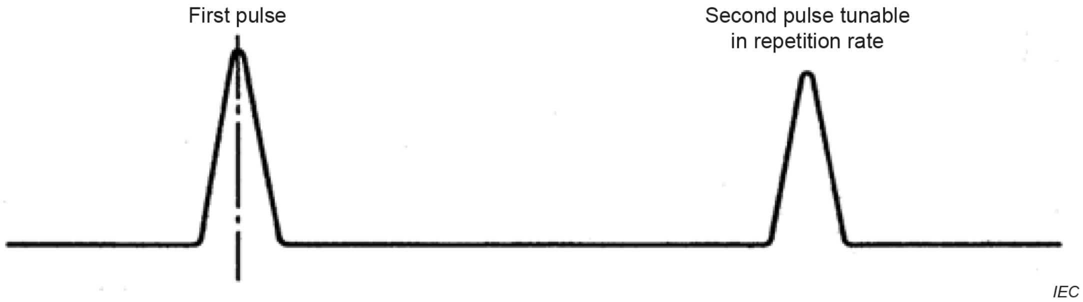
A.4.2 Average group index value

On a known length of mechanically measured fibre, the measurement of Δt, gives the average value, N, of the group index of the fibre.

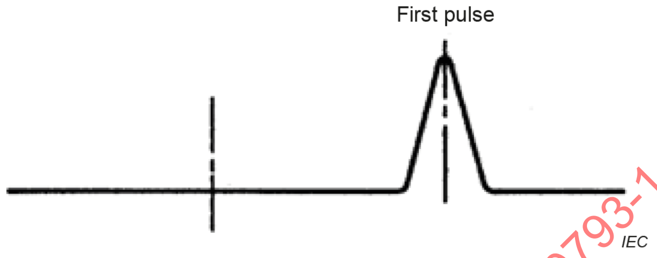
A.4.3 Length measurement

The length measurement is a time-domain reading on the screen of an oscilloscope (or the reading of the averaged travelling time on the display of an electronic counter to be corrected for the calibration value).

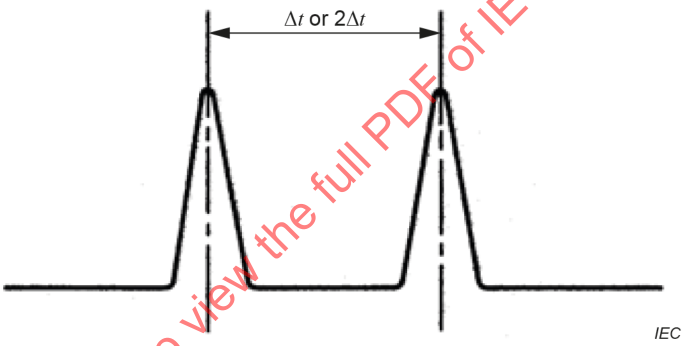
NOTE See Figure A.3 for an illustration of an important practical improvement for achieving the accuracy of the measurement, independent of the actual length of the fibre ~~specimen~~ sample. This uses a dual-channel approach.



a) **Channel 1: emitted pulse**



b) **Channel 2: transmitted pulse**



c) **Emitted pulse after adjustment of the repetition rate in such a way that the second pulse of channel 1 coincides with the transmitted pulse of channel 2**

Figure A.3 – Principle of fibre-length measurement

A.5 Calculations

A.5.1 General

Obtain the fibre length from one of the following formulae:

A.5.2 Transmitted-pulse technique

$$L = \frac{\Delta t \times c}{N} \qquad \text{(A.2)}$$

A.5.3 Reflected-pulse technique

$$L = \frac{\Delta t \times c}{2N} \tag{A.3}$$

where

L is the fibre length, in m;

Δt is the transmission or reflection time, in ns;

c is the light velocity in vacuum, in m/ns;

N is the average group index.

A.6 Results

In addition to the results in Clause 9, the following information ~~shall~~ can be available upon request:

– average group index;

– delay time of the measurement apparatus ~~(optional)~~;

– transmission or reflection time ~~(optional)~~.

Annex B
(normative)

Requirements specific to method B – Backscattering

B.1 General

This method uses an OTDR to measure the length of optical fibre by itself and installed in cable.

B.2 Apparatus

B.2.1 General

This method uses an optical time-domain reflectometer (OTDR), which shall normally consist of the following minimum list of components. See Figure B.1 for a block diagram.

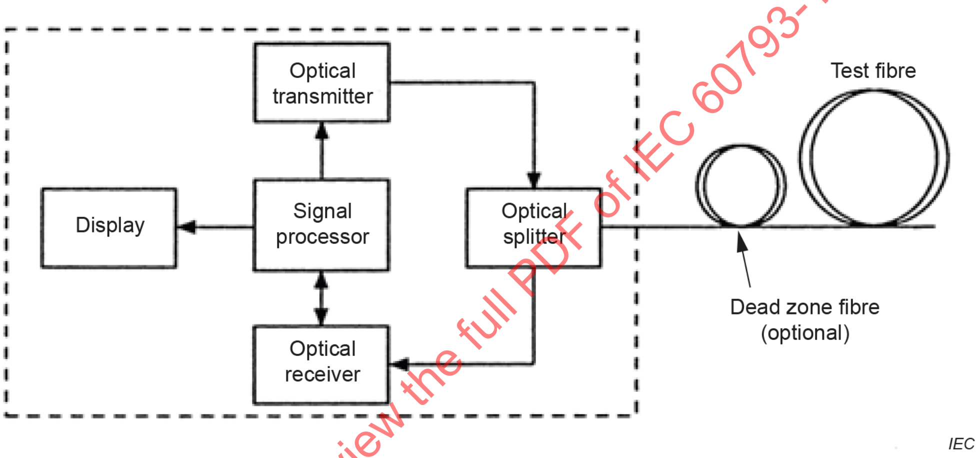


Figure B.1 – Block diagram of an OTDR

B.2.2 Optical transmitter

B.2.2.1 This usually includes one or more pulsed laser diode sources capable of one or more pulse durations and pulse repetition rates. Unless otherwise specified in the detail specification, the spectrum for each wavelength shall satisfy the following.

B.2.2.2 The ~~central~~ centroidal wavelength 3 shall lie within 15 nm of the specified value; report the difference between the ~~central~~ centroidal wavelength and the specified value if it is greater than 10 nm.

B.2.2.3 The root-mean-squared width (RMSW) shall not exceed 10 nm, or the full-width at half maximum (FWHM) shall not exceed 25 nm.

B.2.2.4 If the data are to be used in a spectral attenuation model:

– the spectral width shall not exceed 15 nm (FWHM) or 6 nm (RMS) for wavelengths in the water peak region (e.g. 1 360 nm to 1 430 nm);

– report the actual ~~central~~ centroidal wavelength to within 2 nm of the actual value.

B.2.3 Launch conditions

Provide a means for connecting the test fibre (or the optional dead-zone fibre of B.2.10) to the instrument panel, or to a fibre pigtail from the source.

For type A fibre, optical sources ~~may not~~ can produce launch conditions that are neither well controlled nor appropriate for this measurement method. Therefore, unless otherwise specified in the detail specification, launch conditions for attenuation measurements shall be those used in cut-back attenuation measurements (IEC 60793-1-40 method A).

B.2.4 Optical coupler or splitter

A coupler~~/~~ or splitter within the instrument directs the power from the transmitter into the fibre. It also directs light returning in the fibre from the opposite direction to the receiver.

B.2.5 Optical receiver

This usually includes a photodiode detector having a bandwidth, sensitivity, linearity and dynamic range compatible with the pulse durations used and signal levels received.

B.2.6 Pulse duration and repetition rate

The OTDR ~~may~~ can be provided a choice of several pulse durations and repetition rates (sometimes coupled to the distance control) to optimize the trade-off between resolution and range. With a high amplitude reflection, it ~~may~~ can be necessary to set the rate or range to a value exceeding twice the distance of the reflection in order to prevent spurious 'ghost' images. Pulse coding techniques ~~may~~ can also be used.

NOTE Care should be taken when selecting the pulse duration, repetition rate and source power. For shorter distance measurements, short pulse durations are necessary to provide adequate resolution. This in turn will limit dynamic range and maximum measurable length. For long length measurements, the dynamic range can be increased by increasing the peak optical power up to a level below which non-linear effects are insignificant. Alternatively, pulse width can be increased, which will reduce the resolution of the measurements.

B.2.7 Signal processor

If required, the signal-to-noise level ~~may~~ can be increased using signal averaging over a longer measurement time.

B.2.8 Display

This is incorporated into the OTDR and is part of the equipment controlling the OTDR. The OTDR signal is displayed in a graphical form with the vertical scale as decibels and the horizontal scale as distance. The vertical decibel scale shall correspond to half the round-trip of the backscatter loss. The horizontal scale shall correspond to half the associated (round-trip) optical group delay, converted to distance. Tools such as cursors ~~may~~ can be used to manually or automatically measure all or part of the OTDR trace on the display.

B.2.9 Data interface (optional)

The instrument ~~may~~ can be capable of interfacing with a computer for automatic analysis of the signal or for providing a hard copy of the display trace.

B.2.10 Reflection controller (optional)

Means of minimizing transient saturation of the receiver due to high Fresnel reflections ~~may~~ can be required to reduce the length of fibre "dead zone" following each reflector. This can be incorporated into the coupler~~/~~ or splitter or ~~may~~ can be done by electronic masking. To overcome the initial reflection at the OTDR connector, a dead-zone fibre (with a length in metres numerically exceeding one-tenth the displayed pulse duration in nanoseconds) ~~may~~ can be used between the OTDR connector and the ~~specimen~~ sample.

B.2.11 Splices and connectors

Unless otherwise indicated in this procedure, any splices or connectors required by the OTDR (e.g. to join the OTDR or the dead-zone fibre to the test fibre) shall have low insertion loss and reflectance (high return loss). This is to minimize extraneous effects upon the OTDR trace of interest.

B.3 Sampling ~~and specimens~~

The sample comprises a fibre on a reel or within a cable, under conditions specified in the detail specification. The measurement ~~may~~ can be performed in the factory or in the field, upon either single or concatenated sections.

NOTE ~~Care should be taken to~~ Ensure that winding does not introduce substantial elongation for length measurements.

B.4 Procedure

B.4.1 Three techniques

There are three techniques:

- two-point technique (B.4.3.1), to use when a fibre or cable section of unknown length precedes the test fibre or cable;
- single-point technique 0 (B.4.3.2), to use with no preceding section of fibre or cable;
- single-point technique 1 (B.4.3.3), to use with a preceding section of fibre of known length and similar group index as the fibre to be measured.

NOTE For cable measurement, it is important to note that, due to the structure of most cables, there is an excess length of fibre in the cable. Because of this, the cable group index exceeds the fibre group index for the same fibre type. This will lead to discrepancy between the fibre length in the cable and the cable length itself.

B.4.2 Procedure common to all three techniques

B.4.2.1 Connect the ~~specimen~~ sample either to the instrument or to one end of the dead-zone fibre (if used). Connect the other end of the dead-zone fibre (if used) to the instrument.

B.4.2.2 Because accurate distances are to be recorded, the effective group delay index of the ~~specimen~~ sample is required. If this value is not known, use the method described in B.4.4 to determine it.

B.4.2.3 Enter OTDR parameters such as source wavelength, pulse duration, length range and signal averaging into the instrument, along with the ~~specimen~~ sample group index. The values of some of these parameters ~~may~~ can be preset in the instrument.

B.4.2.4 Adjust the instrument to display a backscatter signal from the ~~specimen~~ sample. It ~~may~~ can be advantageous to begin with coarse vertical and horizontal scaling to maximize the length displayed.

B.4.2.5 If increased resolution is necessary, adjust the graphical display, if possible, to expand the section of interest to a larger scale (exercising care to ensure that proper readings of the true signal can still be distinguished from the noise points).

B.4.3 Procedures specific to each technique

B.4.3.1 Two-point technique

B.4.3.1.1 Place a cursor at the beginning of the trace of the ~~specimen~~ sample prior to any power drop-off (which ~~may~~ can be difficult to do) (Figure B.2), or at a point (which ~~may~~ can be specified by the manufacturer) on the rising edge of the reflection pulse (Figure B.3). If the beginning is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.3.1.2 Place the same or another cursor at the end of the trace of the ~~specimen~~ sample at a point similar to that in B.4.3.1.1. If the end is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Alternatively, cleave the fibre far-end, if possible, to produce a reflection there. If the end is below the noise floor, the length measurement ~~may~~ can have a maximum error equal to the pulse length. Obtain the distance co-ordinate, z_2.

B.4.3.1.3 For maximum length accuracy, the nature of the drop-off or rise-time points at z_1 and z_2 should be similar. Obtain the ~~specimen~~ sample length, $(z_2 - z_1)$.

B.4.3.2 Single-point technique 0

B.4.3.2.1 Use this method when no fibre or cable section (or dead-zone fibre) precedes the ~~specimen~~ sample. See Figure B.4.

B.4.3.2.2 Place a cursor at the end of the trace of the ~~specimen~~ sample prior to any power drop-off (which ~~may~~ can be difficult to do), or at a point (which ~~may~~ can be specified by the manufacturer) on the rising edge of the reflection pulse. If the end is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. If the end is below the noise floor, the length measurement ~~may~~ can have a maximum error equal to the pulse length.

Alternatively, cleave the fibre far-end, if possible, to produce a reflection there. Obtain the distance coordinate, z_2.

B.4.3.2.3 The ~~specimen~~ sample length equals z_2.

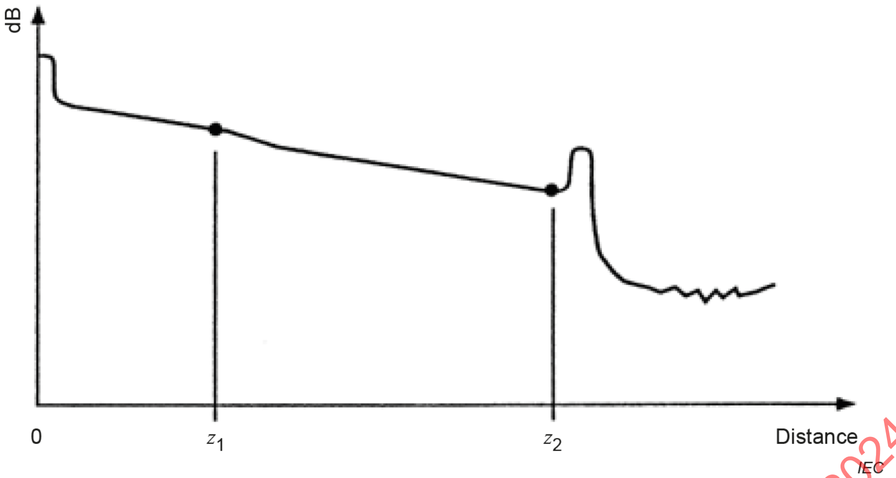
B.4.3.3 Single-point technique 1

B.4.3.3.1 Use this method when a fibre or cable section (or a dead-zone fibre) of known length, z_D, precedes the ~~specimen~~ sample. See Figure B.5. The length ~~may~~ can be obtained by mechanical measurement, for example by using contact-type devices with counters.

~~NOTE~~ The fibre used in the preceding section (or dead-zone fibre) should have a similar group index as the ~~specimen~~ sample.

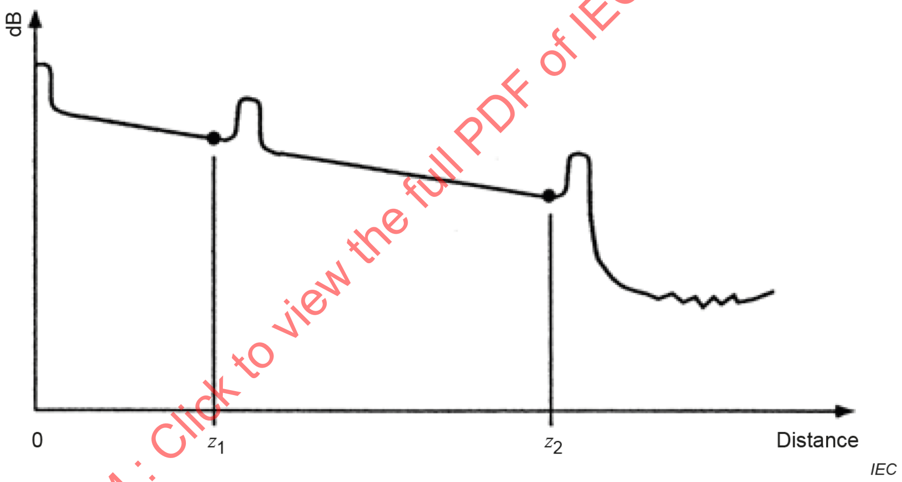
B.4.3.3.2 Perform the steps of B.4.3.2.2.

B.4.3.3.3 The ~~specimen~~ sample length equals $(z_2 - z_D)$.



NOTE An example of the section of unknown length is dead-zone fibre

Figure B.2 – Schematic OTDR trace of a ~~specimen~~ sample (z_1 to z_0) with a section ~~(e.g. dead-zone fibre)~~ of unknown length, z_1, preceding it and without a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))



NOTE An example of the section of unknown length is dead-zone fibre

Figure B.3 – Schematic OTDR trace of ~~specimen~~ sample (z_1 to z_2) with a section ~~(e.g. dead-zone fibre)~~ of unknown length, z_1, preceding it and with a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))

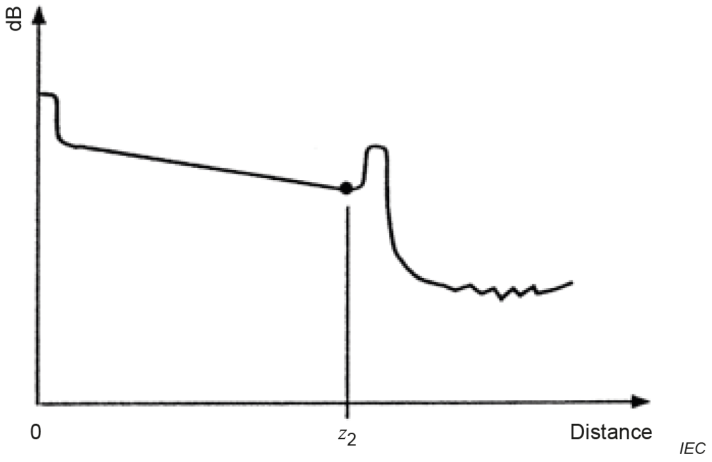
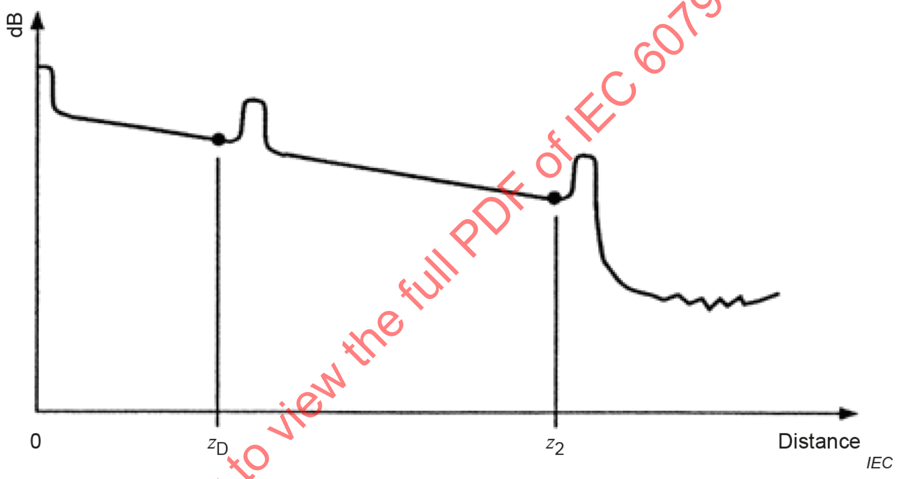


Figure B.4 – Schematic trace of a ~~specimen~~ sample (0 to z_2) with no section preceding it (single-point technique 0 (B.4.3.2))



NOTE an example of the section of unknown length is dead-zone fibre

Figure B.5 – Schematic OTDR trace of a ~~specimen~~ sample (z_D to z_2) with a section ~~(e.g. dead-zone fibre)~~ of known length, z_D, preceding it (single-point technique 1 (B.4.3.3))

B.4.4 Determination of group index

B.4.4.1 Accurately determine the physical length of the calibration fibre or cable. This ~~may~~ can be done by mechanical measurement, for example by using contact-type devices with counters.

B.4.4.2 Perform the steps given in B.4.2.1 for the calibration fibre or cable.

B.4.4.3 Perform the steps given in B.4.2.3, but with an arbitrary group index.

B.4.4.4 Place one cursor at the beginning of the trace as indicated in B.4.3.1.1. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.4.5 Place another cursor at the end of the trace as indicated in B.4.3.1.2. Obtain the distance coordinate, z_2.

B.4.4.6 Adjust the group index scale until the difference, (z_2 – z_1), which ~~may~~ can be automatically calculated by the instrument, equals the length determined in B.4.4.1.

B.5 Results

In addition to the results in Clause 9, the following information shall be available upon request:

– group index.

Annex C
(normative)

Requirements specific to method C – Fibre elongation

C.1 Principle

Derive the fibre elongation by the phase shift technique (C.2.2.1), or by the differential pulse delay (C.2.2.2).

The fibre elongation strain, $\varepsilon = \Delta L/L$, is given by:

$$\varepsilon = V \times \frac{\Delta t}{L} \quad \text{(C.1)}$$

where

Δt is the differential pulse delay;

L is the ~~specimen~~ sample fibre length;

V is a constant that depends on the photoelastic coefficient (k), the speed of light in a vacuum (c), and the group index of refraction (N_{eff}).

$$V = \frac{kc}{N_{\text{eff}}} \quad \text{(C.2)}$$

The factor, V, corrects the results for changes in the fibre's refractive index with strain.

When using the phase-shift technique (C.2.2.1), derive the differential delay, Δt, from:

$$\Delta t = \frac{\Delta\Theta}{360 \times f} \quad \text{(C.3)}$$

where

$\Delta\Theta$ is the phase shift (degrees);

f is the modulation frequency.

Because the factor, V, depends on the fibre type, the measurement set-up shall be calibrated.

C.2 Apparatus

C.2.1 General requirements

The measurement fixture of known gauge length shall be capable of applying and varying longitudinal stresses on the cable or fibre. Observe the proper fixing of the ends of the ~~specimen~~ sample to prevent the fibres from slipping during loading. Provide a suitable elongation bench for the calibration of the phase-shift or pulse-delay versus the mechanically measured fibre elongation.

C.2.2 Optical measurement equipment

C.2.2.1 General

The equipment for either technique, phase shift technique or differential pulse delay, should be stable over the measurement time period and temperature range encountered. See Figure C.1 and Figure C.2, respectively, for diagrams of typical equipment set-ups.

C.2.2.2 Phase-shift technique

Use a light source (either a laser diode or filtered light-emitting diode), modulator, launch optics, signal detector and reference signal for measuring chromatic dispersion using the phase-shift technique. These pieces of equipment are outlined and specified in method A of IEC 60793-1-42. The difference is that only one laser diode is used. The phase shifts observed are a function of strain changes on the fibre.

~~NOTE Care should be exercised in observing~~ Ensure that 360° phase-shift roll-over ambiguities of the phase meter are accounted for when using this method.

C.2.2.3 Pulse-delay (time of flight) technique

Use equipment required for an appropriate time-of-flight measurement technique, such as a short-pulse~~/Fresnel~~ optical time domain reflectometer (OTDR).

C.2.3 Instrument resolution

The strain measurement resolution of the entire measurement system should be equal to or less than 0,01 %. This includes the optical measurement equipment (modulation frequency or pulse width, etc.) and the measurement fixture (~~specimen~~ sample gauge length, cable~~/~~ or fibre end fixers, load measurement, etc.). Since all these factors are involved in determining the entire measurement system's accuracy and resolution, each measurement bench should be evaluated separately.

This measurement procedure is intended to be conducted at ambient room conditions typically found in laboratories. This method is feasible under other conditions, provided the temperature is stable to ±2 °C for the duration of the test. For extreme temperature and pressure changes (more than 40 atmospheres), corrections ~~may~~ can be necessary, particularly regarding the V factor.

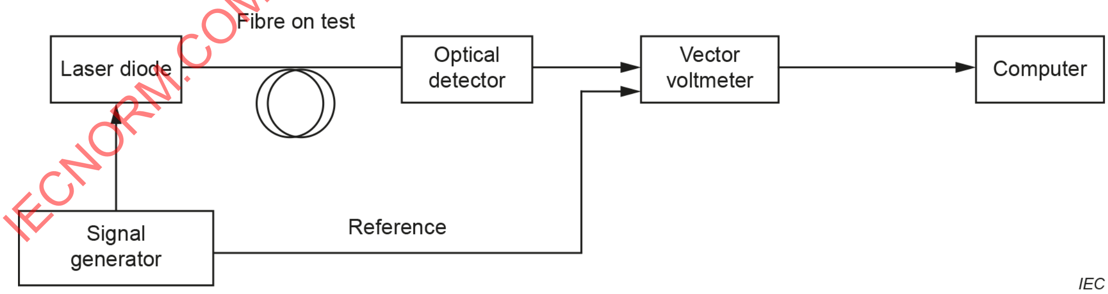


Figure C.1 – Equipment set-up for phase-shift technique (C.2.2.2)

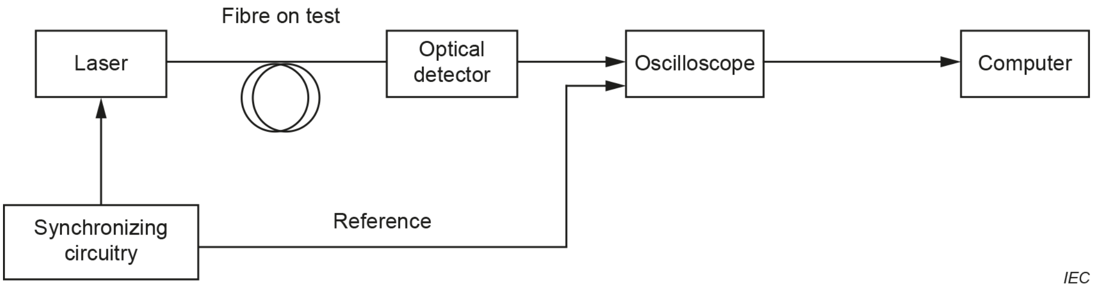


Figure C.2 – Equipment set-up for differential pulse-delay technique (C.2.2.3)

C.3 Procedure

C.3.1 Calibration

Install the reference fibre on the elongation bench and connect it to the optical measurement apparatus.

Progressively increase the fibre elongation within a known range of elongation that is sufficiently linear to determine the factor, V.

Measure and record, preferably continuously, the phase shift or pulse delay as a function of the mechanical fibre elongation.

The relation thus determined accounts for the strain-induced changes of the group index.

~~NOTE 1~~ It is recommended that the operator carry out the calibration with a random selection of fibre samples of the same type.

NOTE ~~2~~ It is not necessary to repeat this calibration before each fibre elongation measurement, if the same type of fibre (design and manufacturer) is used.

C.3.2 ~~Specimen~~ Sample measurement

Take either a phase reading in degrees or time-delay reading for the reference condition (typically ambient conditions). Record the reference value. Longitudinally strain the ~~specimen~~ sample to the specified load. After the applied load is stabilized, repeat the measurement procedures and record either the strained phase value or length value. Repeat these steps for any additional load conditions. Upon releasing the applied load, take a final measurement to ensure that the applied fibre strain has returned to its original reference condition.

~~NOTE~~ Perform a single-end measurement using one of the techniques shown below. If the phase-shift technique is used, the phase should be continuously recorded while applying the load to account for 360° phase-shift roll-overs.

a) For a cable under test, form an optical path by two fibres that are connected at the far end. However, due to the averaging effect of the strains on the two fibres, take particular care when interpreting the results.

b) Insert, at the near end, a suitable directional coupler connected, on one side, to the optical source and to the detector, and, on the other side, to the fibre under test. Then measure the phase shift or pulse delay between the input signal and the signal reflected from the far end. The cleaved fibre far end face shall be clean and perpendicular to maximize the reflected signal. Minimize other reflections (e.g. from the near end of the fibre).

In both cases, use a factor 2 to correct the collected phase-shift or pulse-delay data to take into account the double length of the optical path.

C.4 Results

In addition to the results in Clause 9, the following information shall be available upon request:

– load applied at each phase (or length) reading, and the calculated strain;
– type and frequency of modulator (phase-shift method).

Annex D
(normative)

Requirements specific to method D – Mechanical length

D.1 Principle

This method of measuring fibre length is carried out by winding the fibre onto a spool. It may can be done on the draw, during the tensile-proof operation, or any other such winding process. During the process, the fibre engages with a fixed diameter calibrated wheel that rotates. The number of revolutions resulting from the winding process, multiplied by $\pi D/1\ 000$, yields the length of the fibre in kilometres, where D is the diameter of the counting wheel, in metres.

D.2 Apparatus

Provide a wheel, or arrangement of wheels, so that the passage of fibre length through the assembly is linked to the counter wheel rotation in a linear fashion. Ensure that no slippage of the fibre relative to the surface of the counting wheel occurs.

The counter wheel shall be rigid, with a surface that is free of burrs or other features that can damage the fibre. Link the counter wheel with an electronic counter that may can optionally convert counts to length.

D.3 Procedure

D.3.1 Calibration

Calibrate the wheel by passing a fibre of known length (calibration fibre) through the winding process. This can correct for variations in wheel surface treatment or wheel machining.

Use surveying equipment to obtain length measurements on the calibration fibre. Use a fibre of a length that is long enough for the desired accuracy. When being measured, deploy it in a straight line and measure it at a temperature that is consistent with the operating temperature of the mechanical measurement device.

D.3.2 Operation

Reset the counter and initiate the winding process. At the completion of the winding process, note the count and convert to length.

NOTE Care should be taken to Ensure that winding does not introduce substantial elongation and that elongation conditions are the same during calibration.

Annex E
(normative)

Requirements specific to method E – Phase shift

E.1 General

This test method uses the phase shift change in an optical fibre or cable when the frequency is increased to a predetermined modulation frequency f_{max}. It ~~may~~ can be applied to fibre lengths typically in the range of less than 1 m to several kilometres for type A1 fibres and to several hundreds of kilometres for type B fibres.

E.2 Apparatus

E.2.1 General

A diagram of the measurement apparatus is shown in Figure E.1. The apparatus used in this measurement method ~~may~~ can also be configured to measure the chromatic dispersion of a fibre. Measurement of chromatic dispersion by the phase shift method is described in method A of IEC 60793-1-42.

E.2.2 Light source

Either a laser diode or a filtered light-emitting diode ~~may~~ can be used. The centre wavelength and modulated output phase shall be stable over the measurement time period at the bias current, modulation frequency and diode temperature range encountered.

The spectral width of the source at full-width half-maximum (FWHM) shall be less than or equal to 30 nm. This ~~may~~ can be achieved using a monochromator or optical filter, if necessary.

E.2.3 Modulator

Provide a means to modulate the intensity of the output of the optical source over a wide frequency range, typically from about 100 Hz up to a few gigahertz, to produce a waveform that has a single dominant Fourier component, such as a sine wave.

The choice of modulation frequency is determined by the maximum fibre length that is to be measured and the measurement precision that is required. To avoid ambiguities caused by 2π phase shifts, where there is more than one complete modulation cycle in the fibre, it is necessary to start with a low frequency and count the number of complete cycles as the frequency is slowly increased. It is important that the number of 2π phase shifts are counted unambiguously. The use of a higher frequency usually gives a more precise measurement of length. For a given fibre length L, in metres, the maximum starting frequency f_{start}, in hertz, is given by:

$$f_{start} \le \frac{c}{N \times L} \tag{E.1}$$

where

c is the velocity of light in a vacuum, in m/s;

N is the group index.

For example, for a length of 10 km a typical maximum value of f_{start} would be 20 kHz.

Alternatively, if the starting frequency has already been chosen then the maximum length of fibre that can be measured ~~may~~ can be calculated from a re-arrangement of Formula (E.1).

The choice of upper frequency, the corresponding phase noise at this frequency and the uncertainty of the modulation frequency itself will determine the measurement resolution. For a minimum measurable phase change of $\Delta\phi$, in radians, the minimum resolvable length ΔL, in the absence of phase noise and frequency uncertainty, is given by:

$$\Delta L = \frac{\Delta\varphi \times c}{f_{\text{max}} \times N \times 2\pi} \tag{E.2}$$

Note that the value of $\Delta\phi$ ~~may~~ can depend on the modulation frequency used.

Alternatively, for a given fibre length resolution, then the maximum frequency required ~~may~~ can be determined from a re-arrangement of Formula (E.2).

For example, for a phase resolution of 0,01 rad and a maximum frequency of 100 MHz, the length resolution would be approximately 3 mm.

E.2.4 Launch optics

Couple light from the source into the fibre under test by, for example, optically imaging the source onto the end of the test fibre or by direct butt coupling from a fibre pigtail that is coupled to the source. For type A1 fibres it is necessary to restrict the launch conditions to excite only low-order modes in the fibre, to minimize the effects of modal dispersion. This ~~may~~ can be achieved either by direct imaging of the source onto the end of the test fibre using an optical system in which the numerical aperture and the spot-size ~~may~~ can be restricted, or by direct coupling from a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

E.2.5 Signal detector and signal detection electronics

For signal detection use an optical detector that is sensitive at the wavelength of measurement, is stable over the duration of the measurement, and is linear over the intensity modulation range. An amplifier ~~may~~ can be used to increase detection sensitivity. Couple light from the test fibre onto the detector using, for example, direct imaging with lenses or a fibre pigtail that is directly coupled to the detector. For type A1 fibres it is necessary to collect only light from low-order modes in the test fibre. This ~~may~~ can be achieved by direct imaging onto the detector using an optical system in which the numerical aperture and the spot-size ~~may~~ can be restricted, or by direct coupling into a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

Use a phase-measuring instrument, such as a phase meter, vector voltmeter or network analyzer, that responds only to the fundamental Fourier component of the modulating signal to determine the phase of the detected light. Any phase shift that is introduced by the phase measuring system itself shall be constant for the duration of the measurement.

E.2.6 Reference signal

A reference signal is required by the phase meter, which has the same dominant Fourier component as the modulating signal, against which the phase of the output signal is measured. The reference signal shall be phase locked to the modulating signal. The reference signal ~~may~~ can be derived by either taking a direct electrical connection from the modulation source to the phase meter, or by using a detector coupled to an optical beam splitter or fibre coupler which is inserted between the source and the test fibre.

E.2.7 Computation equipment

A computer ~~may~~ can be used for the purposes of equipment control, data acquisition and numerical evaluation of data.

E.3 Sampling ~~and specimens~~

The test sample shall be a ~~fibre which may, or may not, be~~ cabled or non-cabled fibre. Typical fibre sample lengths are 1 m to hundreds of kilometres. The sample, launch optics and pigtails, if used, shall be fixed in position at a nominally constant temperature for the duration of the measurement. In the case of installed fibres and cables, the prevailing deployment and environmental conditions ~~may~~ can be used.

Either a phase calibration fibre of the same type as the fibre under test, (or the fibre pigtails, if used), is required to compensate for phase shifts that ~~may~~ can be introduced by the phase meter or internal optical path lengths. A typical length is 0 m to 2 m.

Prepare end faces for the input and output ends of the calibration fibre and test fibre, as appropriate for the requirements of E.2.3 and E.2.4.

E.4 Procedure

E.4.1 Selection of starting frequency

Select a suitably low modulation frequency f_{start}, determined using Formula (E.1). If the approximate length of the fibre is unknown then use the lowest available modulation frequency but exercise caution with respect to the possibility of 2π phase errors in the fibre.

E.4.2 Selection of maximum frequency

Select a suitable maximum frequency f_{max}, determined using Formula (E.2), for the required length resolution.

E.4.3 Phase measurement performance

Subclause E.4.3 applies to all length measurements made on the test fibre and the phase calibration fibre, and if required, during the determination of group index.

Starting at modulation frequency f_{start} increase the frequency, until f_{max} is reached, at a rate sufficient to allow the unambiguous determination of the number, m, of 2π phase shifts that occur. Measure the phase angle ϕ' at the output of the fibre at f_{max}.

Calculate the total phase angle ϕ as follows:

$$\varphi = \varphi' + m \times 2\pi \quad \text{(E.3)}$$

E.4.4 Measurement of length of test fibre

E.4.4.1 Calibration of reference phase

Depending on whether fibre pigtails are used or not, calibrate the reference phase by following one of the two methods below:

a) When pigtails are not used, couple one end of the phase calibration fibre (input) to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{ref} according to E.4.3.

b) When pigtails are used at both the launch and receive ends, these are connected to perform the reference phase measurement instead of using a separate phase calibration fibre. Measure the phase shift ϕ_{ref} according to E.4.3.

It is sometimes convenient to remove either the phase calibration fibre and/or the pigtails, or both, from the apparatus after the reference measurement has been made. This may can be done if the phase shift that occurred within either the phase calibration fibre and/or the pigtails, or both, is known and is subsequently added to the measured phase shift of the fibre under test, see E.4.4.2.

NOTE It is not normally necessary to calibrate the reference phase before each measurement. The use of a stored reference value is permitted if it is understood that the presence of phase drift in the system may can degrade the measurement uncertainty.

E.4.4.2 Measurement of test fibre phase

Depending on whether fibre pigtails are used or not, measure the test fibre phase by following one of the two methods below.

a) When pigtails are not used, uncouple the output of the phase calibration fibre from the detection system and couple it to one end of the fibre under test (input). Couple the other end (output) of the fibre under test to the detection system. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used E.4.4.1.

b) When pigtails are used instead of a phase calibration fibre, disconnect the pigtails from each other and couple the free ends to the fibre under test. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used in E.4.4.1.

E.5 Calculation and interpretation of results

~~E.5.1 Determination of test fibre length~~

Calculate the length, L, of the test fibre as follows:

$$L = \frac{(\varphi_{sig} - \varphi_{ref}) \times c}{N \times f_{max} \times 2\pi} \tag{E.4}$$

where

L	is in metres;
ϕ_{ref}, ϕ_{sig}	are in radians;
c	is in metres per second;
f_{max}	is in hertz;
N	is the group index.

Note that ϕ_{ref} and ϕ_{sig} represent the total phase angle at the maximum frequency f_{max} used, including the total number of 2π phase shifts, see Formula (E.3).

NOTE The group index N ~~may~~ can be supplied by the fibre or cable manufacturer. The accuracy in measurement of length using this method largely depends on the certainty with which the group index is known. Group index values vary from fibre to fibre and ~~may~~ can also be temperature sensitive. Typical manufacturers' values have an uncertainty equivalent to 0,1 % in length measurement. If the group index is not known, then it ~~may~~ can be determined according to the procedure described in E.6.

E.6 Group index

E.6.1 ~~Introduction~~ General

To determine the value of group index it is necessary to measure the phase shift associated with a fibre of known length at the wavelength of measurement. This ~~may~~ can be performed either by cutting a known length of fibre from the output end of the test fibre, known as the cut-back method, described in E.6.2 or by connecting a fibre of known length, which is of the same class and type as the test fibre, to the apparatus in place of the test fibre, known as the substitution method, described in E.6.3.

NOTE Uncertainties due to non-linearities in the phase measurement system ~~may~~ can be minimized by choosing cut-back and substitution fibre lengths corresponding to approximately one 2π phase cycle of the modulation frequency. For example, at a maximum frequency f_{max} of 100 MHz this corresponds to a length of approximately 2 m.

E.6.2 Cut-back method

E.6.2.1 Couple one end (input) of the test fibre to the light source. Couple the other (output) end of the test fibre to the detection system. Measure the phase shift ϕ_{long} according to E.4.3.

E.6.2.2 From the output end of the test fibre, remove a short length of fibre L_{cut} typically 2 m to 3 m (see E.6.1). Re-prepare the new output end of the test fibre, which is now slightly shorter, and couple it to the detection system. Measure the phase shift ϕ_{short} according to E.4.3 using the same value of f_{max} that was used in E.6.2.1.

E.6.2.3 Measure the length of the fibre L_{cut} that was removed in E.6.2.2 using, for example, a calibrated metre rule. Note that the uncertainty in this measurement will proportionally affect the measurement uncertainty of the group index of the test fibre.

E.6.2.4 Calculate the group index using Formula:

$$N = \frac{(\varphi_{long} - \varphi_{short}) \times c}{L_{cut} \times f_{max} \times 2\pi} \tag{E.5}$$

E.6.3 Substitution method

E.6.3.1 Couple one end (input) of the phase calibration fibre to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{cal} according to E.4.3.

E.6.3.2 Uncouple the output of the phase calibration fibre from the detection system and couple a fibre of known length L_{sub}, typically 2 m to 3 m (see E.6.1), which is of the same class and type as the test fibre, between the output of the phase calibration fibre and the detection system. The length of this fibre ~~may~~ can be measured with, for example, a calibrated metre rule. Measure the phase shift ϕ_{sub} according to E.4.3 using the same value of f_{max} used in E.6.3.1.

E.6.3.3 Calculate the group index using Formula:

$$N = \frac{(\varphi_{sub} - \varphi_{cal}) \times c}{L_{sub} \times f_{max} \times 2\pi} \quad (E.6)$$

The precision of the group index determination will affect the precision of the length as measured by phase shift method. Note, for very precise values, the group index value can vary from fibre to fibre, as well as with temperature and stress.

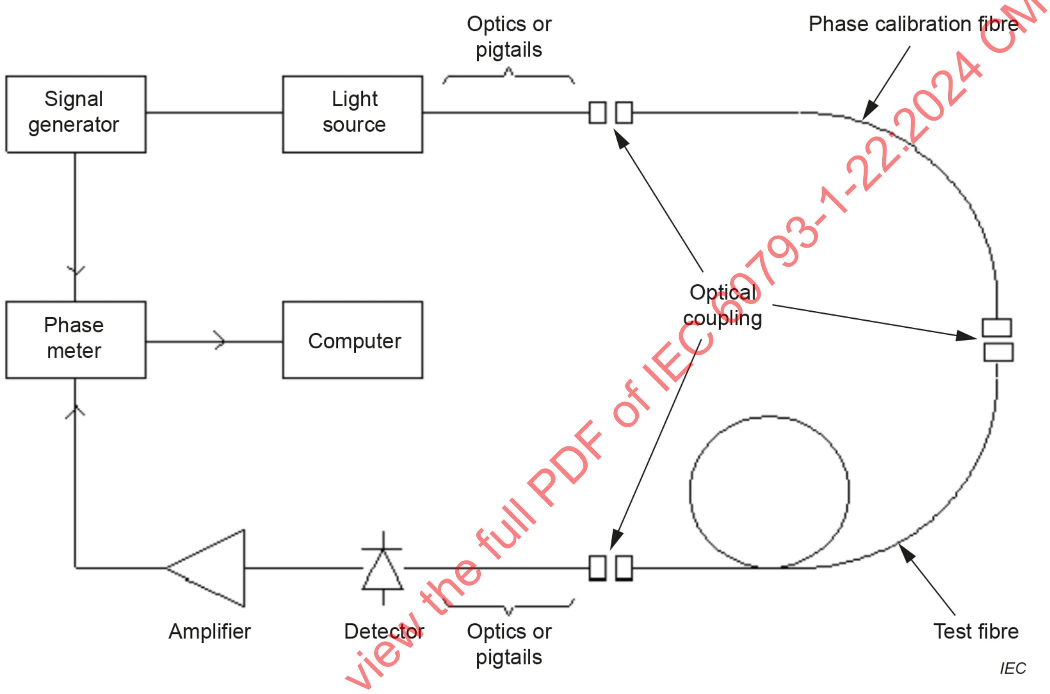


Figure E.1 – Apparatus for fibre length measurement

Annex F
(informative)

Brillouin frequency shift test method 4

F.1 General

This Brillouin frequency shift method describes a procedure for determining the tensile strain applied to a fibre. It uses Brillouin reflectometry (BOTDR) or so-called Brillouin analysis (BOTDA), which are single-sided and double-sided methods respectively. A single distributed measurement of the Brillouin frequency shift gives access to distributed tensile strain, which can be absolute if one dispose of a strain-free portion. An absolute reading is essential to determine the initial state of a fibre prior to the pulling test, or for testing the state of a fibre over a long-distance cable. The difference of two subsequent measurements gives access to the distributed and relative fibre elongation, but also to an average elongation over the strained section that is equivalent to the one obtained with method C.

F.2 Principle

Derive the fibre elongation along the fibre from the distributed measurement of the Brillouin frequency shift. In the Brillouin process, the back-scattered radiation suffers a doppler shift, namely the Brillouin frequency shift f_B, which writes:

$$f_B = \frac{2 \cdot n \cdot V_a}{\lambda} \quad \text{(F.1)}$$

where

n is the refractive index;

V_a is the velocity of an acoustic wave at frequency f_B, expressed in m/s;

λ the optical wavelength of the probe laser expressed in m.

There is a linear dependency between the Brillouin frequency shift and the tensile strain applied on fibre, associated with the changes of material density and elastic properties of the material under tensile strain [1].

$$f_B = f_{B0} + C_{f\varepsilon} \cdot \varepsilon \quad \text{(F.2)}$$

where

f_{B0} is the Brillouin frequency shift for the strain free material, expressed in Hz;

$C_{f\varepsilon}$ is the coefficient of variation of the Brillouin frequency shift with tensile strain applied;

$\varepsilon = \frac{\Delta L}{L}$ is the relative elongation of the fibre of length L under tensile strain.

Several reflectometric techniques were reported allowing the determination of the Brillouin frequency shift $f_B(z)$, with z the position along an optical fibre. Metric spatial resolutions are commonly reported but centimetric spatial resolutions are also possible [4] and [6].

Distributed measurement of $f_B(z)$ gives access to a tensile strain state $\varepsilon(z)$, thanks to Formula F.2. The method F is the sole method providing an absolute value of the tensile strain, it only requires the possibility of measurement of the given fibre in a strain-free state ($\varepsilon = 0$) so to determine f_{B0} Absolute and distributed tensile strain measurements can therefore be determined in two ways:

a) From a single distributed measurement on a fibre link that include one section which is known to be in a strain-free state.

b) From a set of two distributed measurements in two states, the first state being considered as a strain-free state.

For an optimal accuracy, the coefficient $Cf\varepsilon$ is calibrated for the given fibre, but in practice numerous publications already report very consistent values of this coefficient for a large range of fibre types. A nominal coefficient of $Cf\varepsilon$ = 490 MHz/% can however be used with an associated accuracy on tensile strain measurements better than 5 %. The accuracy on coefficients and length measurements was not debated for the other methods described in the present document, so these accuracy considerations are only provided as an indication of what can reasonably be expected.

F.3 Apparatus

F.3.1 General requirements

The measurement fixture of known gauge length shall be capable of applying and varying longitudinal stresses on the cable or fibre. Observe the proper fixing of the ends of the sample to prevent the fibres from slipping during loading. Provide an elongation bench for the calibration of the Brillouin frequency shift versus the mechanically measured fibre elongation.

F.3.2 Optical measurement equipment

F.3.2.1 General

The equipment for either technique, BOTDR or BOTDA, should be stable over the measurement time period and temperature range encountered. See Figure F.1 and Figure F.2, respectively, for diagrams of typical equipment set-ups. These diagrams only represent the general concepts leading to a distributed measurement of the Brillouin frequency shift. Many implementations are possible in practice [5], including coherent detection as a filter mechanism, additional amplifiers, pulsed RF-driven electro-optic modulators to produce wavelength tunability at the same time as pulsing.

F.3.2.2 BOTDR

Use of a pulsed light source to probe the fibre under test, the backscattered radiation is filtered to resolve temporally and spectrally the spontaneous Brillouin scattering. The instrument can also dispose of a Rayleigh OTDR to measure the fibre attenuation during pulling test.

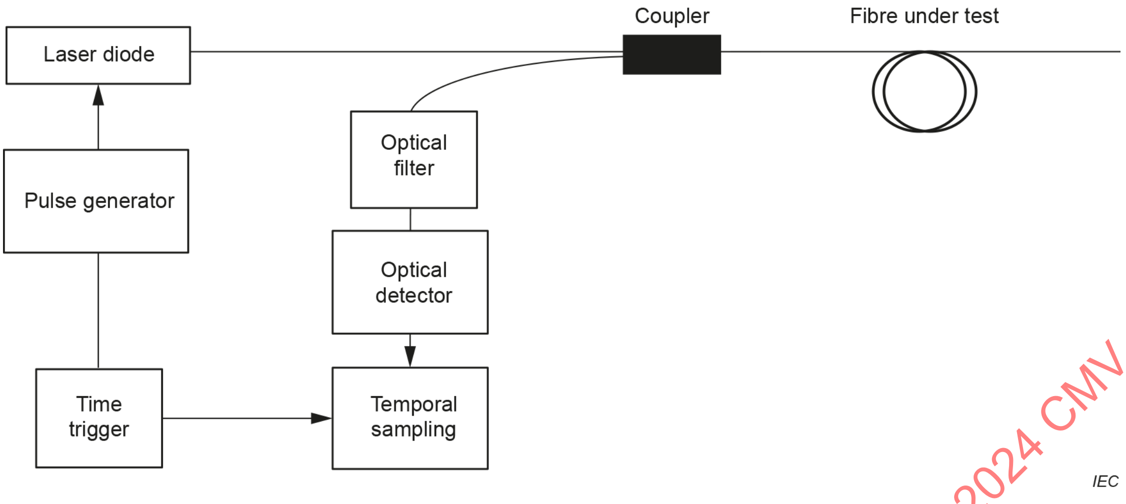


Figure F.1 – Equipment setup for BOTDR technique

F.3.2.3 BOTDA

Use of both a pulsed light source and a continuous wave light source sent in counter-propagation in the fibre under test, so to generate a strong stimulated Brillouin scattering interaction. The power of the transmitted continuous light source is detected as it carries the distributed information of the interaction that took place when and where it crossed the pulse. Tuning the relative frequency shift in between the two lasers allow to scan and record the Brillouin gain profile. The instrument can also dispose of a Rayleigh OTDR to measure the fibre attenuation during pulling test.

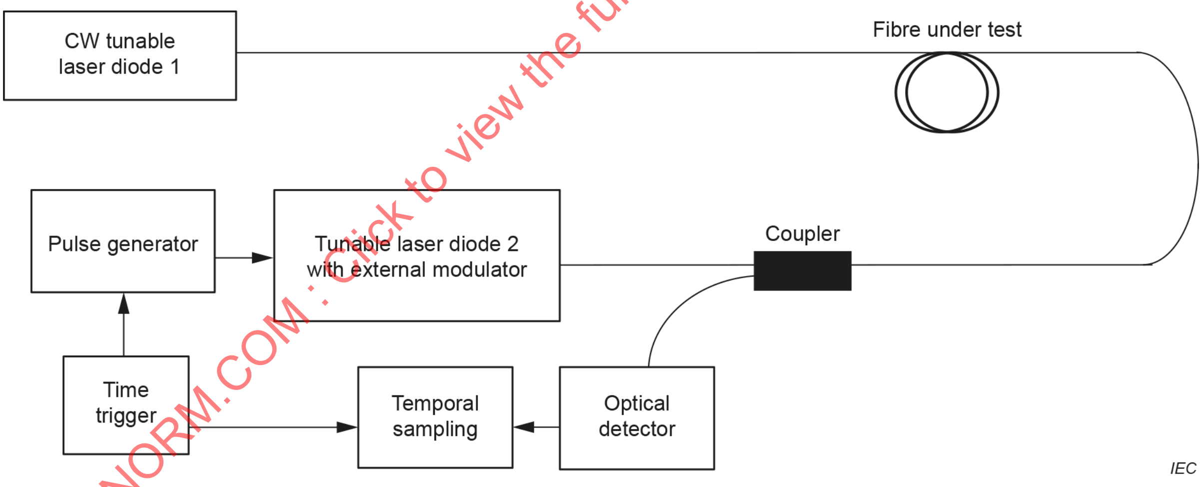


Figure F.2 – Equipment setup for BOTDR technique

F.3.3 Instrument resolution

The strain measurement resolution of the entire measurement system should be ≤ 0,01 %. This includes the optical measurement equipment (frequency sampling or pulse width, etc.) and the measurement fixture (sample gauge length, cable or fibre end fixers, load measurement, etc.). Since all these factors are involved in determining the entire measurement system's accuracy and resolution, evaluate each measurement bench separately.

This measurement procedure is intended to be conducted at ambient room conditions typically found in laboratories. This method is feasible under other conditions, provided the temperature is stable to ±2 °C for the duration of the test. For extreme temperature and pressure changes (more than 40 atmospheres), corrections can be necessary, particularly regarding the $C_{f\varepsilon}$ factor.

The 0,01 % corresponds to a maximal frequency sampling resolution of 5 MHz when recording the Brillouin spectrum. The "spatial resolution" is defined in IEC 61757-1-2. Any localized strain applied to a fibre distance larger than the spatial resolution expected is measured with a 90 % accuracy. To provide valuable distributed information during a standard cable pulling test over a 100 m long fibre, the spatial resolution shall not exceed 1,4 m.

F.4 Procedure

F.4.1 Calibration

It is recommended that the operator carry out the calibration with a random selection of fibre samples of the same type.

a) Install the reference fibre on the elongation bench and connect it to the optical measurement apparatus.
b) Progressively increase the fibre elongation within a known range of elongation that is sufficiently linear to determine the factor $Cf\varepsilon$.
c) Measure and record, preferably continuously, the Brillouin frequency shift as a function of the mechanical fibre elongation.
d) The relation thus determined accounts for the strain-induced changes of the group index, elastic and acoustic properties.

NOTE It is not necessary to repeat this calibration before each fibre elongation measurement if the same type of fibre (design and manufacturer) is used.

F.4.2 Sample measurement

Take a distributed Brillouin frequency shift reading for the reference condition (typically ambient conditions). Record the reference trace. Longitudinally strain the sample to the specified load. After the applied load is stabilized, repeat the measurement procedures and record the strained Brillouin frequency shift trace.

To determine a relative elongation averaged over the strained section, (i.e. with the generally adopted measurement for the elongation that would match a measurement obtained with method C) it is necessary to precisely identify the strained portion. Figure F.3 shows an example of differential tensile strain derived from two measurements of distributed frequency shift, in first acquisition the whole cable and fibre herein were strain-free, while in the second measurement a 1 % strain was applied to a 100 m section of cable, resulting here in an average strain of approximately 0,6 % on the fibre herein. Measure the maximal strain level recorded and determine the left and right positions where the strain crosses 90 % of this maximum and calculate the average elongation over that section.

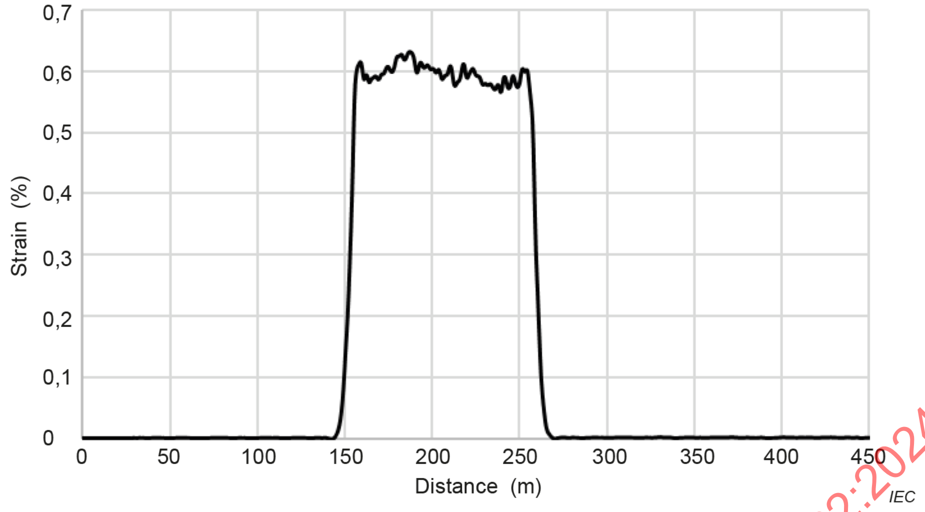


Figure F.3 – Differential strain recorded during a pulling test over a 100 m of cable

The Brillouin frequency shift method of referencing can however be operated differently so to display absolute measurements of strain from a single acquisition. Figure F.4 shows the second acquisition that was used to produce the differential strain of Figure F.3. Several sections are clearly identified, the section from 25 m to 140 m corresponds to a launch fibre of a different type than the one in the cable under test, then starts the cable under test, with about 10 m left unstrained, then from 150 m to 250 m the pulled section of cable, and then again, a long portion of the same unstrained cable. The Brillouin frequency shift of this latter section was used to determine f_{B0}, and allows to display absolute strain state, and would result in a same ~0,6 % strain level in the pulled section as was obtained from Figure F.1 data with a differential measurement. This referencing technique is not suitable for the fibre section from 25 m to 140 m which is of a different type. While the technique proposed here differs from the method C, it can provide some extra information. For example, one can verify that the initial state of the fibre prior to pulling is strain-free, so that differential strain subsequently measured after pulling does not add to an already high strain value. In addition, this measurement would allow the absolute strain state measurement of any long-distance cable at production level and make a systematic assessment of the quality of the cabling.

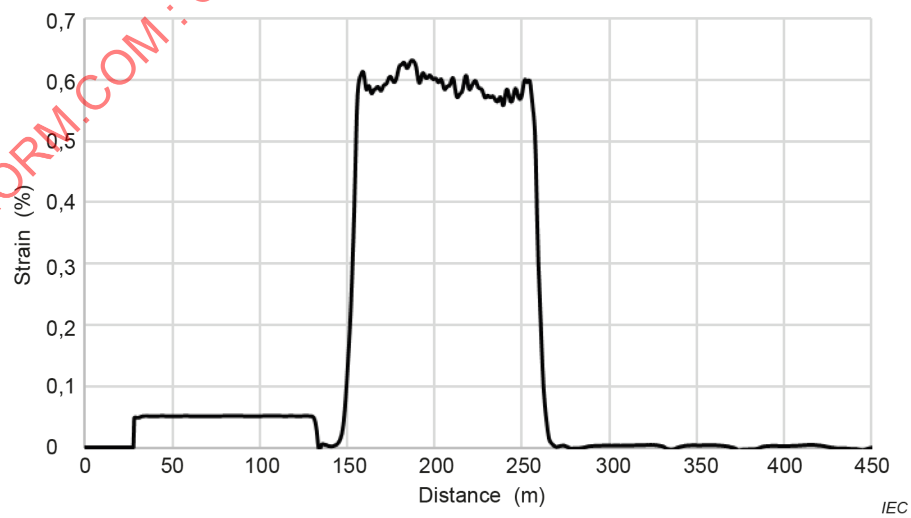


Figure F.4 – Absolute strain profile recorded during a pulling test over a 100 m of cable

Report peak value, average of distributed value, absolute or relative as applicable to your test.

Repeat these steps for any additional load conditions. Upon releasing the applied load, take a final measurement to ensure that the applied fibre strain returned to its original reference condition.

F.5 Results

In addition to the results in Clause 9, the following information shall be available upon request:

- load applied at each reading, and the calculated strain,
- refractive index and $Cf\varepsilon$.

Bibliography

[1] IEC 60794-1-1, *Optical fibre cables – Part 1-1: Generic specification – General*

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[3] T. Horiguchi, T. Kurashima and M. Tateda, "*Tensile strain dependence of Brillouin frequency shift in silica optical fibers*," in IEEE Photonics Technology Letters, vol. 1, no. 5, pp. 107-108, May 1989, https://doi.org/10.1109/68.34756

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[6] Thévenaz, L. Brillouin distributed time-domain sensing in optical fibers: state of the art and perspectives. Front. Optoelectron. China 3, 13–21 (2010). https://doi.org/10.1007/s12200-009-0086-9

List of comments

1 IEC 60793-1-22:2001 was published before IEC 60793-2-60:2008 specifying category C single mode fibre. IEC 60793-2-60 refers to IEC 60793-1-22 for measuring length of fibre. Therefore, category C fibre is included in this revision.

2 “Specimen” is a word normally used in biological area, usually indicating an individual animal, plant, piece of a mineral, etc., used as an example of its species or type for scientific study or display. Working group experts reach to an agreement to use “sample” instead of “specimen” for optical fibre related standards.

3 Central wavelength is replaced by centroidal wavelength to harmonized with IEC 60793-1-40.

4 This standard describes different optical techniques to measure either fibre length or fibre elongation (see Table 1, Method C), and is applicable to assess the tensile strain status of the fibres within a cable during a cable tensile test. Brillouin frequency shift is a quantity that reflects very well the tensile strain and its use is getting normalized in the fibre sensing standards (IEC 61757 series). An informative annex to determine tensile strain on a fibre by the Brillouin frequency shift test method is included in this edition.

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IEC 60793-1-22

Edition 2.0 2024-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical fibres –
Part 1-22: Measurement methods and test procedures – Length measurement

Fibres optiques –
Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur

IEC 60793-1-22:2024-06(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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OPTICAL FIBRES –

Part 1-22: Measurement methods and test procedures – Length measurement

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 60793-1-22 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This second edition cancels and replaces the first edition published in 2001. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Inclusion of category C single mode fibres in Table 1;
b) Inclusion of a new informative Annex F on Brillouin frequency shift test method to determine the tensile strain applied to a fibre.

The text of this International Standard is based on the following documents:

Draft	Report on voting
86A/2456/FDIS	86A/2474/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60793 series, published under the general title *Optical fibres*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

Publications in the IEC 60793-1 series concern measurement methods and test procedures as they apply to optical fibres.

Within the same series several different areas are grouped, as follows:

- IEC 60793-1-20 to IEC 60793-1-29: *Measurement methods and test procedures for dimensions*
- IEC 60793-1-30 to IEC 60793-1-39: *Measurement methods and test procedures for mechanical characteristics*
- IEC 60793-1-40 to IEC 60793-1-49: *Measurement methods and test procedures for transmission and optical characteristics*
- IEC 60793-1-50 to IEC 60793-1-59: *Measurement methods and test procedures for environmental characteristics*.
- IEC 60793-1-60 to IEC 60793-1-69: *Measurement methods and test procedures for polarization-maintaining fibres*.

IEC 60793-1-2X consists of the following parts, under the general title: Optical fibres:

- Part 1-20: Measurement methods and test procedures – Fibre geometry
- Part 1-21: Measurement methods and test procedures – Coating geometry
- Part 1-22: Measurement methods and test procedures – Length measurement

OPTICAL FIBRES –

Part 1-22: Measurement methods and test procedures – Length measurement

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the length and elongation of optical fibre (typically within cable).

The length of an optical fibre is a fundamental value for the evaluation of transmission characteristics such as losses and bandwidths.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60793-1-40, *Optical fibres – Part 1-40: Attenuation measurement methods*

IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

BOTDA Brillouin optical time domain analysis

BOTDR Brillouin optical time domain reflectometry

FWHM full-width half-maximum

OTDR optical time domain reflectometer

RMSW root-mean-squared width

RTM reference test method

4 Overview of method

4.1 General

This document gives five methods for measuring length, which are presented in Table 1.

Table 1 – Measurement methods

Method		Characteristics covered	Fibre categories covered
A	Delay measuring	Length	All A1, B, and C
B	Backscattering	Length	All A1, B, and C
C	Fibre elongation [a]	Fibre elongation [c]	A1, B1 [b], and C
D	Mechanical	Length	All
E	Phase shift	Length	All A1, B, and C

[a] The measurement of fibre elongation is used in IEC 60794-1-1.

[b] This measurement is applicable unreservedly to type B single-mode fibres. For type A1 multimode fibres, take particular care when interpreting the results because the results of this measurement can be influenced by interfering modal effects, for example, due to the occurrence of non-longitudinal stresses on the fibre. Application of the measurement to A2 to A4 multimode fibres is under consideration.

[c] Informative Annex F has been added to determine the tensile strain applied to a fibre. It uses Brillouin reflectometry (BOTDR) or so-called Brillouin analysis (BOTDA), which are single-sided and double-sided methods respectively.

Information common to all measurements is contained in Clause 2 to Clause 8. Information on specific application appears in Annex A, Annex B, Annex C, Annex D, and Annex E for methods A, B, C, D and E, respectively.

4.2 Method A – Delay measuring

The delay measuring method applies to measurements of the fibre length by the measurement of the propagation time of an optical pulse or a pulse train based on a known value of the group index of the fibre.

Alternatively, this method is suitable for measuring the group index of a fibre of known length. Therefore, in practice this fibre length measurement method is calibrated against a known length of fibre of the same type.

4.3 Method B – Backscattering

The backscattering method, which is a single-sided measurement, uses an optical time domain reflectometer (OTDR), and measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

4.4 Method C – Fibre elongation

This measurement method describes a procedure for determining the fibre elongation. It does not measure absolute strain, but instead measures the changes in strain from one loading condition to another.

4.5 Method D – Mechanical length

This measurement method describes a procedure for determining the fibre length by winding a fibre around a fixed diameter calibrated wheel that rotates. The length is determined by the number of revolutions of the wheel.

4.6 Method E – Phase shift

The phase shift method describes a procedure for determining the fibre length. The length is determined from the phase shift that occurs when a predetermined modulation frequency f_{max} is applied.

4.7 Reference test method

The reference test method (RTM), which shall be the one used to settle disputes, varies depending on whether the fibre is cabled or not, such as

– uncabled fibre: method D;
– length of fibre within cable: method B;
– elongation of fibre within cable: method C;
– elongation of uncabled fibre: method C.

5 Apparatus

Annex A, Annex B, Annex C, Annex D, and Annex E include layout drawings and other equipment requirements for each of the methods A, B, C, D and E, respectively.

6 Sampling

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements. General requirements follow.

Prepare a flat end face, perpendicular to the fibre axis, at the input and output ends of each sample for measurements based on optical delay measurements.

7 Procedure

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements.

8 Calculations

See the appropriate Annex A, Annex B, Annex C, Annex D or Annex E for specific requirements.

9 Results

The following information shall be provided with each measurement:

– date and title of measurement;
– identification and description of sample, including whether fibre or cable;
– sample length, or elongation;
– measurement method used: A, B, C, D or E;
– other results, as required by the appropriate Annex A, Annex B, Annex C, Annex D or Annex E.

The following information shall be available upon request:

- description of measurement apparatus arrangement;
- type and wavelength of measurement source;
- launch conditions;
- details of computation technique;
- date of latest calibration of equipment.

See Annex A, Annex B, Annex C, Annex D and Annex E for any additional information that shall be available upon request.

10 Specification information

The detail specification shall specify the following information:

- type of fibre (or cable) to be measured;
- failure or acceptance criteria;
- information to be reported;
- deviations to the procedure that apply.

Annex A
(normative)

Requirements specific to method A – Delay measuring

A.1 General

Use this method to measure the length of optical fibre by itself or installed in cable. If the sample is a fibre in a cable, determine the value of group index N under conditions applicable to the sample under measurement (for example, tension, temperature). This is done by inverting Formula (A.1) and the measurements on a sample with a known length.

A.2 Principle

An optical pulse travelling through an optical fibre with length L and average group index N experiences a time delay, Δt:

$$\Delta t = \frac{NL}{C} \tag{A.1}$$

where

Δt is the time delay;

N is the average group index;

C is the velocity of light in vacuum.

If N is known, the measurement of Δt gives L. On the other hand, the measurement of Δt gives the value of N when L is known.

A.3 Apparatus

A.3.1 Two techniques

There are two techniques for measuring the propagation time of an optical pulse:

– time measurement of the transmitted pulse (Δt measured);

– time measurement of the reflected pulse ($2\Delta t$ measured).

See Figure A.1 and Figure A.2 for two different arrangements corresponding to the two techniques applying a sampling oscilloscope.

Instead of the sampling oscilloscope, backscattering equipment, or a counter with separate start-stop gate and averaging capability (e.g. at least 10^4 counts), can be used.

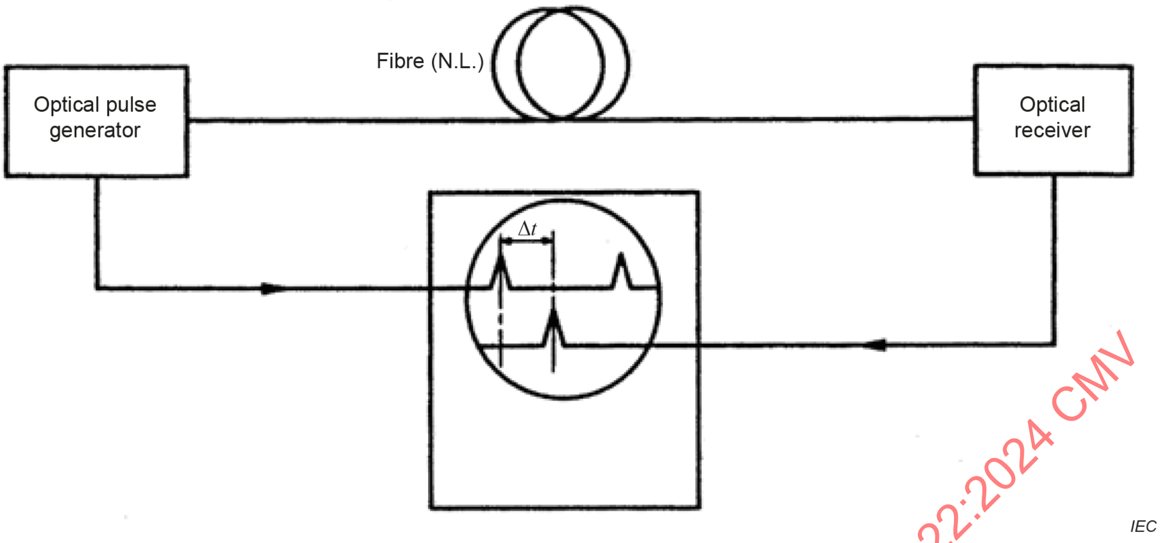


Figure A.1 – Time measurement of the transmitted pulse

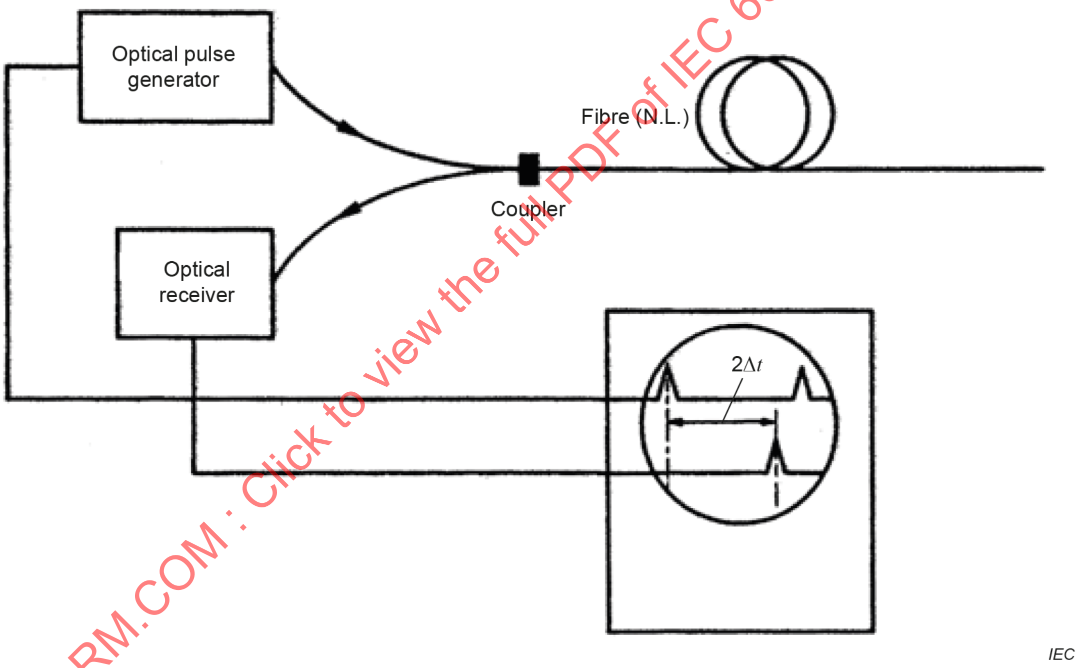


Figure A.2 – Time measurement of the reflected pulse

A.3.2 Optical source

A.3.2.1 Measurement with the sampling oscilloscope

An optical pulse generator shall be a high-power laser diode, excited by an electrical pulse train generator, tunable in frequency and width. Record the wavelength and the spectral width.

A.3.2.2 Measurement with a counter or a backscattering apparatus

An optical pulse generator shall be a high-power laser diode, excited by an electrical pulse train generator, tunable in width. The time between two pulses shall be longer than the travelling time of the transmitted pulse (Δt, with counter) or the reflected pulse ($2\Delta t$, with backscattering equipment). Record the wavelength and the spectral width of the laser diode.

A.3.3 Optical detector

The receiver shall be a high-speed avalanche photodiode. The sensitivity of the optical detector at the measuring wavelength, and its bandwidth shall not influence the shape of the pulse.

A.4 Procedure

A.4.1 Calibration

Measure the delay time of the optical source to the launching point (this is the delay time of the measurement apparatus itself).

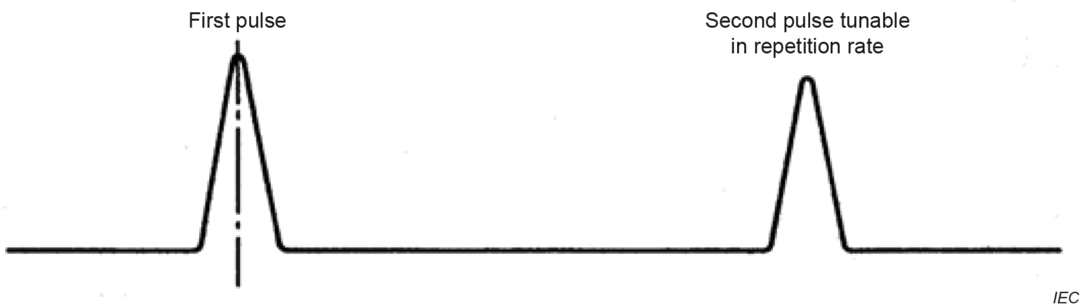
A.4.2 Average group index value

On a known length of mechanically measured fibre, the measurement of Δt, gives the average value, N, of the group index of the fibre.

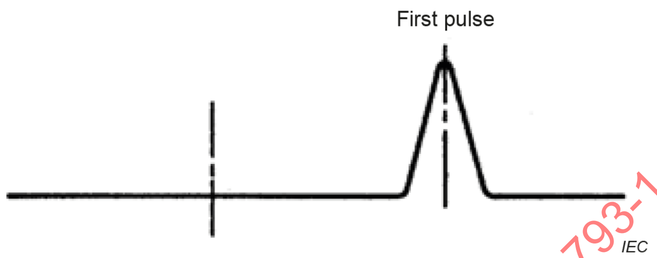
A.4.3 Length measurement

The length measurement is a time-domain reading on the screen of an oscilloscope (or the reading of the averaged travelling time on the display of an electronic counter to be corrected for the calibration value).

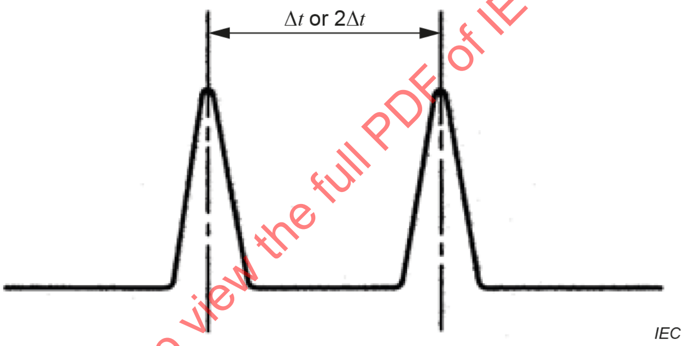
NOTE See Figure A.3 for an illustration of an important practical improvement for achieving the accuracy of the measurement, independent of the actual length of the fibre sample. This uses a dual-channel approach.



a) **Channel 1: emitted pulse**



b) **Channel 2: transmitted pulse**



c) **Emitted pulse after adjustment of the repetition rate in such a way that the second pulse of channel 1 coincides with the transmitted pulse of channel 2**

Figure A.3 – Principle of fibre-length measurement

A.5 Calculations

A.5.1 General

Obtain the fibre length from one of the following formulae:

A.5.2 Transmitted-pulse technique

$$L = \frac{\Delta t \times c}{N} \tag{A.2}$$

A.5.3 Reflected-pulse technique

$$L = \frac{\Delta t \times c}{2N} \tag{A.3}$$

where

L is the fibre length, in m;

Δt is the transmission or reflection time, in ns;

c is the light velocity in vacuum, in m/ns;

N is the average group index.

A.6 Results

In addition to the results in Clause 9, the following information can be available upon request:

– average group index;
– delay time of the measurement apparatus;
– transmission or reflection time.

Annex B
(normative)

Requirements specific to method B – Backscattering

B.1 General

This method uses an OTDR to measure the length of optical fibre by itself and installed in cable.

B.2 Apparatus

B.2.1 General

This method uses an optical time-domain reflectometer (OTDR), which shall normally consist of the following minimum list of components. See Figure B.1 for a block diagram.

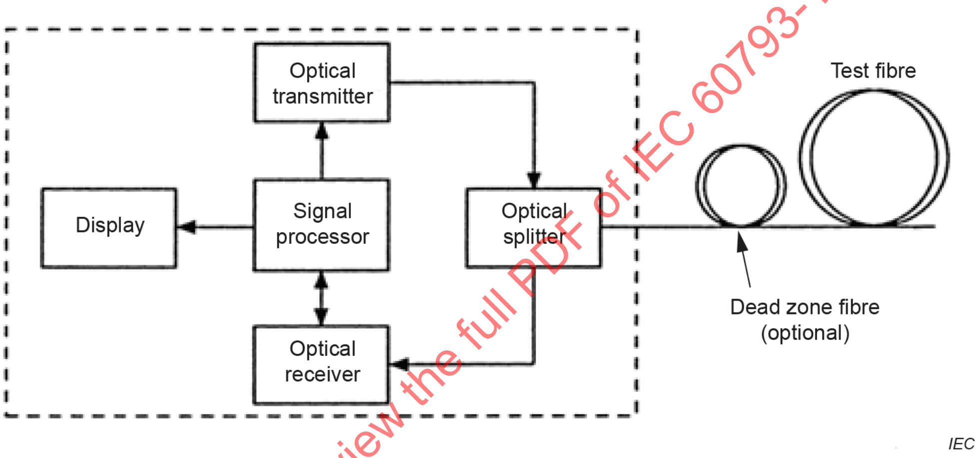


Figure B.1 – Block diagram of an OTDR

B.2.2 Optical transmitter

B.2.2.1 This usually includes one or more pulsed laser diode sources capable of one or more pulse durations and pulse repetition rates. Unless otherwise specified in the detail specification, the spectrum for each wavelength shall satisfy the following.

B.2.2.2 The centroidal wavelength shall lie within 15 nm of the specified value; report the difference between the centroidal wavelength and the specified value if it is greater than 10 nm.

B.2.2.3 The root-mean-squared width (RMSW) shall not exceed 10 nm, or the full-width at half maximum (FWHM) shall not exceed 25 nm.

B.2.2.4 If the data are to be used in a spectral attenuation model:

– the spectral width shall not exceed 15 nm (FWHM) or 6 nm (RMS) for wavelengths in the water peak region (e.g. 1 360 nm to 1 430 nm);
– report the actual centroidal wavelength to within 2 nm of the actual value.

B.2.3 Launch conditions

Provide a means for connecting the test fibre (or the optional dead-zone fibre of B.2.10) to the instrument panel, or to a fibre pigtail from the source.

For type A fibre, optical sources can produce launch conditions that are neither well controlled nor appropriate for this measurement method. Therefore, unless otherwise specified in the detail specification, launch conditions for attenuation measurements shall be those used in cut-back attenuation measurements (IEC 60793-1-40 method A).

B.2.4 Optical coupler or splitter

A coupler or splitter within the instrument directs the power from the transmitter into the fibre. It also directs light returning in the fibre from the opposite direction to the receiver.

B.2.5 Optical receiver

This usually includes a photodiode detector having a bandwidth, sensitivity, linearity and dynamic range compatible with the pulse durations used and signal levels received.

B.2.6 Pulse duration and repetition rate

The OTDR can be provided a choice of several pulse durations and repetition rates (sometimes coupled to the distance control) to optimize the trade-off between resolution and range. With a high amplitude reflection, it can be necessary to set the rate or range to a value exceeding twice the distance of the reflection in order to prevent spurious ‘ghost’ images. Pulse coding techniques can also be used.

NOTE Care should be taken when selecting the pulse duration, repetition rate and source power. For shorter distance measurements, short pulse durations are necessary to provide adequate resolution. This in turn will limit dynamic range and maximum measurable length. For long length measurements, the dynamic range can be increased by increasing the peak optical power up to a level below which non-linear effects are insignificant. Alternatively, pulse width can be increased, which will reduce the resolution of the measurements.

B.2.7 Signal processor

If required, the signal-to-noise level can be increased using signal averaging over a longer measurement time.

B.2.8 Display

This is incorporated into the OTDR and is part of the equipment controlling the OTDR. The OTDR signal is displayed in a graphical form with the vertical scale as decibels and the horizontal scale as distance. The vertical decibel scale shall correspond to half the round-trip of the backscatter loss. The horizontal scale shall correspond to half the associated (round-trip) optical group delay, converted to distance. Tools such as cursors can be used to manually or automatically measure all or part of the OTDR trace on the display.

B.2.9 Data interface (optional)

The instrument can be capable of interfacing with a computer for automatic analysis of the signal or for providing a hard copy of the display trace.

B.2.10 Reflection controller (optional)

Means of minimizing transient saturation of the receiver due to high Fresnel reflections can be required to reduce the length of fibre "dead zone" following each reflector. This can be incorporated into the coupler or splitter or can be done by electronic masking. To overcome the initial reflection at the OTDR connector, a dead-zone fibre (with a length in metres numerically exceeding one-tenth the displayed pulse duration in nanoseconds) can be used between the OTDR connector and the sample.

B.2.11 Splices and connectors

Unless otherwise indicated in this procedure, any splices or connectors required by the OTDR (e.g. to join the OTDR or the dead-zone fibre to the test fibre) shall have low insertion loss and reflectance (high return loss). This is to minimize extraneous effects upon the OTDR trace of interest.

B.3 Sampling

The sample comprises a fibre on a reel or within a cable, under conditions specified in the detail specification. The measurement can be performed in the factory or in the field, upon either single or concatenated sections.

NOTE Ensure that winding does not introduce substantial elongation for length measurements.

B.4 Procedure

B.4.1 Three techniques

There are three techniques:

- two-point technique (B.4.3.1), to use when a fibre or cable section of unknown length precedes the test fibre or cable;
- single-point technique 0 (B.4.3.2), to use with no preceding section of fibre or cable;
- single-point technique 1 (B.4.3.3), to use with a preceding section of fibre of known length and similar group index as the fibre to be measured.

NOTE For cable measurement, it is important to note that, due to the structure of most cables, there is an excess length of fibre in the cable. Because of this, the cable group index exceeds the fibre group index for the same fibre type. This will lead to discrepancy between the fibre length in the cable and the cable length itself.

B.4.2 Procedure common to all three techniques

B.4.2.1 Connect the sample either to the instrument or to one end of the dead-zone fibre (if used). Connect the other end of the dead-zone fibre (if used) to the instrument.

B.4.2.2 Because accurate distances are to be recorded, the effective group delay index of the sample is required. If this value is not known, use the method described in B.4.4 to determine it.

B.4.2.3 Enter OTDR parameters such as source wavelength, pulse duration, length range and signal averaging into the instrument, along with the sample group index. The values of some of these parameters can be preset in the instrument.

B.4.2.4 Adjust the instrument to display a backscatter signal from the sample. It can be advantageous to begin with coarse vertical and horizontal scaling to maximize the length displayed.

B.4.2.5 If increased resolution is necessary, adjust the graphical display, if possible, to expand the section of interest to a larger scale (exercising care to ensure that proper readings of the true signal can still be distinguished from the noise points).

B.4.3 Procedures specific to each technique

B.4.3.1 Two-point technique

B.4.3.1.1 Place a cursor at the beginning of the trace of the sample prior to any power drop-off (which can be difficult to do) (Figure B.2), or at a point (which can be specified by the manufacturer) on the rising edge of the reflection pulse (Figure B.3). If the beginning is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.3.1.2 Place the same or another cursor at the end of the trace of the sample at a point similar to that in B.4.3.1.1. If the end is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. Alternatively, cleave the fibre far-end, if possible, to produce a reflection there. If the end is below the noise floor, the length measurement can have a maximum error equal to the pulse length. Obtain the distance co-ordinate, z_2.

B.4.3.1.3 For maximum length accuracy, the nature of the drop-off or rise-time points at z_1 and z_2 should be similar. Obtain the sample length, $(z_2 - z_1)$.

B.4.3.2 Single-point technique 0

B.4.3.2.1 Use this method when no fibre or cable section (or dead-zone fibre) precedes the sample. See Figure B.4.

B.4.3.2.2 Place a cursor at the end of the trace of the sample prior to any power drop-off (which can be difficult to do), or at a point (which can be specified by the manufacturer) on the rising edge of the reflection pulse. If the end is not apparent because of minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement. If the end is below the noise floor, the length measurement can have a maximum error equal to the pulse length.

Alternatively, cleave the fibre far-end, if possible, to produce a reflection there. Obtain the distance coordinate, z_2.

B.4.3.2.3 The sample length equals z_2.

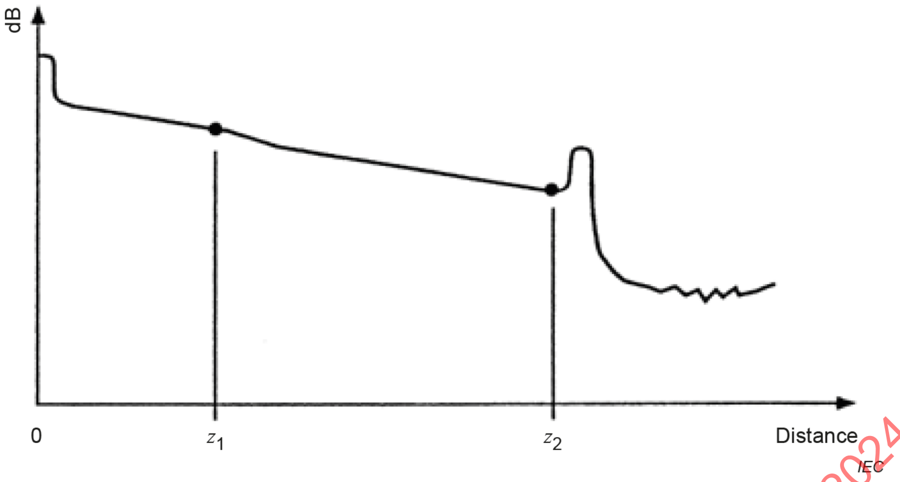
B.4.3.3 Single-point technique 1

B.4.3.3.1 Use this method when a fibre or cable section (or a dead-zone fibre) of known length, z_D, precedes the sample. See Figure B.5. The length can be obtained by mechanical measurement, for example by using contact-type devices with counters.

The fibre used in the preceding section (or dead-zone fibre) should have a similar group index as the sample.

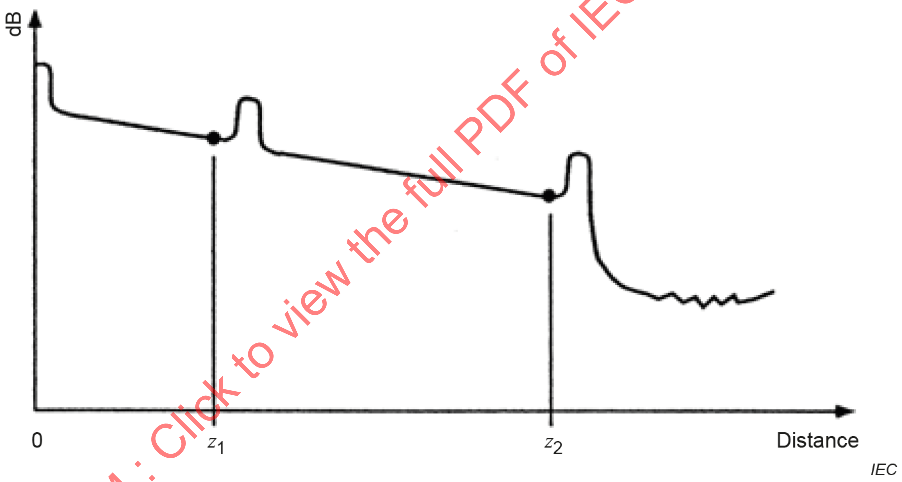
B.4.3.3.2 Perform the steps of B.4.3.2.2.

B.4.3.3.3 The sample length equals $(z_2 - z_D)$.



NOTE An example of the section of unknown length is dead-zone fibre

Figure B.2 – Schematic OTDR trace of a sample (z_1 to z_0) with a section of unknown length, z_1, preceding it and without a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))



NOTE An example of the section of unknown length is dead-zone fibre

Figure B.3 – Schematic OTDR trace of sample (z_1 to z_2) with a section of unknown length, z_1, preceding it and with a reflection pulse from the fibre joint point (two-point technique (B.4.3.1))

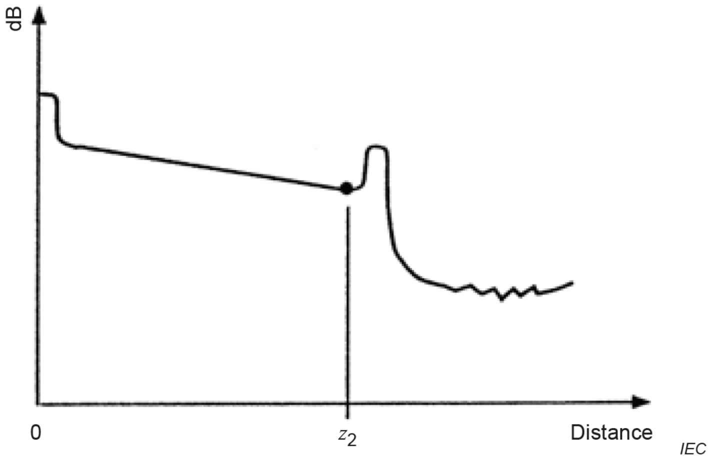
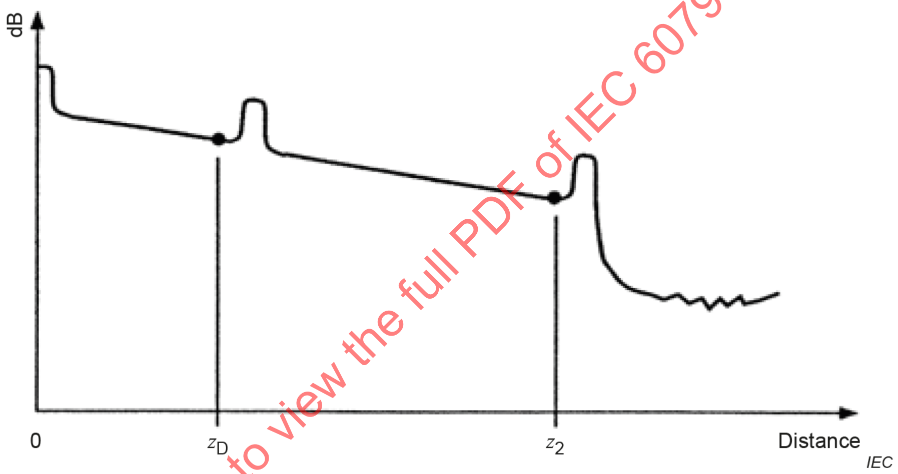


Figure B.4 – Schematic trace of a sample (0 to z_2) with no section preceding it (single-point technique 0 (B.4.3.2))



NOTE an example of the section of unknown length is dead-zone fibre

Figure B.5 – Schematic OTDR trace of a sample (z_D to z_2) with a section of known length, z_D, preceding it (single-point technique 1 (B.4.3.3))

B.4.4 Determination of group index

B.4.4.1 Accurately determine the physical length of the calibration fibre or cable. This can be done by mechanical measurement, for example by using contact-type devices with counters.

B.4.4.2 Perform the steps given in B.4.2.1 for the calibration fibre or cable.

B.4.4.3 Perform the steps given in B.4.2.3, but with an arbitrary group index.

B.4.4.4 Place one cursor at the beginning of the trace as indicated in B.4.3.1.1. Obtain the distance coordinate, z_1, via the alphanumeric display.

B.4.4.5 Place another cursor at the end of the trace as indicated in B.4.3.1.2. Obtain the distance coordinate, z_2.

B.4.4.6 Adjust the group index scale until the difference, $(z_2 - z_1)$, which can be automatically calculated by the instrument, equals the length determined in B.4.4.1.

B.5 Results

In addition to the results in Clause 9, the following information shall be available upon request:

– group index.

Annex C
(normative)

Requirements specific to method C – Fibre elongation

C.1 Principle

Derive the fibre elongation by the phase shift technique (C.2.2.1), or by the differential pulse delay (C.2.2.2).

The fibre elongation strain, $\varepsilon = \Delta L/L$, is given by:

$$\varepsilon = V \times \frac{\Delta t}{L} \tag{C.1}$$

where

Δt is the differential pulse delay;

L is the sample fibre length;

V is a constant that depends on the photoelastic coefficient (k), the speed of light in a vacuum (c), and the group index of refraction (N_{eff}).

$$V = \frac{kc}{N_{\text{eff}}} \tag{C.2}$$

The factor, V, corrects the results for changes in the fibre's refractive index with strain.

When using the phase-shift technique (C.2.2.1), derive the differential delay, Δt, from:

$$\Delta t = \frac{\Delta\Theta}{360 \times f} \tag{C.3}$$

where

$\Delta\Theta$ is the phase shift (degrees);

f is the modulation frequency.

Because the factor, V, depends on the fibre type, the measurement set-up shall be calibrated.

C.2 Apparatus

C.2.1 General requirements

The measurement fixture of known gauge length shall be capable of applying and varying longitudinal stresses on the cable or fibre. Observe the proper fixing of the ends of the sample to prevent the fibres from slipping during loading. Provide a suitable elongation bench for the calibration of the phase-shift or pulse-delay versus the mechanically measured fibre elongation.

C.2.2 Optical measurement equipment

C.2.2.1 General

The equipment for either technique, phase shift technique or differential pulse delay, should be stable over the measurement time period and temperature range encountered. See Figure C.1 and Figure C.2, respectively, for diagrams of typical equipment set-ups.

C.2.2.2 Phase-shift technique

Use a light source (either a laser diode or filtered light-emitting diode), modulator, launch optics, signal detector and reference signal for measuring chromatic dispersion using the phase-shift technique. These pieces of equipment are outlined and specified in method A of IEC 60793-1-42. The difference is that only one laser diode is used. The phase shifts observed are a function of strain changes on the fibre.

Ensure that 360° phase-shift roll-over ambiguities of the phase meter are accounted for when using this method.

C.2.2.3 Pulse-delay (time of flight) technique

Use equipment required for an appropriate time-of-flight measurement technique, such as a short-pulse optical time domain reflectometer (OTDR).

C.2.3 Instrument resolution

The strain measurement resolution of the entire measurement system should be equal to or less than 0,01 %. This includes the optical measurement equipment (modulation frequency or pulse width, etc.) and the measurement fixture (sample gauge length, cable or fibre end fixers, load measurement, etc.). Since all these factors are involved in determining the entire measurement system's accuracy and resolution, each measurement bench should be evaluated separately.

This measurement procedure is intended to be conducted at ambient room conditions typically found in laboratories. This method is feasible under other conditions, provided the temperature is stable to ±2 °C for the duration of the test. For extreme temperature and pressure changes (more than 40 atmospheres), corrections can be necessary, particularly regarding the V factor.

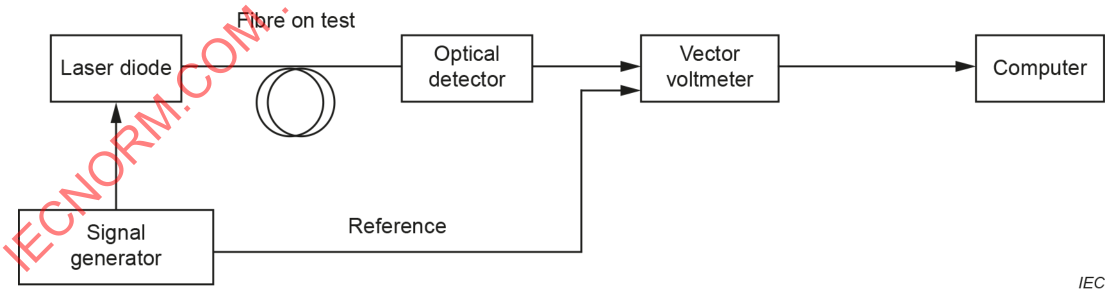


Figure C.1 – Equipment set-up for phase-shift technique (C.2.2.2)

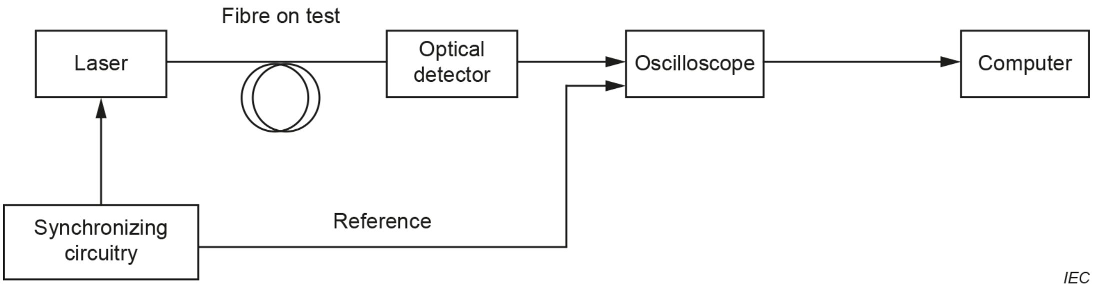


Figure C.2 – Equipment set-up for differential pulse-delay technique (C.2.2.3)

C.3 Procedure

C.3.1 Calibration

Install the reference fibre on the elongation bench and connect it to the optical measurement apparatus.

Progressively increase the fibre elongation within a known range of elongation that is sufficiently linear to determine the factor, V.

Measure and record, preferably continuously, the phase shift or pulse delay as a function of the mechanical fibre elongation.

The relation thus determined accounts for the strain-induced changes of the group index.

It is recommended that the operator carry out the calibration with a random selection of fibre samples of the same type.

NOTE It is not necessary to repeat this calibration before each fibre elongation measurement, if the same type of fibre (design and manufacturer) is used.

C.3.2 Sample measurement

Take either a phase reading in degrees or time-delay reading for the reference condition (typically ambient conditions). Record the reference value. Longitudinally strain the sample to the specified load. After the applied load is stabilized, repeat the measurement procedures and record either the strained phase value or length value. Repeat these steps for any additional load conditions. Upon releasing the applied load, take a final measurement to ensure that the applied fibre strain has returned to its original reference condition.

Perform a single-end measurement using one of the techniques shown below. If the phase-shift technique is used, the phase should be continuously recorded while applying the load to account for 360° phase-shift roll-overs.

a) For a cable under test, form an optical path by two fibres that are connected at the far end. However, due to the averaging effect of the strains on the two fibres, take particular care when interpreting the results.

b) Insert, at the near end, a suitable directional coupler connected, on one side, to the optical source and to the detector, and, on the other side, to the fibre under test. Then measure the phase shift or pulse delay between the input signal and the signal reflected from the far end. The cleaved fibre far end face shall be clean and perpendicular to maximize the reflected signal. Minimize other reflections (e.g. from the near end of the fibre).

In both cases, use a factor 2 to correct the collected phase-shift or pulse-delay data to take into account the double length of the optical path.

C.4 Results

In addition to the results in Clause 9, the following information shall be available upon request:

– load applied at each phase (or length) reading, and the calculated strain;
– type and frequency of modulator (phase-shift method).

Annex D
(normative)

Requirements specific to method D – Mechanical length

D.1 Principle

This method of measuring fibre length is carried out by winding the fibre onto a spool. It can be done on the draw, during the tensile-proof operation, or any other such winding process. During the process, the fibre engages with a fixed diameter calibrated wheel that rotates. The number of revolutions resulting from the winding process, multiplied by $\pi D/1\ 000$, yields the length of the fibre in kilometres, where D is the diameter of the counting wheel, in metres.

D.2 Apparatus

Provide a wheel, or arrangement of wheels, so that the passage of fibre length through the assembly is linked to the counter wheel rotation in a linear fashion. Ensure that no slippage of the fibre relative to the surface of the counting wheel occurs.

The counter wheel shall be rigid, with a surface that is free of burrs or other features that can damage the fibre. Link the counter wheel with an electronic counter that can optionally convert counts to length.

D.3 Procedure

D.3.1 Calibration

Calibrate the wheel by passing a fibre of known length (calibration fibre) through the winding process. This can correct for variations in wheel surface treatment or wheel machining.

Use surveying equipment to obtain length measurements on the calibration fibre. Use a fibre of a length that is long enough for the desired accuracy. When being measured, deploy it in a straight line and measure it at a temperature that is consistent with the operating temperature of the mechanical measurement device.

D.3.2 Operation

Reset the counter and initiate the winding process. At the completion of the winding process, note the count and convert to length.

Ensure that winding does not introduce substantial elongation and that elongation conditions are the same during calibration.

Annex E
(normative)

Requirements specific to method E – Phase shift

E.1 General

This test method uses the phase shift change in an optical fibre or cable when the frequency is increased to a predetermined modulation frequency f_{max}. It can be applied to fibre lengths typically in the range of less than 1 m to several kilometres for type A1 fibres and to several hundreds of kilometres for type B fibres.

E.2 Apparatus

E.2.1 General

A diagram of the measurement apparatus is shown in Figure E.1. The apparatus used in this measurement method can also be configured to measure the chromatic dispersion of a fibre. Measurement of chromatic dispersion by the phase shift method is described in method A of IEC 60793-1-42.

E.2.2 Light source

Either a laser diode or a filtered light-emitting diode can be used. The centre wavelength and modulated output phase shall be stable over the measurement time period at the bias current, modulation frequency and diode temperature range encountered.

The spectral width of the source at full-width half-maximum (FWHM) shall be less than or equal to 30 nm. This can be achieved using a monochromator or optical filter, if necessary.

E.2.3 Modulator

Provide a means to modulate the intensity of the output of the optical source over a wide frequency range, typically from about 100 Hz up to a few gigahertz, to produce a waveform that has a single dominant Fourier component, such as a sine wave.

The choice of modulation frequency is determined by the maximum fibre length that is to be measured and the measurement precision that is required. To avoid ambiguities caused by 2π phase shifts, where there is more than one complete modulation cycle in the fibre, it is necessary to start with a low frequency and count the number of complete cycles as the frequency is slowly increased. It is important that the number of 2π phase shifts are counted unambiguously. The use of a higher frequency usually gives a more precise measurement of length. For a given fibre length L, in metres, the maximum starting frequency f_{start}, in hertz, is given by:

$$f_{start} \le \frac{c}{N \times L} \tag{E.1}$$

where

c is the velocity of light in a vacuum, in m/s;

N is the group index.

For example, for a length of 10 km a typical maximum value of f_{start} would be 20 kHz.

Alternatively, if the starting frequency has already been chosen then the maximum length of fibre that can be measured can be calculated from a re-arrangement of Formula (E.1).

The choice of upper frequency, the corresponding phase noise at this frequency and the uncertainty of the modulation frequency itself will determine the measurement resolution. For a minimum measurable phase change of $\Delta\phi$, in radians, the minimum resolvable length ΔL, in the absence of phase noise and frequency uncertainty, is given by:

$$\Delta L = \frac{\Delta\varphi \times c}{f_{\text{max}} \times N \times 2\pi} \tag{E.2}$$

Note that the value of $\Delta\phi$ can depend on the modulation frequency used.

Alternatively, for a given fibre length resolution, then the maximum frequency required can be determined from a re-arrangement of Formula (E.2).

For example, for a phase resolution of 0,01 rad and a maximum frequency of 100 MHz, the length resolution would be approximately 3 mm.

E.2.4 Launch optics

Couple light from the source into the fibre under test by, for example, optically imaging the source onto the end of the test fibre or by direct butt coupling from a fibre pigtail that is coupled to the source. For type A1 fibres it is necessary to restrict the launch conditions to excite only low-order modes in the fibre, to minimize the effects of modal dispersion. This can be achieved either by direct imaging of the source onto the end of the test fibre using an optical system in which the numerical aperture and the spot-size can be restricted, or by direct coupling from a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

E.2.5 Signal detector and signal detection electronics

For signal detection use an optical detector that is sensitive at the wavelength of measurement, is stable over the duration of the measurement, and is linear over the intensity modulation range. An amplifier can be used to increase detection sensitivity. Couple light from the test fibre onto the detector using, for example, direct imaging with lenses or a fibre pigtail that is directly coupled to the detector. For type A1 fibres it is necessary to collect only light from low-order modes in the test fibre. This can be achieved by direct imaging onto the detector using an optical system in which the numerical aperture and the spot-size can be restricted, or by direct coupling into a single-mode fibre pigtail which is positioned on the axis of the test fibre and in contact with it.

Use a phase-measuring instrument, such as a phase meter, vector voltmeter or network analyzer, that responds only to the fundamental Fourier component of the modulating signal to determine the phase of the detected light. Any phase shift that is introduced by the phase measuring system itself shall be constant for the duration of the measurement.

E.2.6 Reference signal

A reference signal is required by the phase meter, which has the same dominant Fourier component as the modulating signal, against which the phase of the output signal is measured. The reference signal shall be phase locked to the modulating signal. The reference signal can be derived by either taking a direct electrical connection from the modulation source to the phase meter, or by using a detector coupled to an optical beam splitter or fibre coupler which is inserted between the source and the test fibre.

E.2.7 Computation equipment

A computer can be used for the purposes of equipment control, data acquisition and numerical evaluation of data.

E.3 Sampling

The test sample shall be a cabled or non-cabled fibre. Typical fibre sample lengths are 1 m to hundreds of kilometres. The sample, launch optics and pigtails, if used, shall be fixed in position at a nominally constant temperature for the duration of the measurement. In the case of installed fibres and cables, the prevailing deployment and environmental conditions can be used.

Either a phase calibration fibre of the same type as the fibre under test, (or the fibre pigtails, if used), is required to compensate for phase shifts that can be introduced by the phase meter or internal optical path lengths. A typical length is 0 m to 2 m.

Prepare end faces for the input and output ends of the calibration fibre and test fibre, as appropriate for the requirements of E.2.3 and E.2.4.

E.4 Procedure

E.4.1 Selection of starting frequency

Select a suitably low modulation frequency f_{start}, determined using Formula (E.1). If the approximate length of the fibre is unknown then use the lowest available modulation frequency but exercise caution with respect to the possibility of 2π phase errors in the fibre.

E.4.2 Selection of maximum frequency

Select a suitable maximum frequency f_{max}, determined using Formula (E.2), for the required length resolution.

E.4.3 Phase measurement performance

Subclause E.4.3 applies to all length measurements made on the test fibre and the phase calibration fibre, and if required, during the determination of group index.

Starting at modulation frequency f_{start} increase the frequency, until f_{max} is reached, at a rate sufficient to allow the unambiguous determination of the number, m, of 2π phase shifts that occur. Measure the phase angle ϕ' at the output of the fibre at f_{max}.

Calculate the total phase angle ϕ as follows:

$$\varphi = \varphi' + m \times 2\pi \quad \text{(E.3)}$$

E.4.4 Measurement of length of test fibre

E.4.4.1 Calibration of reference phase

Depending on whether fibre pigtails are used or not, calibrate the reference phase by following one of the two methods below:

a) When pigtails are not used, couple one end of the phase calibration fibre (input) to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{ref} according to E.4.3.

b) When pigtails are used at both the launch and receive ends, these are connected to perform the reference phase measurement instead of using a separate phase calibration fibre. Measure the phase shift ϕ_{ref} according to E.4.3.

It is sometimes convenient to remove either the phase calibration fibre or the pigtails, or both, from the apparatus after the reference measurement has been made. This can be done if the phase shift that occurred within either the phase calibration fibre or the pigtails, or both, is known and is subsequently added to the measured phase shift of the fibre under test, see E.4.4.2.

It is not normally necessary to calibrate the reference phase before each measurement. The use of a stored reference value is permitted if it is understood that the presence of phase drift in the system can degrade the measurement uncertainty.

E.4.4.2 Measurement of test fibre phase

Depending on whether fibre pigtails are used or not, measure the test fibre phase by following one of the two methods below.

a) When pigtails are not used, uncouple the output of the phase calibration fibre from the detection system and couple it to one end of the fibre under test (input). Couple the other end (output) of the fibre under test to the detection system. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used E.4.4.1.

b) When pigtails are used instead of a phase calibration fibre, disconnect the pigtails from each other and couple the free ends to the fibre under test. Measure the phase shift ϕ_{sig} according to E.4.3 using the same value of f_{max} used in E.4.4.1.

E.5 Calculation and interpretation of results

Calculate the length, L, of the test fibre as follows:

$$L = \frac{(\varphi_{sig} - \varphi_{ref}) \times c}{N \times f_{max} \times 2\pi} \tag{E.4}$$

where

L is in metres;

ϕ_{ref}, ϕ_{sig} are in radians;

c is in metres per second;

f_{max} is in hertz;

N is the group index.

Note that ϕ_{ref} and ϕ_{sig} represent the total phase angle at the maximum frequency f_{max} used, including the total number of 2π phase shifts, see Formula (E.3).

NOTE The group index N can be supplied by the fibre or cable manufacturer. The accuracy in measurement of length using this method largely depends on the certainty with which the group index is known. Group index values vary from fibre to fibre and can also be temperature sensitive. Typical manufacturers' values have an uncertainty equivalent to 0,1 % in length measurement. If the group index is not known, then it can be determined according to the procedure described in E.6.

E.6 Group index

E.6.1 General

To determine the value of group index it is necessary to measure the phase shift associated with a fibre of known length at the wavelength of measurement. This can be performed either by cutting a known length of fibre from the output end of the test fibre, known as the cut-back method, described in E.6.2 or by connecting a fibre of known length, which is of the same class and type as the test fibre, to the apparatus in place of the test fibre, known as the substitution method, described in E.6.3.

NOTE Uncertainties due to non-linearities in the phase measurement system can be minimized by choosing cut-back and substitution fibre lengths corresponding to approximately one 2π phase cycle of the modulation frequency. For example, at a maximum frequency f_{max} of 100 MHz this corresponds to a length of approximately 2 m.

E.6.2 Cut-back method

E.6.2.1 Couple one end (input) of the test fibre to the light source. Couple the other (output) end of the test fibre to the detection system. Measure the phase shift ϕ_{long} according to E.4.3.

E.6.2.2 From the output end of the test fibre, remove a short length of fibre L_{cut} typically 2 m to 3 m (see E.6.1). Re-prepare the new output end of the test fibre, which is now slightly shorter, and couple it to the detection system. Measure the phase shift ϕ_{short} according to E.4.3 using the same value of f_{max} that was used in E.6.2.1.

E.6.2.3 Measure the length of the fibre L_{cut} that was removed in E.6.2.2 using, for example, a calibrated metre rule. Note that the uncertainty in this measurement will proportionally affect the measurement uncertainty of the group index of the test fibre.

E.6.2.4 Calculate the group index using Formula:

$$N = \frac{(\varphi_{long} - \varphi_{short}) \times c}{L_{cut} \times f_{max} \times 2\pi} \quad \text{(E.5)}$$

E.6.3 Substitution method

E.6.3.1 Couple one end (input) of the phase calibration fibre to the light source. Couple the other end (output) to the detection system. Measure the phase shift ϕ_{cal} according to E.4.3.

E.6.3.2 Uncouple the output of the phase calibration fibre from the detection system and couple a fibre of known length L_{sub}, typically 2 m to 3 m (see E.6.1), which is of the same class and type as the test fibre, between the output of the phase calibration fibre and the detection system. The length of this fibre can be measured with, for example, a calibrated metre rule. Measure the phase shift ϕ_{sub} according to E.4.3 using the same value of f_{max} used in E.6.3.1.

E.6.3.3 Calculate the group index using Formula:

$$N = \frac{(\varphi_{sub} - \varphi_{cal}) \times c}{L_{sub} \times f_{max} \times 2\pi} \quad \text{(E.6)}$$

The precision of the group index determination will affect the precision of the length as measured by phase shift method. Note, for very precise values, the group index value can vary from fibre to fibre, as well as with temperature and stress.

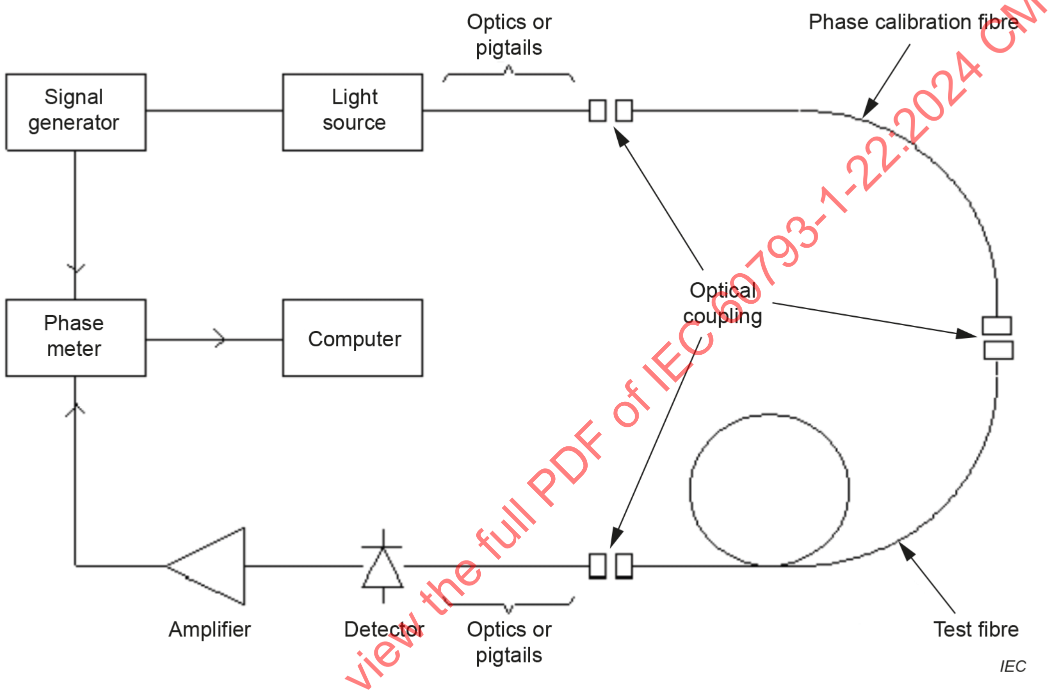


Figure E.1 – Apparatus for fibre length measurement

Annex F
(informative)

Brillouin frequency shift test method

F.1 General

This Brillouin frequency shift method describes a procedure for determining the tensile strain applied to a fibre. It uses Brillouin reflectometry (BOTDR) or so-called Brillouin analysis (BOTDA), which are single-sided and double-sided methods respectively. A single distributed measurement of the Brillouin frequency shift gives access to distributed tensile strain, which can be absolute if one dispose of a strain-free portion. An absolute reading is essential to determine the initial state of a fibre prior to the pulling test, or for testing the state of a fibre over a long-distance cable. The difference of two subsequent measurements gives access to the distributed and relative fibre elongation, but also to an average elongation over the strained section that is equivalent to the one obtained with method C.

F.2 Principle

Derive the fibre elongation along the fibre from the distributed measurement of the Brillouin frequency shift. In the Brillouin process, the back-scattered radiation suffers a doppler shift, namely the Brillouin frequency shift f_B, which writes:

$$f_B = \frac{2 \cdot n \cdot V_a}{\lambda} \tag{F.1}$$

where

n is the refractive index;

V_a is the velocity of an acoustic wave at frequency f_B, expressed in m/s;

λ the optical wavelength of the probe laser expressed in m.

There is a linear dependency between the Brillouin frequency shift and the tensile strain applied on fibre, associated with the changes of material density and elastic properties of the material under tensile strain [1].

$$f_B = f_{B0} + C_{f\varepsilon} \cdot \varepsilon \tag{F.2}$$

where

f_{B0} is the Brillouin frequency shift for the strain free material, expressed in Hz;

$Cf\varepsilon$ is the coefficient of variation of the Brillouin frequency shift with tensile strain applied;

$\varepsilon = \frac{\Delta L}{L}$ is the relative elongation of the fibre of length L under tensile strain.

Several reflectometric techniques were reported allowing the determination of the Brillouin frequency shift $f_B(z)$, with z the position along an optical fibre. Metric spatial resolutions are commonly reported but centimetric spatial resolutions are also possible [4] and [6].

Distributed measurement of $f_B(z)$ gives access to a tensile strain state $\varepsilon(z)$, thanks to Formula F.2. The method F is the sole method providing an absolute value of the tensile strain, it only requires the possibility of measurement of the given fibre in a strain-free state ($\varepsilon = 0$) so to determine f_{B0} Absolute and distributed tensile strain measurements can therefore be determined in two ways:

a) From a single distributed measurement on a fibre link that include one section which is known to be in a strain-free state.

b) From a set of two distributed measurements in two states, the first state being considered as a strain-free state.

For an optimal accuracy, the coefficient $Cf\varepsilon$ is calibrated for the given fibre, but in practice numerous publications already report very consistent values of this coefficient for a large range of fibre types. A nominal coefficient of $Cf\varepsilon$ = 490 MHz/% can however be used with an associated accuracy on tensile strain measurements better than 5 %. The accuracy on coefficients and length measurements was not debated for the other methods described in the present document, so these accuracy considerations are only provided as an indication of what can reasonably be expected.

F.3 Apparatus

F.3.1 General requirements

The measurement fixture of known gauge length shall be capable of applying and varying longitudinal stresses on the cable or fibre. Observe the proper fixing of the ends of the sample to prevent the fibres from slipping during loading. Provide an elongation bench for the calibration of the Brillouin frequency shift versus the mechanically measured fibre elongation.

F.3.2 Optical measurement equipment

F.3.2.1 General

The equipment for either technique, BOTDR or BOTDA, should be stable over the measurement time period and temperature range encountered. See Figure F.1 and Figure F.2, respectively, for diagrams of typical equipment set-ups. These diagrams only represent the general concepts leading to a distributed measurement of the Brillouin frequency shift. Many implementations are possible in practice [5], including coherent detection as a filter mechanism, additional amplifiers, pulsed RF-driven electro-optic modulators to produce wavelength tunability at the same time as pulsing.

F.3.2.2 BOTDR

Use of a pulsed light source to probe the fibre under test, the backscattered radiation is filtered to resolve temporally and spectrally the spontaneous Brillouin scattering. The instrument can also dispose of a Rayleigh OTDR to measure the fibre attenuation during pulling test.

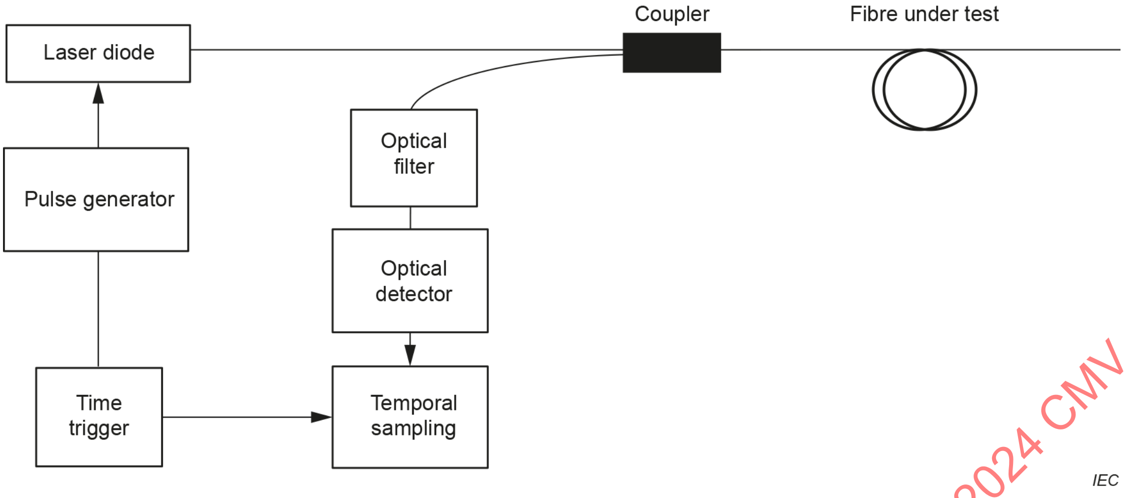


Figure F.1 – Equipment setup for BOTDR technique

F.3.2.3 BOTDA

Use of both a pulsed light source and a continuous wave light source sent in counter-propagation in the fibre under test, so to generate a strong stimulated Brillouin scattering interaction. The power of the transmitted continuous light source is detected as it carries the distributed information of the interaction that took place when and where it crossed the pulse. Tuning the relative frequency shift in between the two lasers allow to scan and record the Brillouin gain profile. The instrument can also dispose of a Rayleigh OTDR to measure the fibre attenuation during pulling test.

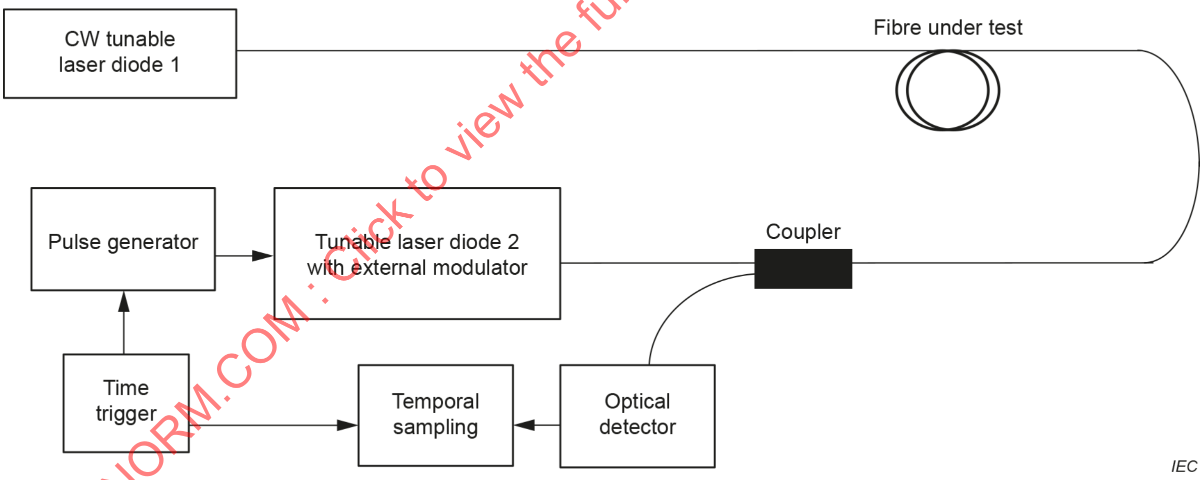


Figure F.2 – Equipment setup for BOTDR technique

F.3.3 Instrument resolution

The strain measurement resolution of the entire measurement system should be ≤ 0,01 %. This includes the optical measurement equipment (frequency sampling or pulse width, etc.) and the measurement fixture (sample gauge length, cable or fibre end fixers, load measurement, etc.). Since all these factors are involved in determining the entire measurement system's accuracy and resolution, evaluate each measurement bench separately.

This measurement procedure is intended to be conducted at ambient room conditions typically found in laboratories. This method is feasible under other conditions, provided the temperature is stable to ±2 °C for the duration of the test. For extreme temperature and pressure changes (more than 40 atmospheres), corrections can be necessary, particularly regarding the $Cf\varepsilon$ factor.

The 0,01 % corresponds to a maximal frequency sampling resolution of 5 MHz when recording the Brillouin spectrum. The “spatial resolution” is defined in IEC 61757-1-2. Any localized strain applied to a fibre distance larger than the spatial resolution expected is measured with a 90 % accuracy. To provide valuable distributed information during a standard cable pulling test over a 100 m long fibre, the spatial resolution shall not exceed 1,4 m.

F.4 Procedure

F.4.1 Calibration

It is recommended that the operator carry out the calibration with a random selection of fibre samples of the same type.

a) Install the reference fibre on the elongation bench and connect it to the optical measurement apparatus.

b) Progressively increase the fibre elongation within a known range of elongation that is sufficiently linear to determine the factor $Cf\varepsilon$.

c) Measure and record, preferably continuously, the Brillouin frequency shift as a function of the mechanical fibre elongation.

d) The relation thus determined accounts for the strain-induced changes of the group index, elastic and acoustic properties.

NOTE It is not necessary to repeat this calibration before each fibre elongation measurement if the same type of fibre (design and manufacturer) is used.

F.4.2 Sample measurement

Take a distributed Brillouin frequency shift reading for the reference condition (typically ambient conditions). Record the reference trace. Longitudinally strain the sample to the specified load. After the applied load is stabilized, repeat the measurement procedures and record the strained Brillouin frequency shift trace.

To determine a relative elongation averaged over the strained section, (i.e. with the generally adopted measurement for the elongation that would match a measurement obtained with method C) it is necessary to precisely identify the strained portion. Figure F.3 shows an example of differential tensile strain derived from two measurements of distributed frequency shift, in first acquisition the whole cable and fibre herein were strain-free, while in the second measurement a 1 % strain was applied to a 100 m section of cable, resulting here in an average strain of approximately 0,6 % on the fibre herein. Measure the maximal strain level recorded and determine the left and right positions where the strain crosses 90 % of this maximum and calculate the average elongation over that section.

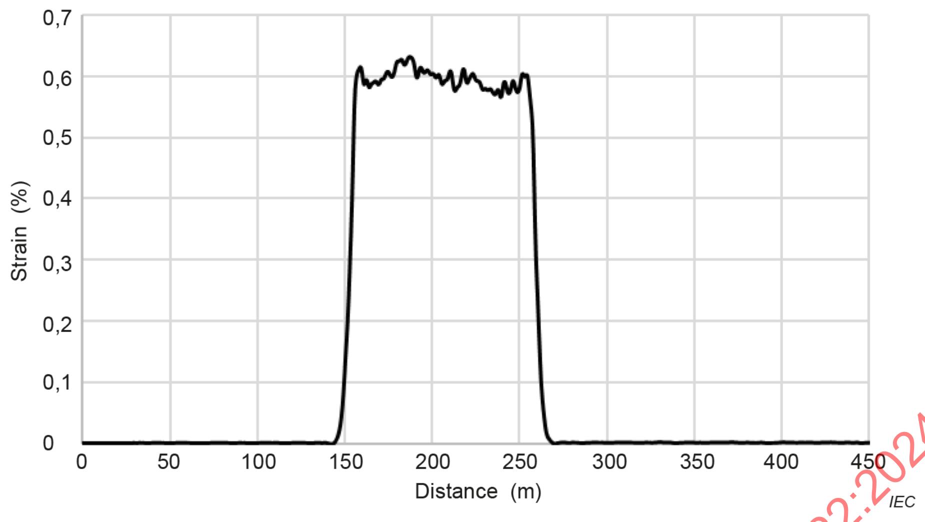


Figure F.3 – Differential strain recorded during a pulling test over a 100 m of cable

The Brillouin frequency shift method of referencing can however be operated differently so to display absolute measurements of strain from a single acquisition. Figure F.4 shows the second acquisition that was used to produce the differential strain of Figure F.3. Several sections are clearly identified, the section from 25 m to 140 m corresponds to a launch fibre of a different type than the one in the cable under test, then starts the cable under test, with about 10 m left unstrained, then from 150 m to 250 m the pulled section of cable, and then again, a long portion of the same unstrained cable. The Brillouin frequency shift of this latter section was used to determine f_{B0} , and allows to display absolute strain state, and would result in a same ~0,6 % strain level in the pulled section as was obtained from Figure F.1 data with a differential measurement. This referencing technique is not suitable for the fibre section from 25 m to 140 m which is of a different type. While the technique proposed here differs from the method C, it can provide some extra information. For example, one can verify that the initial state of the fibre prior to pulling is strain-free, so that differential strain subsequently measured after pulling does not add to an already high strain value. In addition, this measurement would allow the absolute strain state measurement of any long-distance cable at production level and make a systematic assessment of the quality of the cabling.

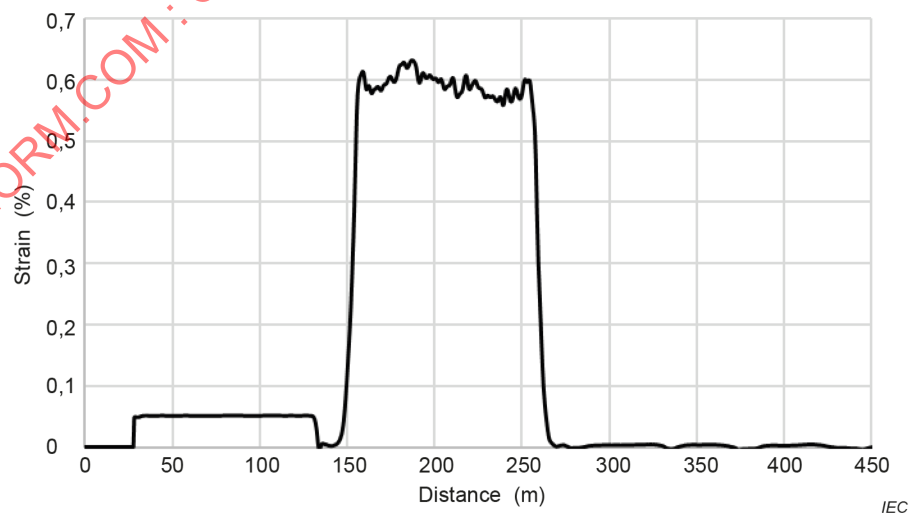


Figure F.4 – Absolute strain profile recorded during a pulling test over a 100 m of cable

Report peak value, average of distributed value, absolute or relative as applicable to your test.

Repeat these steps for any additional load conditions. Upon releasing the applied load, take a final measurement to ensure that the applied fibre strain returned to its original reference condition.

F.5 Results

In addition to the results in Clause 9, the following information shall be available upon request:

- load applied at each reading, and the calculated strain,
- refractive index and $Cf\varepsilon$.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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FIBRES OPTIQUES –

Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur

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L'IEC 60793-1-22 a été établie par le sous-comité 86A: Fibres et câbles, du comité d'études 86 de l'IEC: Fibres optiques. Il s'agit d'une Norme internationale.

Cette deuxième édition annule et remplace la première édition parue en 2001. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) ajout des fibres unimodales de catégorie C dans le Tableau 1,
b) ajout d'une nouvelle Annexe F informative sur la méthode d'essai de décalage de fréquence Brillouin pour déterminer la déformation en traction appliquée à une fibre.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
86A/2456/FDIS	86A/2474/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

La version française de la norme n'a pas été soumise au vote.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 60793, publiée sous le titre général *Fibres optiques*, se trouve sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site Web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera:

- reconduit,
- supprimé, ou
- révisé.

INTRODUCTION

Les publications de la série IEC 60793-1 concernent les informations essentielles sur les méthodes de mesure et les procédures d'essai s'appliquant aux fibres optiques.

Cette même série traite des différents domaines regroupés de la façon suivante:

- IEC 60793-1-20 à IEC 60793-1-29: *Méthodes de mesure et procédures d'essai des dimensions;*
- IEC 60793-1-30 à IEC 60793-1-39: *Méthodes de mesure et procédures d'essai des caractéristiques mécaniques;*
- IEC 60793-1-40 à IEC 60793-1-49: *Méthodes de mesure et procédures d'essai des caractéristiques optiques et de transmission;*
- IEC 60793-1-50 à IEC 60793-1-59: *Méthodes de mesure et procédures d'essai des caractéristiques d'environnement;*
- IEC 60793-1-60 à IEC 60793-1-69: *Méthodes de mesure et procédures d'essai pour les fibres à maintien de polarisation.*

L'IEC 60793-1-2X comprend les parties suivantes, présentées sous le titre général: Fibres optiques:

- Partie 1-20: Méthodes de mesure et procédures d'essai – Géométrie de la fibre
- Partie 1-21: Méthodes de mesure et procédures d'essai – Géométrie du revêtement
- Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur

FIBRES OPTIQUES –

Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur

1 Domaine d'application

La présente partie de l'IEC 60793 établit des exigences uniformes pour mesurer la longueur et l'allongement de la fibre optique (typiquement dans le câble).

La longueur d'une fibre optique est une valeur fondamentale pour l'évaluation des caractéristiques de transmission, telles que les pertes et la bande passante.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60793-1-40, *Fibres optiques – Partie 1-40: Méthodes de mesurage de l'affaiblissement.*

IEC 60793-1-42, *Fibres optiques – Partie 1-42: Méthodes de mesure et procédures d'essai – Dispersion chromatique.*

3 Termes, définitions et abréviations

3.1 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp

3.2 Abréviations

Pour les besoins du présent document, les abréviations suivantes s'appliquent.

BOTDA	Brillouin optical time domain analysis (analyse optique Brillouin temporel)
BOTDR	Brillouin optical time domain reflectometry (réflectométrie optique Brillouin temporel)
FWHM	full-width half-maximum (largeur d'impulsion à mi-hauteur)
OTDR	optical time domain reflectometer (réflectomètre optique temporel)
RMSW	root-mean-squared width (moyenne quadratique de la largeur)
RTM	reference test method (méthode d'essai de référence)

4 Vue d'ensemble de la méthode

4.1 Généralités

Le présent document propose cinq méthodes pour mesurer la longueur de fibre, qui sont présentées dans le Tableau 1.

Tableau 1 – Méthodes de mesure

Méthode		Caractéristiques couvertes	Catégories de fibre couvertes
A	Mesure du retard	Longueur	Toutes les catégories A1, B et C
B	Rétrodiffusion	Longueur	Toutes les catégories A1, B et C
C	Allongement de la fibre[a]	Allongement de la fibre[c]	A1, B1[b] et C
D	Mécanique	Longueur	Toutes
E	Déphasage	Longueur	Toutes les catégories A1, B et C

[a] La mesure de l'allongement de la fibre est utilisée dans l'IEC 60794-1-1.

[b] Cette mesure s'applique sans réserve aux fibres unimodales de type B. Pour les fibres multimodales de type A1, la prudence est de mise dans l'interprétation des résultats, les résultats de cette mesure pouvant être influencés par les interférences dues aux effets modaux, par exemple à la suite de contraintes non longitudinales sur la fibre. L'application de la mesure aux fibres multimodales des types A2 à A4 est à l'étude.

[c] De plus, l'Annexe F informative a été ajoutée pour déterminer la déformation en traction appliquée à une fibre. Elle utilise la réflectométrie Brillouin (BOTDR) ou ladite analyse Brillouin (BOTDA) qui sont respectivement des méthodes par un seul côté et par deux côtés.

Les informations communes à toutes les mesures sont données de l'Article 2 à l'Article 8. Des informations pour application spécifique apparaissent respectivement dans l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D et l'Annexe E pour les méthodes A, B, C, D et E.

4.2 Méthode A, mesure du retard

La méthode de mesure du retard s'applique aux mesures de la longueur de la fibre par la mesure du temps de propagation d'une impulsion optique ou d'une série d'impulsions en se fondant sur une valeur connue de l'indice de groupe de la fibre.

En variante, cette méthode est appropriée pour mesurer l'indice de groupe d'une fibre de longueur connue. En pratique, cette méthode de mesure de la longueur de la fibre est étalonnée par rapport à une longueur connue d'une fibre de même type.

4.3 Méthode B, rétrodiffusion

La méthode de rétrodiffusion, qui est une mesure par un seul côté, utilise un réflectomètre optique fonctionnant dans le domaine temporel (OTDR) et mesure la puissance optique qui est rétrodiffusée vers le début de la fibre à partir des différents points de celle-ci.

4.4 Méthode C, allongement de la fibre

La présente méthode d'essai décrit une procédure destinée à déterminer l'allongement d'une fibre. Elle ne mesure pas la tension absolue, mais elle mesure plutôt les modifications de la déformation entre deux conditions de charge.

4.5 Méthode D, longueur mécanique

La présente méthode de mesure décrit une procédure destinée à déterminer la longueur de la fibre en enroulant une fibre autour d'une roue étalonnée, de diamètre donné, qui tourne. La longueur est déterminée par le nombre de rotations de la roue.

4.6 Méthode E, déphasage

La méthode de déphasage décrit une procédure destinée à déterminer la longueur de la fibre. La longueur est déterminée à partir du déphasage qui a lieu lorsqu'une fréquence de modulation prédéterminée, f_{max}, est appliquée.

4.7 Méthode d'essai de référence

La méthode d'essai de référence (RTM), à laquelle il faut avoir recours pour régler les litiges, diffère selon que la fibre est câblée ou non, de la manière suivante:

– fibre non câblée: méthode D;
– longueur de la fibre dans le câble: méthode B;
– allongement de la fibre dans le câble: méthode C;
– allongement de la fibre non câblée: méthode C.

5 Appareillage

L'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D et l'Annexe E contiennent les dessins et d'autres exigences d'équipement qui s'appliquent, respectivement, à chacune des méthodes A, B, C, D et E.

6 Échantillonnage

Voir l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D ou l'Annexe E appropriée pour les exigences spécifiques. Les exigences générales sont indiquées ci-dessous.

Préparer une face d'extrémité plane, perpendiculaire à l'axe de la fibre, à l'extrémité d'entrée et à l'extrémité de sortie de chaque échantillon pour les mesures basées sur des mesures de retard optiques.

7 Procédure

Voir l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D ou l'Annexe E appropriée pour les exigences spécifiques.

8 Calculs

Voir l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D ou l'Annexe E appropriée pour les exigences spécifiques.

9 Résultats

Les informations suivantes doivent être fournies pour chaque mesure:

– la date et le titre de la mesure;
– l'identification et la description de l'échantillon, indiquant s'il s'agit d'une fibre ou d'un câble;
– la longueur de l'échantillon, ou son allongement;
– la méthode de mesure utilisée: A, B, C, D ou E;
– d'autres résultats, exigés selon l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D ou l'Annexe E appropriée.

Les informations suivantes doivent être disponibles sur demande:

- la description du montage d'appareils de mesure;
- le type et la longueur d'onde de la source de mesure;
- les conditions d'injections;
- les détails de la technique de calcul;
- la date du dernier étalonnage de l'équipement de mesure.

Voir l'Annexe A, l'Annexe B, l'Annexe C, l'Annexe D et l'Annexe E pour les informations supplémentaires qui doivent être fournies sur demande.

10 Informations à mentionner dans la spécification

La spécification particulière doit spécifier les informations suivantes:

- le type et la longueur de la fibre (ou du câble) à mesurer;
- les critères de refus ou d'acceptation;
- les informations à consigner;
- tout écart par rapport à la procédure qui s'applique.

Annexe A
(normative)

Exigences spécifiques à la méthode A – Mesure du retard

A.1 Généralités

Utiliser cette méthode pour mesurer la longueur de la fibre optique elle-même, ou installée dans le câble. Si l'échantillon est une fibre dans un câble, déterminer la valeur de l'indice de groupe, N, dans des conditions applicables à l'échantillon mesuré (par exemple tension, température). Cela est fait en inversant la Formule (A.1) et les mesures sur un échantillon de longueur connue.

A.2 Principe

Une impulsion optique se propageant dans une fibre optique de longueur, L, et un indice de groupe moyen, N, a un temps de retard, Δt:

$$\Delta t = \frac{NL}{C} \tag{A.1}$$

où

Δt est le temps de retard;

N est l'indice de groupe moyen;

C est la vitesse de la lumière dans le vide.

Si N est connu, la mesure de Δt donne L. Par ailleurs, la mesure de Δt donne la valeur de N lorsque L est connu.

A.3 Appareillage

A.3.1 Deux techniques

Il existe deux techniques pour mesurer le temps de propagation d'une impulsion optique:

– la mesure du temps d'une impulsion transmise (Δt mesuré),

– la mesure du temps d'une impulsion réfléchie ($2\Delta t$ mesuré).

Voir la Figure A.1 et la Figure A.2 pour les deux montages correspondant aux deux techniques utilisant un oscilloscope à échantillonnage.

À la place de l'oscilloscope à échantillonnage, un équipement de rétrodiffusion ou un compteur ayant des portes démarrage/arrêt séparées et permettant le moyennage (par exemple au moins 10^4 coups) peuvent être utilisés.

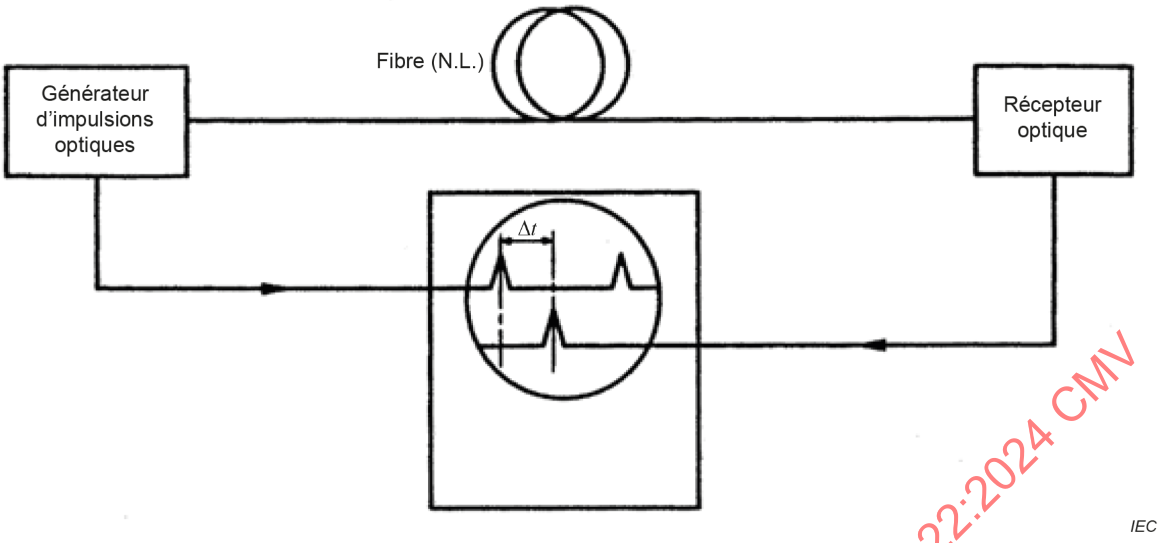


Figure A.1 – Mesure du temps de propagation d'une impulsion transmise

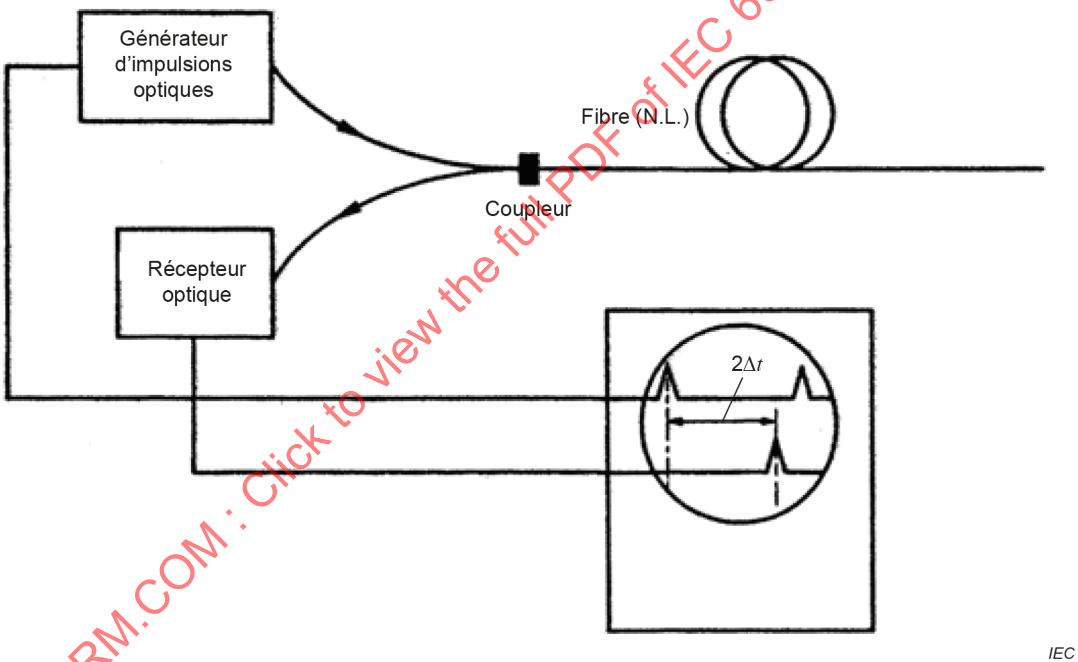


Figure A.2 – Mesure du temps de propagation d'une impulsion réfléchie

A.3.2 Source optique

A.3.2.1 Mesure avec l'oscilloscope à échantillonnage

Un générateur d'impulsions optiques doit être une diode laser de grande puissance, excitée par un générateur à trains d'impulsions électriques, réglable en fréquence et en largeur. Consigner la longueur d'onde et la largeur spectrale.

A.3.2.2 Mesure avec un compteur ou un appareil de rétrodiffusion

Un générateur d'impulsions optiques doit être une diode laser de grande puissance, excitée par un générateur à trains d'impulsions électriques réglable en largeur. Le temps entre deux impulsions doit être plus long que le temps de transmission de l'impulsion transmise (Δt, avec le compteur) ou rétrodiffusée ($2\Delta t$, avec l'équipement de rétrodiffusion). Consigner la longueur d'onde et la largeur spectrale de la diode laser.

A.3.3 Détecteur optique

Le récepteur doit être une photodiode à avalanche ultrarapide. La sensibilité du détecteur optique à la longueur d'onde de mesure et sa bande passante ne doivent pas influencer la forme de l'impulsion.

A.4 Procédure

A.4.1 Étalonnage

Mesurer le temps de retard de la source optique au point d'injection (c'est le temps de retard du montage de mesure proprement dit).

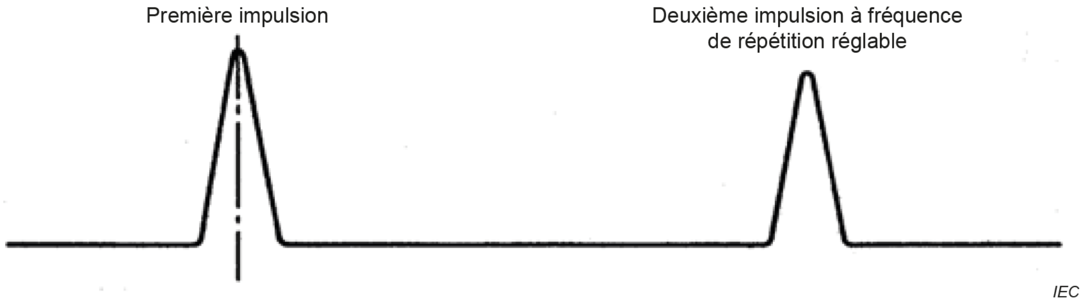
A.4.2 Valeur de l'indice de groupe moyen

Sur une fibre de longueur connue, mesurée par un moyen mécanique, la mesure de Δt donne la valeur moyenne, N, de l'indice de groupe de cette fibre.

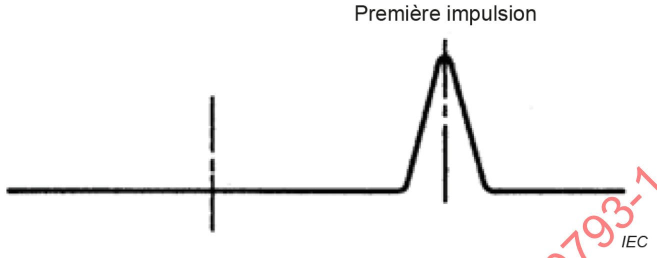
A.4.3 Mesure de la longueur

La mesure de la longueur consiste en la lecture d'un intervalle de temps sur l'écran d'un oscilloscope (ou la lecture du temps moyen de parcours sur l'affichage d'un compteur électronique à corriger par la valeur obtenue à l'étalonnage).

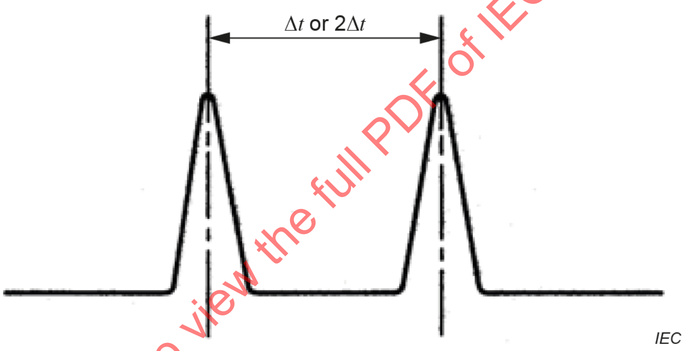
NOTE Voir la Figure A.3 pour la représentation d'une amélioration pratique importante permettant d'atteindre la précision de la mesure indépendamment de la longueur réelle de l'échantillon de fibre. Elle utilise une approche à deux voies.



a) Canal 1: impulsion émise



b) Canal 2: impulsion transmise



c) Impulsion émise après réglage de la fréquence de répétition de sorte que la deuxième impulsion de la voie 1 coïncide avec l'impulsion émise de la voie 2

Figure A.3 – Principe de la mesure de la longueur de la fibre

A.5 Calculs

A.5.1 Généralités

Calculer la longueur de la fibre à l'aide des équations suivantes:

A.5.2 Utilisation de la technique par transmission

$$L = \frac{\Delta t \times c}{N} \tag{A.2}$$

A.5.3 Utilisation de la technique par réflexion

$$L = \frac{\Delta t \times c}{2N} \qquad \text{(A.3)}$$

où

L est la longueur de la fibre, en m;

Δt est le temps de transmission ou de réflexion, en ns;

c est la vitesse de la lumière dans le vide, en m/ns;

N est l'indice de groupe moyen.

A.6 Résultats

En complément aux résultats de l'Article 9, les informations suivantes peuvent être disponibles sur demande:

– l'indice de groupe moyen,
– le temps de retard de l'appareil de mesure,
– le temps de transmission ou de réflexion.

Annexe B
(normative)

Exigences spécifiques à la méthode B – Rétrodiffusion

B.1 Généralités

Cette méthode utilise un réflectomètre optique fonctionnant dans le domaine temporel (OTDR) pour mesurer la longueur de la fibre optique seule, et incorporée dans le câble.

B.2 Appareillage

B.2.1 Généralités

Cette méthode utilise un réflectomètre optique fonctionnant dans le domaine temporel (OTDR), qui doit normalement comprendre la liste minimale suivante de composants. Voir la Figure B.1 pour un schéma fonctionnel.

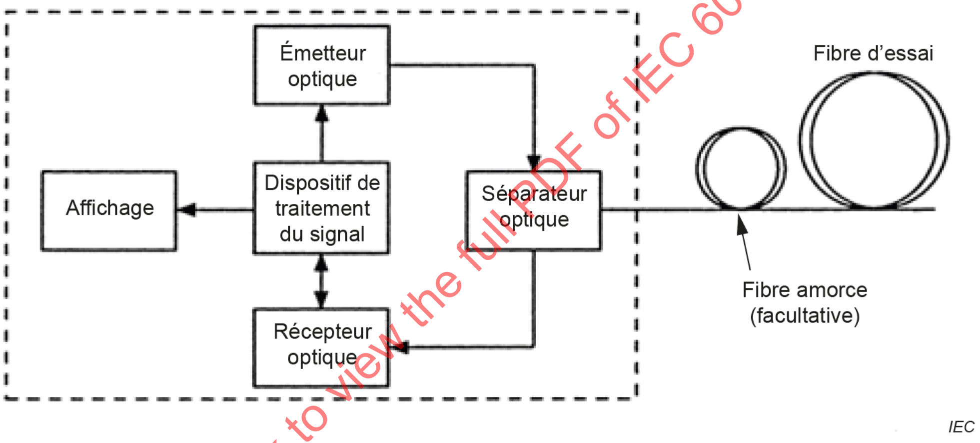


Figure B.1 – Schéma fonctionnel d'un OTDR

B.2.2 Émetteur optique

B.2.2.1 Il comporte habituellement une ou plusieurs sources à diode laser pulsée capables de générer une ou plusieurs largeurs d'impulsions et une ou plusieurs fréquences de répétition d'impulsions. Sauf indication contraire dans la spécification particulière, le spectre pour chaque longueur d'onde doit satisfaire à ce qui suit.

B.2.2.2 La longueur d'onde centrale doit se trouver à 15 nm de la valeur spécifiée; consigner la différence entre la longueur d'onde centrale et la valeur spécifiée, si elle dépasse 10 nm.

B.2.2.3 La largeur quadratique moyenne (LQM) ne doit pas excéder 10 nm ou la largeur d'impulsion à mi-hauteur (LMH) ne doit pas excéder 25 nm.

B.2.2.4 Si les données sont à utiliser dans un modèle d'affaiblissement spectral:

– la largeur spectrale ne doit pas excéder 15 nm (LMH) ou 6 nm (LQM) pour les longueurs d'onde dans la région du pic de l'eau (par exemple 1 360 nm à 1 430 nm);
– relever la longueur d'onde centrale réelle à 2 nm près de la valeur réelle.

B.2.3 Conditions d'injection

Prévoir un moyen de connexion de la fibre en essai (ou la fibre amorce facultative de B.2.10) au panneau des instruments ou à une fibre amorce provenant de la source.

Pour la fibre de type A, les sources optiques peuvent produire des conditions d'injection qui ne sont ni bien contrôlées ni appropriées à cette méthode de mesure. Donc, sauf indication contraire dans la spécification particulière, les conditions d'injection pour les mesures d'affaiblissement doivent être celles utilisées dans les mesures d'affaiblissement par fibre coupée (IEC 60793-1-40, méthode A).

B.2.4 Coupleur ou séparateur optique

Un coupleur ou séparateur installé dans l'instrument permet de diriger la puissance émise par l'émetteur vers la fibre. Ce dispositif dirige également la lumière retournant dans la fibre en sens inverse vers le récepteur.

B.2.5 Récepteur optique

Le récepteur optique comporte habituellement un détecteur à photodiode dont la largeur de bande, la sensibilité, la linéarité et la gamme dynamique sont compatibles avec les largeurs d'impulsions utilisées et les niveaux des signaux reçus.

B.2.6 Durée d'impulsion et fréquence de répétition

L'OTDR peut offrir un choix de plusieurs durées d'impulsions et fréquences de répétition (parfois couplées avec la commande de distance) afin de trouver un compromis optimal entre résolution et portée. En présence d'une réflexion d'amplitude importante, le réglage de la fréquence de répétition ou de la portée à une valeur supérieure au double de la distance au point de réflexion peut s'avérer nécessaire pour éviter la génération d'images "fantômes" parasites. Des techniques de codage d'impulsions peuvent également être utilisées.

NOTE Il convient de prendre des précautions lors du choix de la durée d'impulsion, de la fréquence de répétition des impulsions et de la puissance de la source. En ce qui concerne la mesure de petites longueurs, des largeurs d'impulsions réduites sont nécessaires pour assurer la résolution nécessaire. Cela limite donc la gamme dynamique de mesure et la longueur maximale mesurable. Pour la mesure de grandes longueurs, la gamme dynamique peut être élargie en augmentant la puissance optique de crête à un niveau au-dessous duquel les éléments non linéaires sont négligeables. En variante, la largeur d'impulsion peut être augmentée, ce qui réduit la résolution des mesures.

B.2.7 Dispositif de traitement du signal

Si cela est exigé, une commande peut permettre d'obtenir un signal moyenné pendant un temps de mesure plus long afin d'améliorer le rapport signal sur bruit.

B.2.8 Affichage

Il est incorporé dans l'OTDR et fait partie de l'équipement qui contrôle l'OTDR. Le signal OTDR est affiché sous forme graphique avec l'échelle verticale graduée en décibels et l'échelle horizontale graduée en distance. L'échelle verticale en décibels doit correspondre à la moitié de l'aller et retour des pertes en rétrodiffusion. L'échelle horizontale doit correspondre à la moitié du temps de propagation de groupe (aller et retour) associé, converti en distance. Des outils, tels que des curseurs, peuvent être employés pour mesurer, manuellement et automatiquement, tout ou partie de la trace OTDR sur l'affichage.

B.2.9 Interface de données (facultatif)

L'instrument peut être capable de travailler en interface avec un ordinateur pour une analyse automatique du signal ou pour fournir une copie sur papier de la trace sur l'affichage.