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REDLINE VERSION

INTERNATIONAL STANDARD



Optical fibres –
Part 1-40: Attenuation measurement methods

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Optical fibres –
Part 1-40: Attenuation measurement methods

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OPTICAL FIBRES –

Part 1-40: Attenuation measurement methods

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IEC 60793-1-40 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2019. This edition constitutes a technical revision.

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

- a) modifying the definition of attenuation to be compatible with the definition in electropedia.org

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

Draft	Report on voting
86A/2355/CDV	86A/2446/RVC

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- withdrawn, or
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OPTICAL FIBRES –

Part 1-40: Attenuation measurement methods

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the attenuation of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

Four methods are described for measuring attenuation, one being that for modelling spectral attenuation:

- method A: cut-back;
- method B: insertion loss;
- method C: backscattering;
- method D: modelling spectral attenuation.

Methods A to C apply to the measurement of attenuation for all categories of the following fibres:

- class A multimode fibres;
- class B single-mode fibres.

Method C, backscattering, also covers the location, losses and characterization of point discontinuities.

Method D is applicable only to class B fibres.

Information common to all four methods appears in Clause 1 to Clause 11, and information pertaining to each individual method appears in Annex A, Annex B, Annex C, and Annex D, respectively.

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 60793-1-1, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement*

IEC 61746-1, *Calibration of optical time-domain reflectometers (OTDR) – Part 1: OTDR for single mode fibres*

IEC 61746-2, *Calibration of optical time-domain reflectometers (OTDR) – Part 2: OTDR for multimode fibres*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-1-1 and the following apply.

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

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

3.1.1

attenuation

~~attenuation of~~ optical power reduction along a fibre at wavelength λ between two cross-sections, 1 and 2, separated by a distance and defined as

$$A(\lambda) = 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \quad (1)$$

where

$A(\lambda)$ is the attenuation, in dB, at wavelength λ ;

$P_1(\lambda)$ is the optical power traversing the first cross-section;

$P_2(\lambda)$ is the optical power traversing the second cross-section.

Note 1 to entry: Attenuation is a measure of the decreasing optical power in a fibre at a given wavelength. It depends on the nature and length of the fibre and is also affected by measurement conditions.

3.1.2

attenuation coefficient

attenuation per unit length for a uniform fibre under steady-state conditions

Note 1 to entry: It is possible to define the attenuation per unit length or the attenuation coefficient as follows:

$$\alpha(\lambda) = \frac{A(\lambda)}{L} \quad (2)$$

which is independent of the chosen length of the fibre,

where

$\alpha(\lambda)$ is the attenuation coefficient;

$A(\lambda)$ is the attenuation at wavelength λ ;

L is the length, in kilometres.

Note 2 to entry: Uncontrolled launching conditions normally excite higher order lossy modes that produce transient losses and result in attenuation that is not proportional to the length of the fibre. A controlled, steady-state launching condition yields attenuation that is proportional to the fibre's length. Under steady-state conditions, an attenuation coefficient of a fibre can be determined and the attenuation of concatenated fibres added linearly.

3.1.3

spectral attenuation modelling

technique that predicts the attenuation coefficients across a spectrum of wavelengths from a small number (three to five) of discrete values measured directly at different wavelengths

3.1.4**point discontinuity**

temporary or permanent local deviation of the continuous optical time-domain reflectometer (OTDR) signal in the upward or downward direction

Note 1 to entry: The nature of the deviation can vary with test conditions (e.g. pulse duration, wavelength, and direction of the OTDR signal). Although a point discontinuity can have a length greater than the corresponding displayed pulse duration (including transmitter and receiver effects), the length is usually about equal to the pulse duration. For a correct interpretation, the guidelines in IEC 60793-1-22 should be followed for measuring length.

3.2 Abbreviated terms

FWHM	full width at half maximum
LPS	limited phase space
OTDR	optical time-domain reflectometer
RMSW	root-mean-squared width
RTM	reference test method

4 Calibration requirements

See Annex A, Annex B, and Annex C for methods A, B, and C, respectively.

5 Reference test method

Method A, cut-back, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

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

7 ~~Sampling and specimens~~ Sample preparation**7.1 ~~Specimen~~ Sample length**

The ~~specimen~~ sample shall be a known length of fibre on a reel, or within a cable, as specified in the relevant specification.

7.2 ~~Specimen~~ Sample end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each ~~specimen~~ sample.

8 Procedure

See Annex A, Annex B, Annex C, and Annex D for methods A, B, C and D, respectively.

9 Calculations**9.1 Methods A and B**

Methods A and B, cut-back and insertion loss use Formula (1) and Formula (2) respectively, which appear in 3.1.1 and 3.1.2.

9.2 Method C

See Annex C.

9.3 Method D

See Annex D.

10 Results

10.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of specimen;
- optical source wavelength;
- specimen length;
- spectral attenuation, in dB, or attenuation coefficient, in dB/km, versus wavelength or at specific wavelength(s), as required by the relevant specification.

10.2 Information available upon request

The following information shall be available upon request:

- measurement method used: A, B, C, or D;
- type of optical source used: centroidal wavelength(s) and spectral width(s);
- launching technique and conditions used;
- indication if a dead-zone fibre was used (for method C only);
- description of all key equipment;
- for type B fibres – dimensions and number of turns of the mode filter or mode scrambler;
- pulse duration(s), scale range(s), and signal-averaging details;
- details of computation technique (calculation method);
- any deviations to the procedure that were made;
- date of latest calibration of measurement equipment.

10.3 Method-specific additional information

For methods C and D, see the additional requirements in Clause C.6 and Clause D.6, respectively. This particularly applies when using method C for measuring point discontinuities.

11 Specification information

The relevant specification shall specify the following information:

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

Annex A (normative)

Requirements specific to method A – Cut-back

A.1 General

The cut-back technique is the only method directly derived from the definition of fibre attenuation, in which the power levels, $P_1(\lambda)$ and $P_2(\lambda)$, are measured at two points of the fibre without change of input conditions. $P_2(\lambda)$ is the power emerging from the end of the fibre, and $P_1(\lambda)$ is the power emerging from a point near the input after cutting the fibre. This explains its wide acceptance as the reference test method for attenuation.

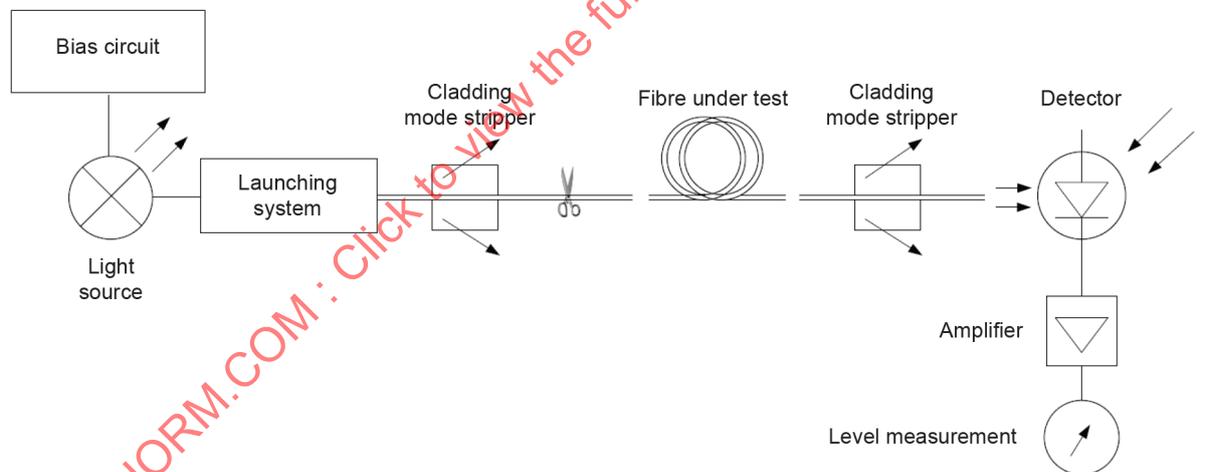
This measurement principle does not permit information to be obtained on the attenuation behaviour over the length of the fibre, nor is it easy to measure the change of attenuation under changing conditions. In some situations, its destructive nature is a disadvantage.

A.2 Apparatus

A.2.1 General apparatus for all fibres

A.2.1.1 General

See Figure A.1 and Figure A.2 for diagrams of suitable test set-ups.



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Figure A.1 – Arrangement of equipment for loss measurement at a specified wavelength

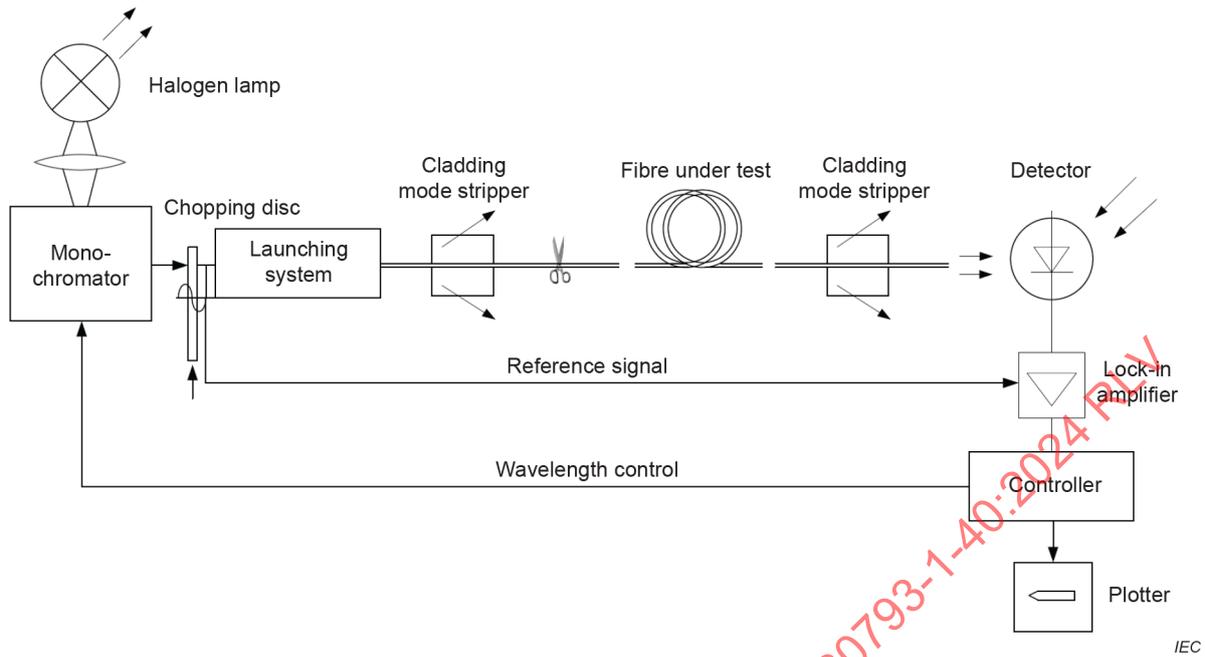


Figure A.2 – Arrangement of equipment used to obtain loss spectrum

A.2.1.2 General launch arrangement

Figure A.3 shows the general launch arrangement used for all fibres. See A.2.2 to A.2.4 for further details as they apply to specific categories of single-mode and multimode fibres.

A.2.1.3 Optical source

Use a suitable radiation source, such as a lamp, laser or light-emitting diode. The choice of source depends upon the type of measurement. The source shall be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. Specify the spectral line width (between the 50 % optical intensity power points of the sources used) such that the line width is narrow, for example <10 nm, compared with any features of the fibre spectral attenuation. Align the fibre to the launch cone or connect it to a launch fibre.

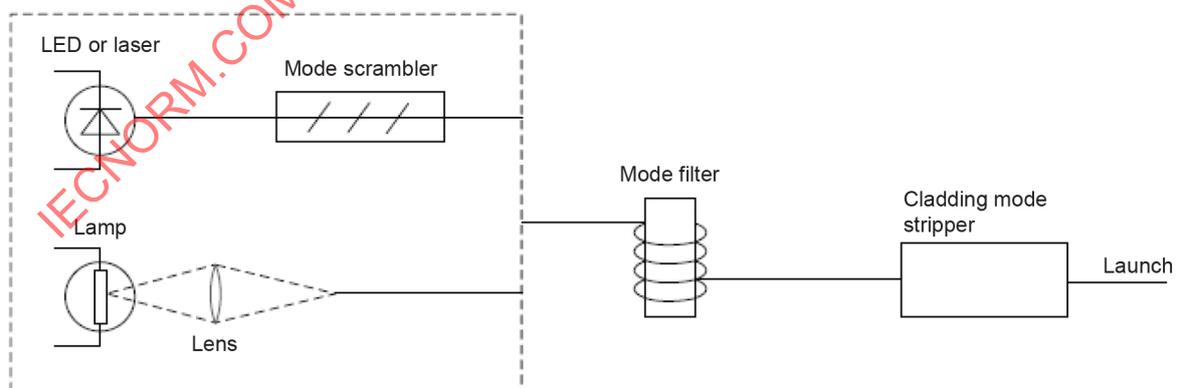


Figure A.3 – General launch arrangement

A.2.1.4 Source wavelength

Measurements can be made at one or more wavelengths. Alternatively, a spectral response can be obtained over a range of wavelengths.

A.2.1.5 Optical detection assembly

Means shall be provided to couple all power emitted from the specimen to the active region of the detector. For example, an optical lens system, a butt spliced to a fibre pigtail, or a coupling directly to the detector ~~may~~ can be used. If the detector is already pigtailed, the pigtail fibre shall have sufficiently large core diameter and numerical aperture to capture all of the light exiting the reference and specimen fibres.

Use an optical detector that is linear and stable over the range of intensities and measurement times that are encountered in performing this measurement. A typical system might include a photovoltaic mode photodiode amplified by a current input amplifier, with synchronous detection by a lock-in amplifier.

A.2.1.6 Signal processing

It is customary to modulate the light source to improve the signal to noise ratio at the receiver. If such a procedure is adopted, link the detector to a signal processing system synchronous with the source modulation frequency. The detecting system should be substantially linear or have been fully characterized with a response function.

A.2.1.7 Cladding mode stripper

Use suitable techniques to remove optical power propagating in the cladding where this would significantly influence the received signal.

A.2.2 Launch apparatus for all single-mode fibres

A.2.2.1 General

An optical lens system or fibre pigtail ~~may~~ can be employed to excite the test fibre. The power coupled into the fibre shall be stable for the duration of the measurement. See Figure A.1.

A.2.2.2 Fibre pigtail

If using a pigtail, it ~~may~~ can be necessary to use index-matching material between the source pigtail and test fibre to eliminate interference effects.

A.2.2.3 Optical lens system

If using an optical lens system, provide a means of stably supporting the input end of the fibre, such as a vacuum chuck. Mount this support on a positioning device so that the fibre end can be repeatedly positioned in the input beam. A method of making the positioning of the fibre less sensitive is to overfill the fibre end spatially and angularly.

A.2.2.4 High-order mode filter

Use a method to remove high-order propagating modes in the wavelength range of interest. An example of such a high-order mode filter is a single loop of radius sufficiently small to shift the cut-off wavelength below the minimum wavelength of interest. For bending loss insensitive single-mode fibres, multiple loops with smaller radius or longer cut-back specimen length can be applied. Care should be taken that the radius is not too small as to induce wavelength-dependent oscillations. Increase of the cut-back specimen length should be accounted for in the attenuation computation.

A.2.2.5 Cladding mode stripper

The cladding mode stripper ensures that no radiation modes, propagating in the cladding region, will be detectable after a short distance along the fibre. The cladding mode stripper often consists of a material having a refractive index equal to or greater than that of the fibre cladding. This ~~may~~ can be an index-matching fluid applied directly to the uncoated fibre near its ends; under some circumstances the fibre coating itself will perform this function.

A.2.3 Launch apparatus for A1 multimode fibres

A.2.3.1 General

The launching conditions are of paramount importance in meeting the objectives stated in Clause 1. Launching conditions are established to avoid launching power into higher-order, transient modes. By not launching power into these transient modes of the test fibre, attenuations which add in an approximately linear fashion will be measured. Because these power distributions are essentially unaltered by the fibre, they are called "steady-state distributions".

There are two commonly used techniques to produce steady-state launch conditions for attenuation measurements: mode filters and a geometrical optics launch. Proper care in the use of each technique gives comparable results.

~~Care should be taken~~ Ensure that mode distribution is related with specimen length. For short A1 multimode fibre cables (less than 1 km), it is possible that the mode distribution ~~may~~ will not reach a steady state. This will induce an increase in attenuation values towards shorter fibre lengths, where the magnitude of the length dependence depends on fibre type, launch condition, etc. In these cases, attenuation values should be obtained from cables long enough to reach a steady-state condition, or they can be taken from the original longer donor cable. As guidance for sufficient cable lengths, see examples of cable test results on A1 multimode fibres in Annex E.

See Figure A.3 for a generic example of the launching arrangement using a mode filter. Examples of each mode filter appear below.

A.2.3.2 Examples of mode filters

A.2.3.2.1 Dummy-fibre mode filter

Select a fibre of a similar type to that of the test fibre. The fibre should be long enough (typically equal to or greater than 1 km) so that the power distribution carried by the fibre, when the launch source of A.2.1.2 is used, is a steady-state distribution.

A.2.3.2.2 Mandrel-wrapped mode filter

Another mode filter takes the form of a mandrel around which a few turns (typically three to five turns) of the fibre under test are wound with low tension. Select the mandrel diameter to ensure that the transient modes excited in the test fibre have been attenuated to steady-state. Use a far-field measurement to compare the power distribution exiting a long length of test fibre (greater than 1 km) that has been excited with a uniformly overfilling source, with the power distribution exiting a short length of the fibre with the mandrel applied. Select the mandrel diameter to produce a far-field distribution in the short length that approximates the long length far-field power distribution.

The numerical aperture (as measured by IEC 60793-1-43) of the radiation pattern exiting the short length shall be 94 % to 100 % of the numerical aperture of the long-length pattern.

The diameter of the mandrel ~~may~~ can differ from fibre to fibre depending on fibre and coating type. Common prescriptions consist of diameters in the range of 15 mm to 40 mm, with five turns of fibre within a 20 mm length of the mandrel. While mandrels of different size and arrangement can be selected, Table A.1 illustrates common mandrel sizes for fibres of different core diameters.

Table A.1 – Size examples

Core diameter µm	Mandrel diameter mm
50	25
62,5	20
100	25

A.2.3.3 Example of geometrical optics launch

A limited phase space (LPS) launch is defined as a geometrically produced launch that uniformly fills 70 % of the test fibre's core diameter and 70 % of the test fibre's numerical aperture. This is the maximum geometrically launched power distribution that does not launch power into leaky, unbounded modes. For a 50/125 µm, 0,2 NA graded-index multimode fibre, the LPS launch condition consists of a uniform 35 µm spot and 0,14 NA.

An example of the optics necessary to produce the LPS launch is given in Figure A.4. It is important to ensure that the axis of the launch beam is coincident with the axis of the fibre so that the spot and incident cone of light are centred on the core of the fibre. Also, set up the optical system at the wavelengths of operation to ensure proper measurement. While mandrels of different size and arrangement can be selected, common mandrel sizes for fibres of different core diameters, are shown in Table A.1.

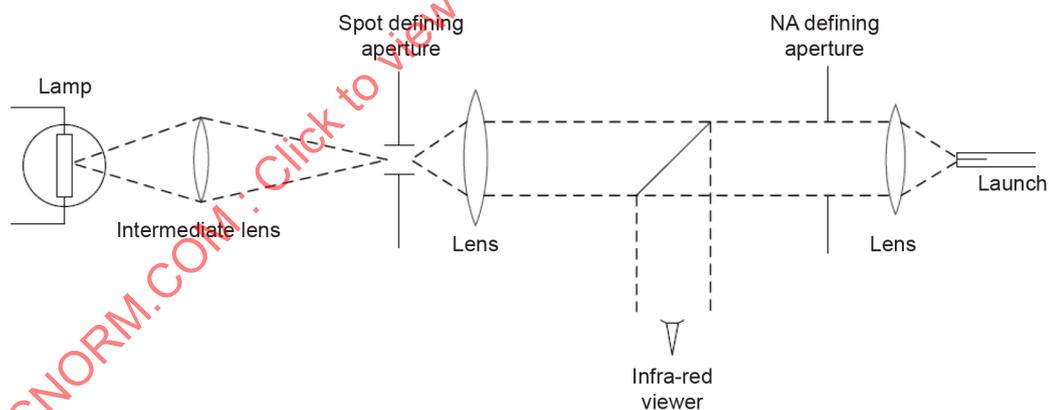


Figure A.4 – Limited phase space launch optics

A.2.3.4 Mode scrambler

An essentially uniform power distribution is launched prior to the mode filter. For a source such as an LED or laser, which does not form a uniform power distribution, use a mode scrambler. The mode scrambler shall comprise a suitable fibre arrangement (for example, a step-graded-step index profile sequence).

A "mode scrambler" is a device which is positioned between the light source and test fibre to control launching conditions. A particular mode scrambler design is not specified. It should be emphasized that the performance of these scramblers depends upon the launch optics and fibre sizes (core and NA) used in the actual construction.

EXAMPLE The two designs given in Figure A.5 are for illustration purposes only.

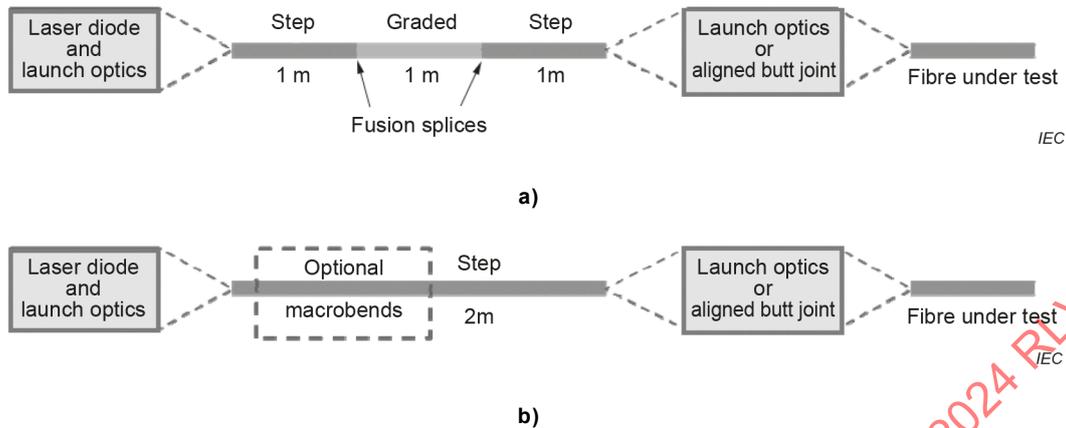


Figure A.5 – Two examples of optical fibre scramblers

A.2.4 Launch apparatus for A2 to A4 multimode fibres

Some examples of generic launching arrangements for short distance fibres are described in Figure A.6, Figure A.7 and Figure A.8.

The reproducibility of the attenuation measurements of multimode fibres is critical. Therefore, a well-defined launching set-up description is necessary. Such a set-up can be achieved by using commercially available optical components and shall be capable of providing for spot sizes and launch NAs as given in Table A.2.

Table A.2 – Launch conditions for A2 to A4 fibres

Attribute	Fibre category		
	A2.2 fibre ^a Glass core/glass cladding	A3 fibre Glass core/plastic cladding	A4 fibre Plastic core/plastic cladding
Spot size	= fibre core size	= fibre core size	= fibre core size with full mode launch (or use mode scrambler with equilibrium mode launch)
Numerical aperture (NA)	= fibre max. Na ^b	= fibre max. NA ^c	= fibre max. NA, with full mode launch ^e
^a Category A2.1 fibre requires further study. ^b This launch condition can be produced by overfilling a mode filter made from 2 m of fibre identical to the fibre under test, with appropriate cladding mode stripping and using the output from this mode filter to launch into the fibre under test. ^c This launch condition can be produced in the same manner as described in footnote b. However, some types of A3 and A4 fibre will not require cladding mode stripping for the mode filter.			

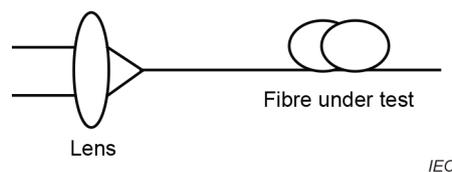


Figure A.6 – Lens system

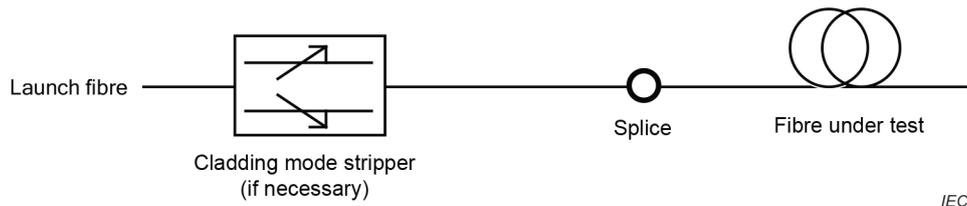


Figure A.7 – Launch fibre

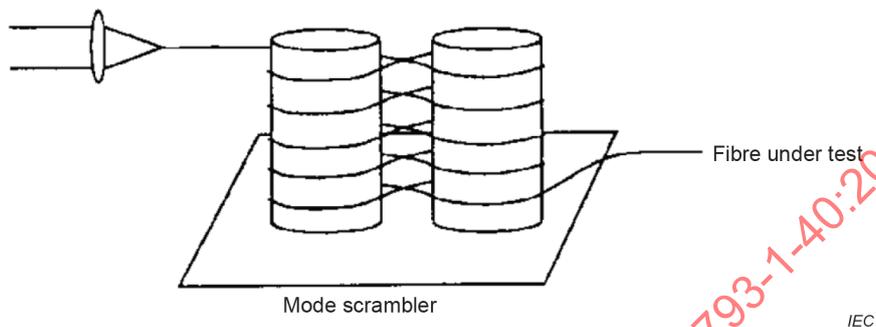


Figure A.8 – Mode scrambler (for A.4 fibre)

A.2.5 Calibration requirements

A.2.5.1 General calibration requirements

Calibrate the optical source's centroidal wavelength to within ± 10 nm.

A.2.5.2 Requirements for A4 fibres

For A4 fibres it is common to perform attenuation measurements at specific wavelengths using an LED as optical source. Owing to characteristic strong sharp variations in attenuation over the wavelength spectrum of some polymeric materials, additional optical characterization measurements should be performed to take into account effects that could affect the measurement when calibrating wide-spectrum sources used for attenuation measurement, especially when the centroidal wavelength is significantly far from the intended wavelength measurement. A full characterization will ensure repeatability of the measurements and avoid the negative influence of the following effects:

– Distortion on the attenuation measurement

An optical source with wide spectrum, for example, an LED, will cause measurement errors on the measurements, since parts of the optical spectrum lie in low-loss wavelengths and other parts lie in higher-loss wavelengths. This is illustrated in Figure A.9 with the Gaussian line "b" showing the spectral response for an LED source used to measure A4 fibres and with the expected spectral attenuation indicated by the line "a". To take proper consideration of the potentially high attenuation variations, the source shall be calibrated both in its centroidal wavelength and spectral width and it should be checked that these two characteristics match the expected wavelength attenuation of the fibre under test.

– Spectral filter effect

Light with a wide spectrum undergoes relatively little attenuation at some wavelengths while other spectral parts suffer higher losses when propagating through A4a fibres. With longer measured fibre lengths, the detected LED spectral maximum shifts towards the fibre attenuation-minimum wavelength. This can be seen in Figure A.9, where the original spectral source is illustrated with the line "b" (characterized through a 0 m fibre length) and the same spectra detected after passing different lengths of an A4 fibre. As the measurement-fibre length increases, a shift on the maximum of the detected Gaussian signal occurs towards the wavelength of minimum attenuation of the fibre (lines "c" to "f" in Figure A.9).

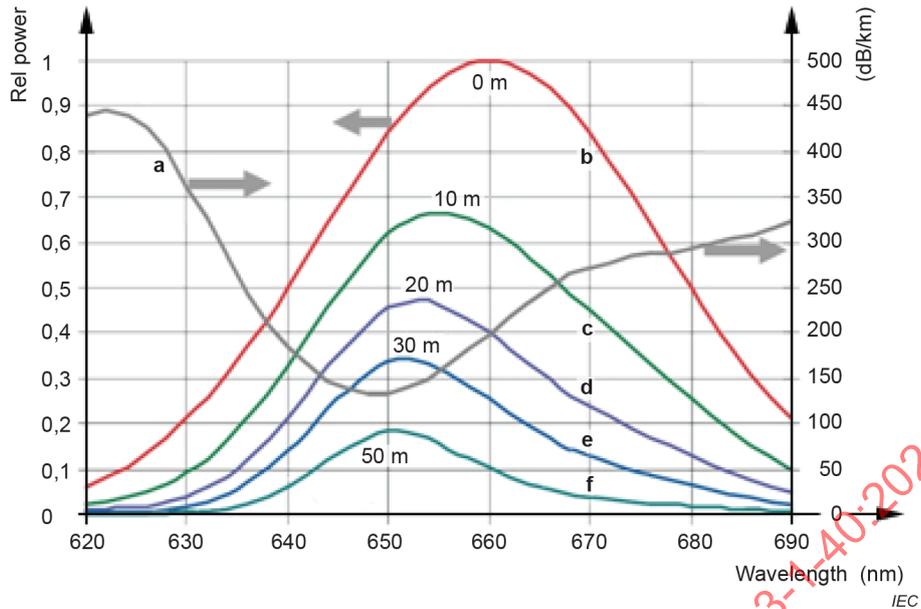


Figure A.9 – A wide-spectrum source (line "b") could lead to attenuation measurement errors due to sharp variations on spectral attenuation of polymer-core fibres (line "a")

A.3 Procedure

A.3.1 Set the fibre under test in the measurement apparatus. Record the output power, $P_2(\lambda)$.

A.3.2 Keeping the launching conditions fixed, cut the fibre to the cut-back length (for example, 2 m from the launching point). Record the output power, $P_1(\lambda)$, of the cut-back length.

A.4 Calculations

A.4.1 Calculate the attenuation between the points where $P_1(\lambda)$ and $P_2(\lambda)$ have been measured using Formula (1) in 3.1.1, or calculate the attenuation coefficient by using Formula (2) in 3.1.2, or both, as required.

A.4.2 Using the attenuation measurement results at discrete wavelengths, a spectral attenuation curve can be calculated with relationships such as those described in Annex D.

Annex B (normative)

Requirements specific to method B – Insertion loss

B.1 General

The insertion loss technique is, in principle, similar to the cut-back technique, but $P_1(\lambda)$ is the power emerging from the output of the launching system.

The insertion loss technique is less accurate than that of the cut-back technique but has the advantage of being non-destructive for the fibre under test and for the terminators possibly fixed at both ends. Therefore, it is suitable for field use, and mainly intended for use with connectorized cable lengths.

This method does not allow for analysis of the attenuation over the length of fibre. Given the previous known power, $P_1(\lambda)$, it is possible with this technique to measure the continuing change in attenuation over changing environmental conditions such as temperature and force.

B.2 Apparatus

B.2.1 General set-ups

Figure B.1 (calibration) and Figure B.2 (measurement) show diagrams of suitable measurement set-ups.

B.2.2 Apparatus common to method A (cut-back)

See the provisions of A.2.1. See also all of the appropriate information on launching conditions in A.2.2 (for single-mode fibre), A.2.3 (for A1 multimode fibre), and A.2.4 (for A2 to A4 multimode fibre).

B.2.3 Additional apparatus specific to method B (insertion-loss)

The insertion-loss technique requires the use of a very precise fibre-to-fibre coupling device to minimize the coupling losses and to ensure reliable results. This coupling device can be a mechanical adjustment that is visually inspected, or a connector with a core-to-core positioning.

B.2.4 Calibration requirements

See A.2.5.

B.3 Procedure

B.3.1 The reference fibre shall be of the same type as that under test. Any connectors and their associated losses are included in the definition of the reference fibre.

B.3.2 Initially calibrate the measurement equipment to obtain an input reference level, $P_1(\lambda)$. Use the same fibre type as a reference fibre at the initial calibration. The length of the reference fibre should be small (for example, 2 m) so that its attenuation can be neglected. (If the attenuation of the reference fibre cannot be neglected, add the value to the calculated value.)

B.3.3 Connect the fibre under test to the measurement apparatus and adjust the coupling to give a maximum level on the optical detector. Record the output power, $P_2(\lambda)$.

B.4 Calculations

Calculate the attenuation by using Formula (1) in 3.1.1, or calculate the attenuation coefficient by using Formula (2) in 3.1.2, or both, as required.

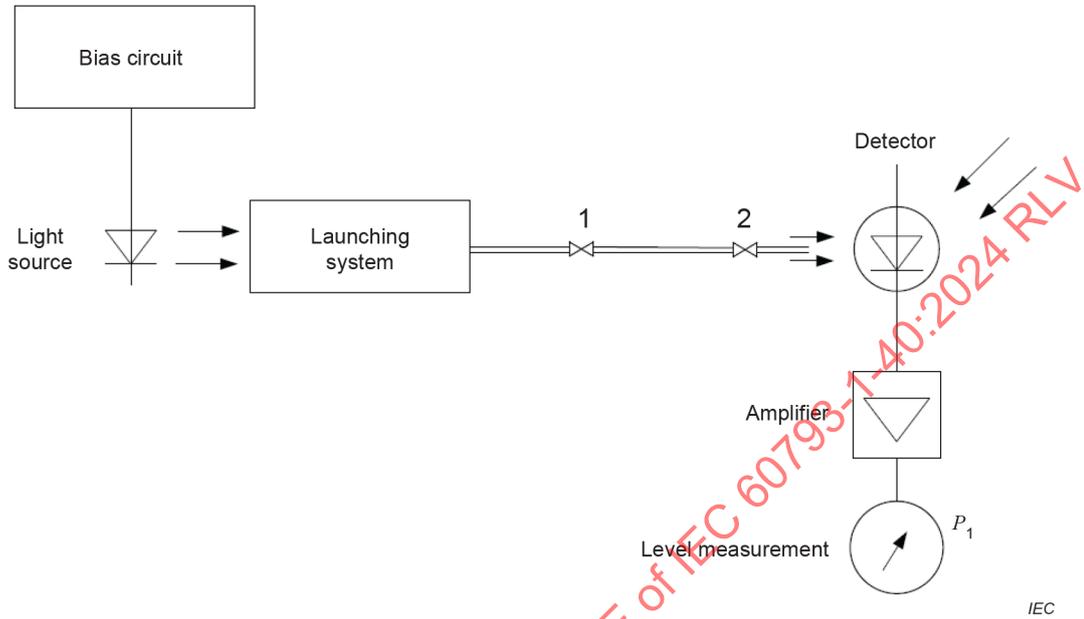


Figure B.1 – Calibration of insertion loss measurement set

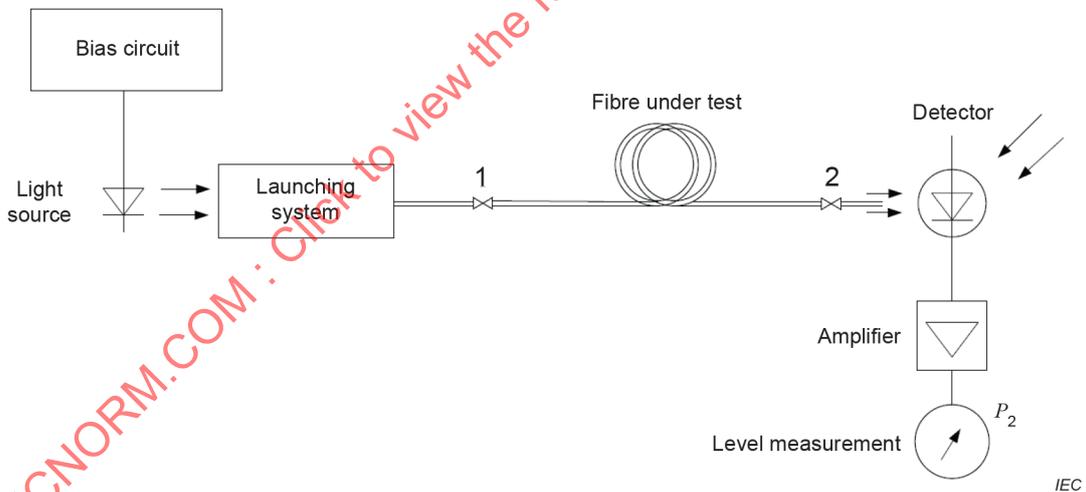


Figure B.2 – Measurement of insertion loss

Annex C (normative)

Requirements specific to method C – Backscattering

C.1 General

The backscattering method, which is a discrete-wavelength, single-sided measurement, measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

The measurement is affected by the propagation speed and the backscattering behaviour of the fibre and ~~may~~ it is possible that it will not be accurate for measuring fibre attenuation. The technique can only be used to measure the fibre's attenuation by taking the backscatter measurements from both ends of the fibre under test and averaging the two backscatter traces.

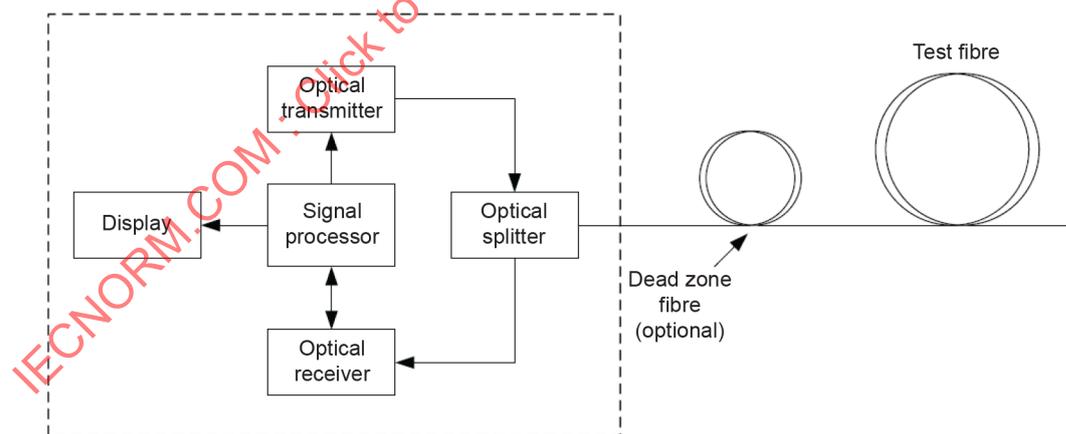
This technique allows analysis of the entire fibre, particularly of longitudinal subsections of the fibre, or even identification of discrete points such as splices. It also permits calculation of the fibre length.

Methods to describe the uniformity of attenuation from the bi-directionally averaged backscattered traces are considered in IEC TR 62316.

C.2 Apparatus

C.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 C.1 for a block diagram.



IEC

Figure C.1 – Block diagram of an OTDR

C.2.2 Optical transmitter

C.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.

C.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.

C.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.

C.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 (RMSW) for wavelengths in the water peak absorption region (e.g. 1 360 nm to 1 430 nm);
- report the actual centroidal wavelength to within 2 nm of the actual value.

C.2.3 Launch conditions

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

For type A fibre, it is possible that optical sources ~~may~~ will not produce launch conditions that are well controlled or appropriate to 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 (method A).

C.2.4 Optical splitter

A coupler/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.

C.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.

C.2.6 Pulse duration and repetition rate

The OTDR ~~may be provided~~ can provide 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.

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.

C.2.7 Signal processor

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

C.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 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.

C.2.9 Data interface (optional)

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

C.2.10 Reflection controller (optional)

Means of minimizing transient saturation of the receiver due to high Fresnel reflections **may** be required to reduce the length of fibre "dead zone" following each reflector. This can be incorporated into the coupler or splitter or **may** 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** be used between the OTDR connector and the specimen.

C.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.

C.3 Sampling and specimens

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

Care should be taken to ensure that winding does not introduce artificial attenuation for point discontinuity or attenuation measurements. Alternatively, any induced loss confined to the ends of the fibre length (as with the first layer on a reel) can be excluded in a calculation of the attenuation coefficient.

C.4 Procedure

C.4.1 General measurement steps

C.4.1.1 The use of an OTDR for indirect measurement of attenuation or fibre attenuation coefficient of an optical fibre or fibre cable is described below.

For type A1 and A2 optical fibres, more accurate values **may** be obtained by using spectral attenuation cut-back measurements. If the values obtained by these two techniques differ from each other, the values from the cut-back technique will be accepted as correct, unless otherwise specified in the detail specification.

For type B1 and B2 optical fibres, by performing these measurements at multiple wavelengths, a spectral attenuation curve can be generated using relationships such as those described in method D (see Annex D).

C.4.1.2 Connect the specimen 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.

C.4.1.3 If the attenuation coefficient and accurate distances are to be recorded, the effective group index of the specimen is required. If this value is not known, use the procedure for the OTDR measurement of fibre or cable length (method B of IEC 60793-1-22) to determine it.

C.4.1.4 Enter OTDR parameters such as source wavelength, pulse duration, length range, and signal averaging into the instrument, along with the specimen's effective group index (if

required by C.4.1.1.3). The values of some of these parameters ~~may~~ can be preset in the instrument.

C.4.1.5 Adjust the instrument to display a backscatter signal from the specimen. It ~~may~~ can be advantageous to begin with coarse vertical and horizontal scaling to maximize the length displayed. Figure C.2 and Figure C.3 give examples for use with measuring attenuation and Figure C.4 and Figure C.5 are example schematics for use with measuring point discontinuities.

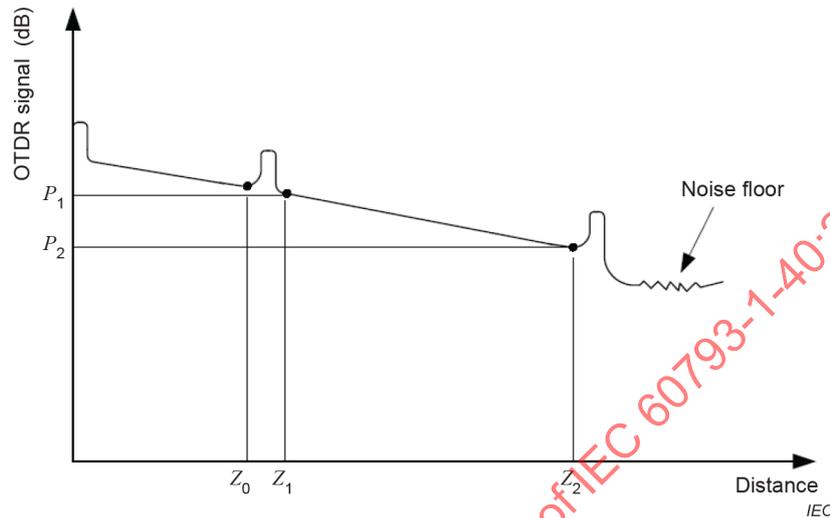


Figure C.2 – Schematic OTDR trace for a "uniform" specimen preceded by a dead-zone fibre

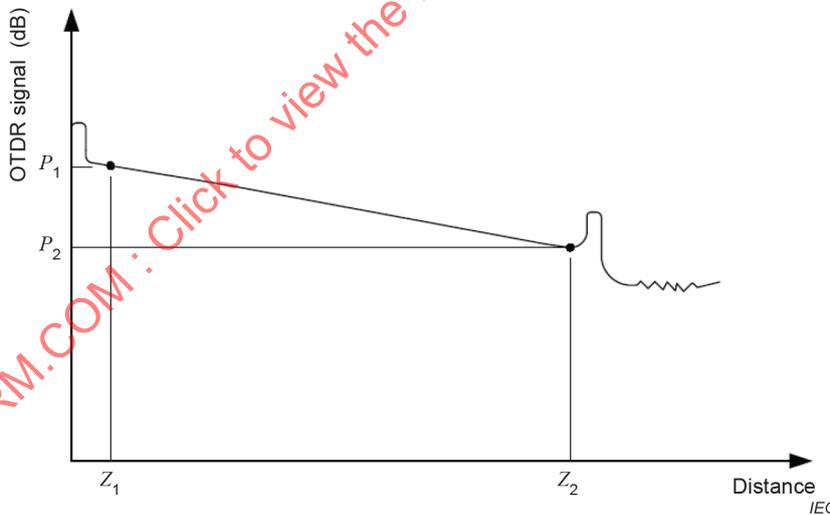


Figure C.3 – Schematic OTDR trace for a "uniform" specimen not preceded by a dead-zone fibre

C.4.2 Further steps for measuring attenuation

C.4.2.1 Step 1

C.4.2.1.1 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).

C.4.2.1.2 (Optional, along with C.5.3) If using a dead-zone fibre, refer to Figure C.2. Place a cursor at the beginning of the trace for the specimen 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 beginning of the trace is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement.) Obtain the distance coordinate, z_0 , via the alphanumeric display. If a dead-zone fibre is not used, no cursor placement is required; take $z_0 = 0$.

C.4.2.1.3 Place a cursor on the beginning of the linear portion (after the near end) of the trace for the specimen. If using the dead-zone fibre (Figure C.2), place the cursor beyond the recovery from the small reflection at the end of the dead-zone fibre. If not using the dead-zone fibre (Figure C.3), place the cursor beyond the dead-zone of the OTDR connector. Obtain the distance and power coordinates, $[z_1, P_1(\lambda)]$, via the alphanumeric display.

C.4.2.1.4 Place the same or another cursor at the end of the trace for the specimen at a point by using the methodology described in C.4.2.1.2 for the beginning of the trace. If the end of the trace 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. Obtain the coordinates, $[z_2, P_2(\lambda)]$.

C.4.2.1.5 Repeat the relevant tests of Clause C.4 at each wavelength required.

C.4.2.2 Step 2

Repeat the measurement for a signal launched into the specimen in the opposite direction. To obtain accurate attenuation values, bi-directional traces at the same wavelength are averaged, to eliminate the effects of length varying backscatter properties.

C.4.3 Further steps for measuring point discontinuities

C.4.3.1 Examine the OTDR signal along the specimen for point discontinuities as defined in 3.1.4. 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). See Figure C.5 for an example.

C.4.3.2 To determine that a point discontinuity (rather than an attenuation non-uniformity situation) exists, observe the area in question, using two different pulse durations. If the shape of the loss or gain changes with the pulse duration, the anomaly is a point discontinuity. If the shape does not change, consider the anomaly to be an attenuation non-uniformity to be measured according to the test procedure for measurement of fibre or cable attenuation. Alternatively, if the OTDR pulse shape and duration are known, the resultant shape of the backscatter curve at point discontinuities ~~may~~ can be used to determine their existence.

C.4.3.3 Determine the discontinuity location, if required, by placing a cursor at the beginning of a power rise or drop (or at another point specified by the OTDR manufacturer). This ~~may~~ can be difficult to do for a power drop. Obtain the coordinate via the alphanumeric display.

C.4.3.4 Obtain the apparent loss or gain of the discontinuity, if required, by the method described by the OTDR manufacturer. Some instruments require placement of a pair of cursors on each side of the discontinuity. Extrapolate the two best-fit straight lines (from a two-point or least-squares fit for each) to the location of the discontinuity. If available, the linear fit method should be chosen. The vertical separation of the lines gives the apparent loss or gain.

Note any reflection peak. The height of a given peak will decrease with increasing pulse width and increase with decreasing pulse width.

C.4.3.5 Repeat the test for a signal launched into the specimen in the opposite direction. Make a loss calculation (and the elimination of apparent gain) by averaging readings taken bi-directionally at the same wavelength. This eliminates the effects of any backscatter differences for the fibre sections on both sides of the discontinuity. Bi-directional measurements **may** **are not be** possible in all cases, thus necessitating unidirectional measurement.

C.4.3.6 Report any point discontinuity deviations that exceed the values specified in the detail specification. Describe the nature of these discontinuities (e.g. apparent loss or gain, reflection, duration, etc.), as required by the detail specification.

C.4.3.7 If required by the detail specification, repeat the test at another wavelength.

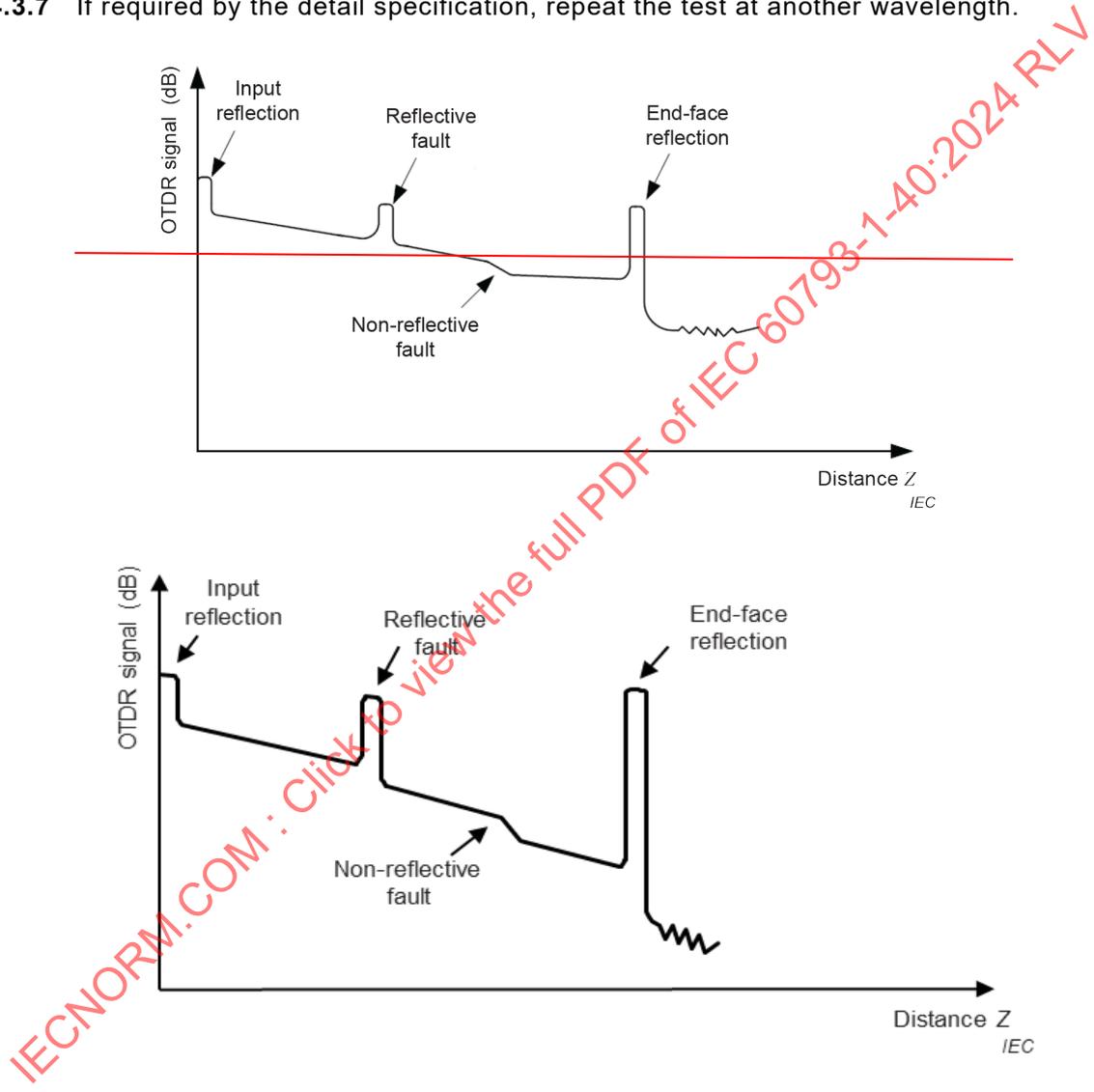


Figure C.4 – Schematic OTDR trace showing apparent loss due to point discontinuities, one reflective and one non-reflective

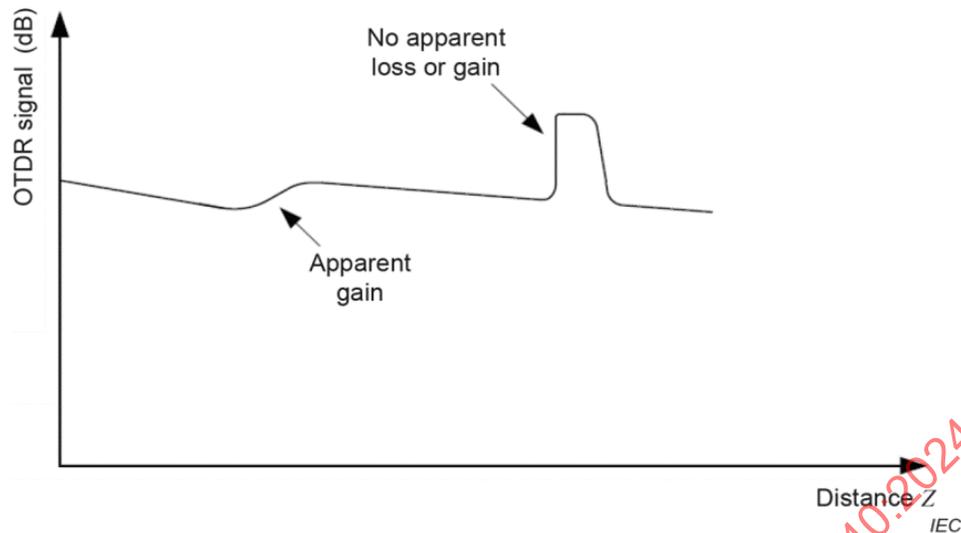


Figure C.5 – Schematic of an expanded OTDR trace showing two point discontinuities, one with apparent gain, and another with no apparent loss or gain

C.4.4 Calibration

Follow the provisions of IEC 61746-1 for the single-mode OTDR calibration method, or of IEC 61746-2 for the multimode OTDR calibration method.

C.5 Calculations

C.5.1 The unidirectional backscatter attenuation of the fibre or cable section beginning after the dead zone is given by $[P_1(\lambda) - P_2(\lambda)]$ in dB.

C.5.2 The unidirectional backscatter attenuation coefficient of the fibre or cable section is given by $\alpha = [P_1(\lambda) - P_2(\lambda)] / (z_2 - z_1)$ in dB/km.

C.5.3 (Optional, along with C.4.2.1.2) The unidirectional backscatter attenuation of the total fibre or cable section is given by $[P_1(\lambda) - P_2(\lambda)] + \alpha (z_1 - z_0)$ in dB (where α is given in C.5.2), or equivalently by $[P_1(\lambda) - P_2(\lambda)](z_2 - z_0) / (z_2 - z_1)$, in dB.

C.5.4 Some OTDRs can automatically perform the two-point subtractions in C.5.1 to C.5.2.

NOTE Some OTDRs can also utilize a least-squares fit to a line, but this can give results that differ from those given by the two-point subtractions. The type of calculation is indicated in the detail specification. While the least-square average (LSA) method can be the more repeatable method due to noise effects, it can err in the presence of inhomogeneities.

C.5.5 Repeat the calculations for the measurements made in the opposite direction. Compute the average of the two calculations made in C.5.2 to arrive at the fibre's attenuation coefficient at that wavelength.

C.5.6 Repeat the calculations of C.5.1 through C.5.5 at each wavelength to determine the attenuation coefficient at each wavelength.

C.6 Results

C.6.1 In addition to the requirements of 10.1, report the following when measuring point defects:

- specimen end where the OTDR was located;
- features of the point discontinuities as required by the detail specification.

C.6.2 In addition to the requirements in 10.2, the following information shall also be available on request:

- fibre or cable specimen, including its type, effective group index, length, and deployment conditions;
- OTDR instrument (including brand, model and manuals);
- pulse duration(s), scale range(s), and signal averaging details;
- centroidal wavelength(s) and spectral width(s) as periodically verified in accordance with C.2.2;
- indication of whether dead-zone fibre is used;
- method of calculation.
- indication of the bi-directional or unidirectional measurement method.

Figure C.4 and Figure C.5 show examples of OTDR traces for several types of point discontinuities: a reflective discontinuity and a non-reflective one, both exhibiting apparent loss (Figure C.4); a discontinuity exhibiting an apparent "gain", and one with no apparent loss or gain (Figure C.5).

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Annex D (normative)

Requirements specific to method D – Spectral attenuation modelling

D.1 General

Method D can be demonstrated on class B single-mode fibres.

The attenuation coefficient of a fibre across a spectrum of wavelengths ~~may~~ can be calculated by means of a characterizing matrix, M , and a vector, v . The vector v contains the measured attenuation coefficients of a small number (three to five) of wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, ~~and~~ or 1 550 nm).

In one approach, the fibre or cable supplier shall provide a matrix characteristic of its product, and the modelled spectral attenuation is a vector, w , calculated from the product of M and v :

$$w = M \times v \quad (D.1)$$

Alternatively, if using a generic matrix, the supplier shall provide a correction factor vector such that the prediction formula becomes

$$W = w + e \quad (D.2)$$

where

W is the modified vector;

w comes from Formula (D.1);

e is the correction factor vector.

A generic matrix is a characterizing matrix which can be applied to a variety of fibres, designs and suppliers (presumably within a single fibre type), and which is either determined or invoked, or both, by a standards body, single customer/end-user, or other industry source to which individual suppliers can compare their products, the difference being resolved by the vector, e .

D.2 Apparatus

Since this technique involves a calculation using predetermined values, no specific apparatus is required. Please refer to the specific technique used to generate the measured values upon which the calculations are made.

D.3 Sampling and specimens

See Clause D.2.

D.4 Procedure

See Clause D.2.

D.5 Calculations

The attenuation coefficient of a fibre across a spectrum of wavelengths ~~may~~ can be calculated by means of Formula (D.1). The vector, v , contains the measured attenuation coefficients of a small number (three to five) of predictor wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, ~~and/or~~ 1 550 nm). Multiplying the matrix, M , times the vector, v , yields another vector, w , which contains the predicted attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1 240 nm to 1 600 nm). The resultant vector, w , contains the predicted attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1 240 nm to 1 600 nm).

The matrix, M , is given by

$$\begin{matrix} A_{11} & A_{12} & A_{1n} \\ A_{21} & A_{22} & A_{2n} \\ \vdots & & \\ A_{m1} & A_{m2} & A_{mn} \end{matrix}$$

where

m is the number of wavelengths for which the attenuation coefficients have to be estimated;

n is the number of predictor wavelengths.

The standard deviation of the difference between the actual and predicted attenuation coefficients at each wavelength shall be less than a maximum attenuation value (in dB/km) within a stated wavelength range. A different value of maximum attenuation ~~may~~ can be necessary if an additional wavelength range is specified. The value(s) of maximum attenuation and the wavelength range(s) should be agreed upon between the user and the manufacturer.

If the estimate is obtained by using the supplier's specific matrix, M , then no correction vector, e , is necessary.

Since the elements of both M and e are achieved on a statistical basis, the w vector elements shall be statistically determined. To indicate the accuracy of the predicted attenuation coefficients, the fibre suppliers shall give a vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients, together with either M or e , or both (see Clause D.6).

In order to facilitate the use of this matrix, the fibre should be routinely measured at the predictor wavelengths. The predictor wavelengths should number from three to five, with a strong preference given to the lower number if sufficient accuracy can be achieved. The specific wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, ~~and/or~~ 1 550 nm) are an item for further study.

This model considers only uncabled fibre attenuation. An additional vector should be added to w in order to account for cabling and environmental effects.

D.6 Results

D.6.1 In addition to the information required by 10.1, report the predicted attenuation and corresponding wavelength.

D.6.2 In addition to the information required by 10.2, the following shall be available upon request:

- the method used to obtain the measured attenuation values;
- the matrix used to predict the spectral attenuation, or the correction vector if a standard matrix was used;
- the vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients obtained during the development of the matrix.

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Annex E (informative)

Examples of short cable test results on A1 multimode fibres

Figure E.1, Figure E.2, and Figure E.3 represent examples of length-dependent attenuation coefficient measurement results on ~~A1a.1, A1a.3~~ A1-OM2, A1-OM4 and ~~A1b~~ A1-OM1 multimode fibres at 850 nm and at 1 300 nm, respectively. Each value is an average of measurements repeated 3 times.

Test method: method A, cut-back;

Launch condition: geometrical optics launch (70/70)

Sample configuration: in fibre spool, 30 g winding tension

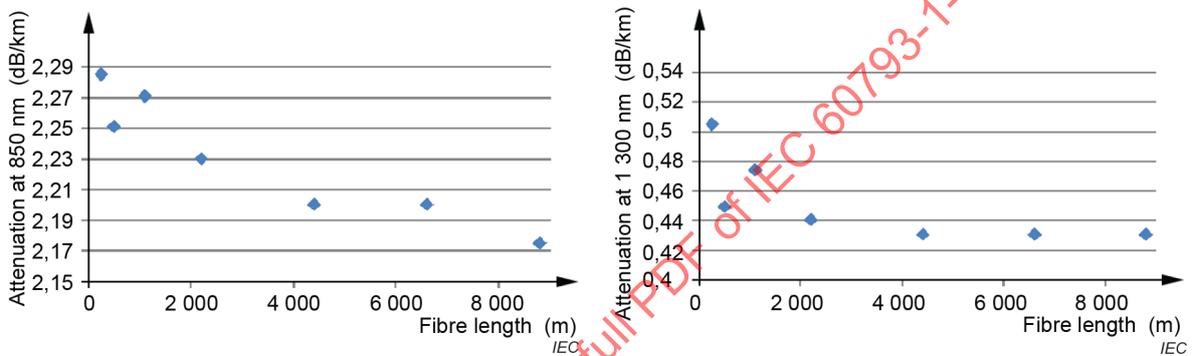


Figure E.1 – Example of attenuation coefficient tests on ~~A1a.1~~ A1-OM2 fibre

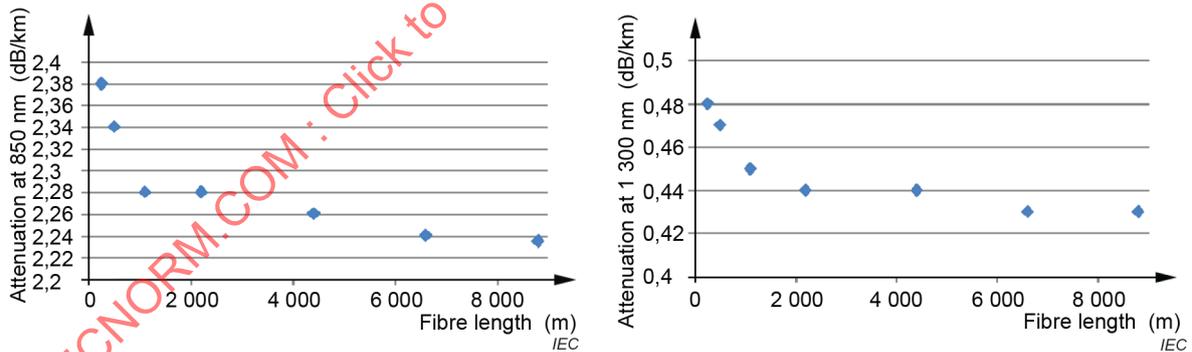


Figure E.2 – Example of attenuation coefficient tests on ~~A1a.3~~ A1-OM4 fibre

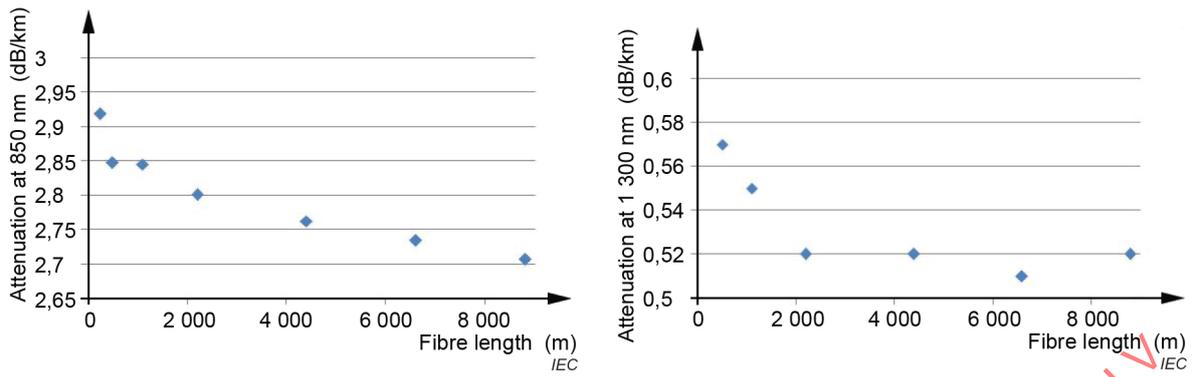


Figure E.3 – Example of attenuation coefficient tests on ~~A1b~~ A1-OM1 fibre

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IEC TR 62316, *Guidance for the interpretation of OTDR backscattering traces for single-mode fibres*

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INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Optical fibres –
Part 1-40: Attenuation measurement methods**

**Fibres optiques –
Partie 1-40: Méthodes de mesure de l'affaiblissement**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL FIBRES –

Part 1-40: Attenuation measurement methods

FOREWORD

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IEC 60793-1-40 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2019. This edition constitutes a technical revision.

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

- a) modifying the definition of attenuation to be compatible with the definition in electropedia.org

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

Draft	Report on voting
86A/2355/CDV	86A/2446/RVC

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.

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OPTICAL FIBRES –

Part 1-40: Attenuation measurement methods

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the attenuation of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

Four methods are described for measuring attenuation, one being that for modelling spectral attenuation:

- method A: cut-back;
- method B: insertion loss;
- method C: backscattering;
- method D: modelling spectral attenuation.

Methods A to C apply to the measurement of attenuation for all categories of the following fibres:

- class A multimode fibres;
- class B single-mode fibres.

Method C, backscattering, also covers the location, losses and characterization of point discontinuities.

Method D is applicable only to class B fibres.

Information common to all four methods appears in Clause 1 to Clause 11, and information pertaining to each individual method appears in Annex A, Annex B, Annex C, and Annex D, respectively.

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 60793-1-1, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement*

IEC 61746-1, *Calibration of optical time-domain reflectometers (OTDR) – Part 1: OTDR for single mode fibres*

IEC 61746-2, *Calibration of optical time-domain reflectometers (OTDR) – Part 2: OTDR for multimode fibres*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-1-1 and the following apply.

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

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

3.1.1

attenuation

optical power reduction along a fibre at wavelength λ between two cross-sections, 1 and 2, separated by a distance and defined as

$$A(\lambda) = 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \quad (1)$$

where

$A(\lambda)$ is the attenuation, in dB, at wavelength λ ;

$P_1(\lambda)$ is the optical power traversing the first cross-section;

$P_2(\lambda)$ is the optical power traversing the second cross-section.

Note 1 to entry: Attenuation is a measure of the decreasing optical power in a fibre at a given wavelength. It depends on the nature and length of the fibre and is also affected by measurement conditions.

3.1.2

attenuation coefficient

attenuation per unit length for a uniform fibre under steady-state conditions

Note 1 to entry: It is possible to define the attenuation per unit length or the attenuation coefficient as follows:

$$\alpha(\lambda) = \frac{A(\lambda)}{L} \quad (2)$$

which is independent of the chosen length of the fibre,

where

$\alpha(\lambda)$ is the attenuation coefficient;

$A(\lambda)$ is the attenuation at wavelength λ ;

L is the length, in kilometres.

Note 2 to entry: Uncontrolled launching conditions normally excite higher order lossy modes that produce transient losses and result in attenuation that is not proportional to the length of the fibre. A controlled, steady-state launching condition yields attenuation that is proportional to the fibre's length. Under steady-state conditions, an attenuation coefficient of a fibre can be determined and the attenuation of concatenated fibres added linearly.

3.1.3

spectral attenuation modelling

technique that predicts the attenuation coefficients across a spectrum of wavelengths from a small number (three to five) of discrete values measured directly at different wavelengths

3.1.4

point discontinuity

temporary or permanent local deviation of the continuous optical time-domain reflectometer (OTDR) signal in the upward or downward direction

Note 1 to entry: The nature of the deviation can vary with test conditions (e.g. pulse duration, wavelength, and direction of the OTDR signal). Although a point discontinuity can have a length greater than the corresponding displayed pulse duration (including transmitter and receiver effects), the length is usually about equal to the pulse duration. For a correct interpretation, the guidelines in IEC 60793-1-22 should be followed for measuring length.

3.2 Abbreviated terms

FWHM	full width at half maximum
LPS	limited phase space
OTDR	optical time-domain reflectometer
RMSW	root-mean-squared width
RTM	reference test method

4 Calibration requirements

See Annex A, Annex B, and Annex C for methods A, B, and C, respectively.

5 Reference test method

Method A, cut-back, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

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

7 Sample preparation

7.1 Sample length

The sample shall be a known length of fibre on a reel, or within a cable, as specified in the relevant specification.

7.2 Sample end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each sample.

8 Procedure

See Annex A, Annex B, Annex C, and Annex D for methods A, B, C and D, respectively.

9 Calculations

9.1 Methods A and B

Methods A and B, cut-back and insertion loss use Formula (1) and Formula (2) respectively, which appear in 3.1.1 and 3.1.2.

9.2 Method C

See Annex C.

9.3 Method D

See Annex D.

10 Results

10.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of specimen;
- optical source wavelength;
- specimen length;
- spectral attenuation, in dB, or attenuation coefficient, in dB/km, versus wavelength or at specific wavelength(s), as required by the relevant specification.

10.2 Information available upon request

The following information shall be available upon request:

- measurement method used: A, B, C, or D;
- type of optical source used: centroidal wavelength(s) and spectral width(s);
- launching technique and conditions used;
- indication if a dead-zone fibre was used (for method C only);
- description of all key equipment;
- for type B fibres – dimensions and number of turns of the mode filter or mode scrambler;
- pulse duration(s), scale range(s), and signal-averaging details;
- details of computation technique (calculation method);
- any deviations to the procedure that were made;
- date of latest calibration of measurement equipment.

10.3 Method-specific additional information

For methods C and D, see the additional requirements in Clause C.6 and Clause D.6, respectively. This particularly applies when using method C for measuring point discontinuities.

11 Specification information

The relevant specification shall specify the following information:

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

Annex A (normative)

Requirements specific to method A – Cut-back

A.1 General

The cut-back technique is the only method directly derived from the definition of fibre attenuation, in which the power levels, $P_1(\lambda)$ and $P_2(\lambda)$, are measured at two points of the fibre without change of input conditions. $P_2(\lambda)$ is the power emerging from the end of the fibre, and $P_1(\lambda)$ is the power emerging from a point near the input after cutting the fibre. This explains its wide acceptance as the reference test method for attenuation.

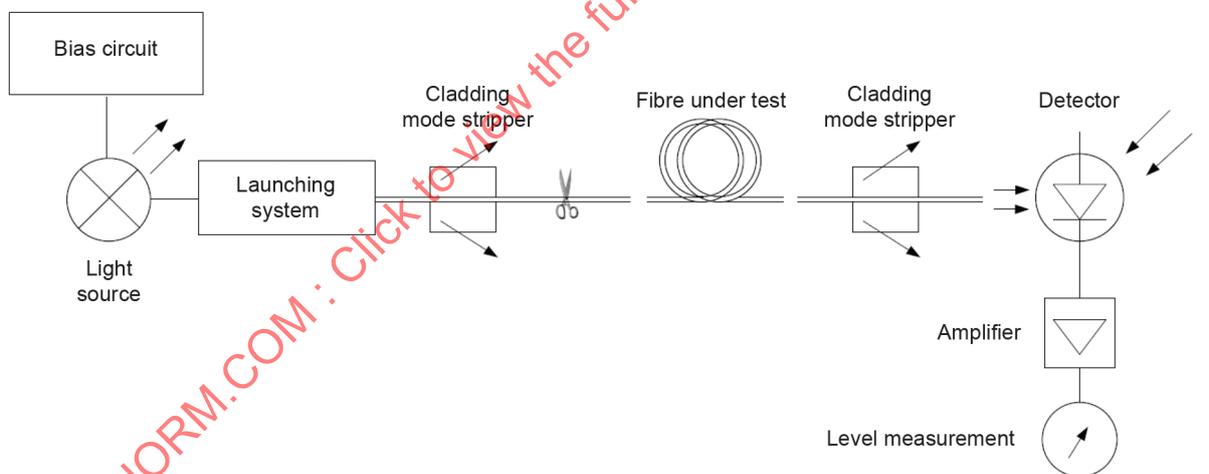
This measurement principle does not permit information to be obtained on the attenuation behaviour over the length of the fibre, nor is it easy to measure the change of attenuation under changing conditions. In some situations, its destructive nature is a disadvantage.

A.2 Apparatus

A.2.1 General apparatus for all fibres

A.2.1.1 General

See Figure A.1 and Figure A.2 for diagrams of suitable test set-ups.



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Figure A.1 – Arrangement of equipment for loss measurement at a specified wavelength

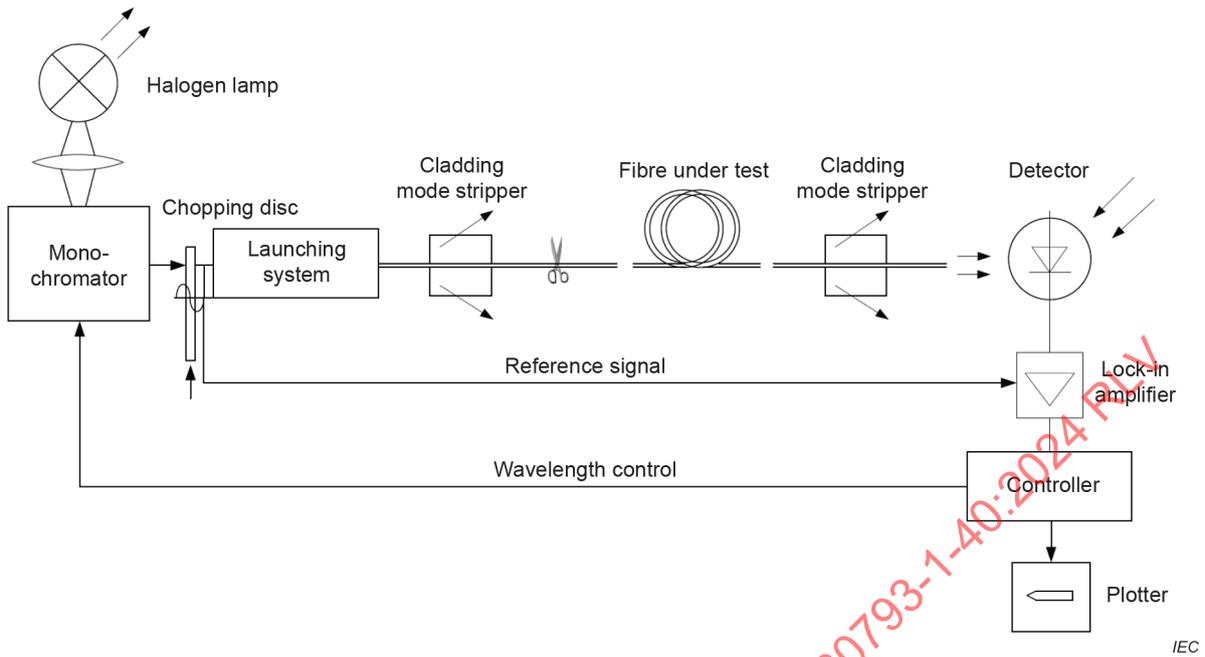


Figure A.2 – Arrangement of equipment used to obtain loss spectrum

A.2.1.2 General launch arrangement

Figure A.3 shows the general launch arrangement used for all fibres. See A.2.2 to A.2.4 for further details as they apply to specific categories of single-mode and multimode fibres.

A.2.1.3 Optical source

Use a suitable radiation source, such as a lamp, laser or light-emitting diode. The choice of source depends upon the type of measurement. The source shall be stable in position, intensity and wavelength over a time period sufficiently long to complete the measurement procedure. Specify the spectral line width (between the 50 % optical intensity power points of the sources used) such that the line width is narrow, for example <10 nm, compared with any features of the fibre spectral attenuation. Align the fibre to the launch cone or connect it to a launch fibre.

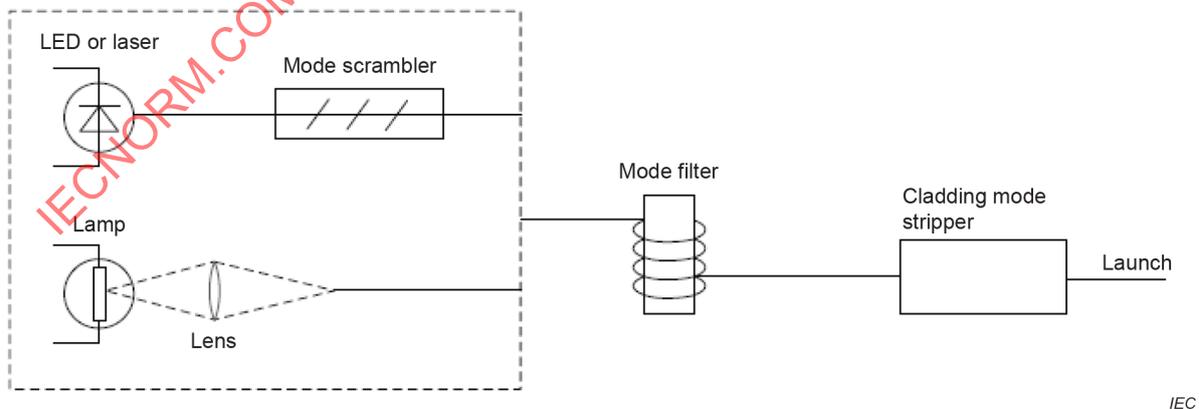


Figure A.3 – General launch arrangement

A.2.1.4 Source wavelength

Measurements can be made at one or more wavelengths. Alternatively, a spectral response can be obtained over a range of wavelengths.

A.2.1.5 Optical detection assembly

Means shall be provided to couple all power emitted from the specimen to the active region of the detector. For example, an optical lens system, a butt spliced to a fibre pigtail, or a coupling directly to the detector can be used. If the detector is already pigtailed, the pigtail fibre shall have sufficiently large core diameter and numerical aperture to capture all of the light exiting the reference and specimen fibres.

Use an optical detector that is linear and stable over the range of intensities and measurement times that are encountered in performing this measurement. A typical system might include a photovoltaic mode photodiode amplified by a current input amplifier, with synchronous detection by a lock-in amplifier.

A.2.1.6 Signal processing

It is customary to modulate the light source to improve the signal to noise ratio at the receiver. If such a procedure is adopted, link the detector to a signal processing system synchronous with the source modulation frequency. The detecting system should be substantially linear or have been fully characterized with a response function.

A.2.1.7 Cladding mode stripper

Use suitable techniques to remove optical power propagating in the cladding where this would significantly influence the received signal.

A.2.2 Launch apparatus for all single-mode fibres

A.2.2.1 General

An optical lens system or fibre pigtail can be employed to excite the test fibre. The power coupled into the fibre shall be stable for the duration of the measurement. See Figure A.1.

A.2.2.2 Fibre pigtail

If using a pigtail, it can be necessary to use index-matching material between the source pigtail and test fibre to eliminate interference effects.

A.2.2.3 Optical lens system

If using an optical lens system, provide a means of stably supporting the input end of the fibre, such as a vacuum chuck. Mount this support on a positioning device so that the fibre end can be repeatedly positioned in the input beam. A method of making the positioning of the fibre less sensitive is to overfill the fibre end spatially and angularly.

A.2.2.4 High-order mode filter

Use a method to remove high-order propagating modes in the wavelength range of interest. An example of such a high-order mode filter is a single loop of radius sufficiently small to shift the cut-off wavelength below the minimum wavelength of interest. For bending loss insensitive single-mode fibres, multiple loops with smaller radius or longer cut-back specimen length can be applied. Care should be taken that the radius is not too small as to induce wavelength-dependent oscillations. Increase of the cut-back specimen length should be accounted for in the attenuation computation.

A.2.2.5 Cladding mode stripper

The cladding mode stripper ensures that no radiation modes, propagating in the cladding region, will be detectable after a short distance along the fibre. The cladding mode stripper often consists of a material having a refractive index equal to or greater than that of the fibre cladding. This can be an index-matching fluid applied directly to the uncoated fibre near its ends; under some circumstances the fibre coating itself will perform this function.

A.2.3 Launch apparatus for A1 multimode fibres

A.2.3.1 General

The launching conditions are of paramount importance in meeting the objectives stated in Clause 1. Launching conditions are established to avoid launching power into higher-order, transient modes. By not launching power into these transient modes of the test fibre, attenuations which add in an approximately linear fashion will be measured. Because these power distributions are essentially unaltered by the fibre, they are called "steady-state distributions".

There are two commonly used techniques to produce steady-state launch conditions for attenuation measurements: mode filters and a geometrical optics launch. Proper care in the use of each technique gives comparable results.

Ensure that mode distribution is related with specimen length. For short A1 multimode fibre cables (less than 1 km), it is possible that the mode distribution will not reach a steady state. This will induce an increase in attenuation values towards shorter fibre lengths, where the magnitude of the length dependence depends on fibre type, launch condition, etc. In these cases, attenuation values should be obtained from cables long enough to reach a steady-state condition, or they can be taken from the original longer donor cable. As guidance for sufficient cable lengths, see examples of cable test results on A1 multimode fibres in Annex E.

See Figure A.3 for a generic example of the launching arrangement using a mode filter. Examples of each mode filter appear below.

A.2.3.2 Examples of mode filters

A.2.3.2.1 Dummy-fibre mode filter

Select a fibre of a similar type to that of the test fibre. The fibre should be long enough (typically equal to or greater than 1 km) so that the power distribution carried by the fibre, when the launch source of A.2.1.2 is used, is a steady-state distribution.

A.2.3.2.2 Mandrel-wrapped mode filter

Another mode filter takes the form of a mandrel around which a few turns (typically three to five turns) of the fibre under test are wound with low tension. Select the mandrel diameter to ensure that the transient modes excited in the test fibre have been attenuated to steady-state. Use a far-field measurement to compare the power distribution exiting a long length of test fibre (greater than 1 km) that has been excited with a uniformly overfilling source, with the power distribution exiting a short length of the fibre with the mandrel applied. Select the mandrel diameter to produce a far-field distribution in the short length that approximates the long length far-field power distribution.

The numerical aperture (as measured by IEC 60793-1-43) of the radiation pattern exiting the short length shall be 94 % to 100 % of the numerical aperture of the long-length pattern.

The diameter of the mandrel can differ from fibre to fibre depending on fibre and coating type. Common prescriptions consist of diameters in the range of 15 mm to 40 mm, with five turns of fibre within a 20 mm length of the mandrel. While mandrels of different size and arrangement can be selected, Table A.1 illustrates common mandrel sizes for fibres of different core diameters.

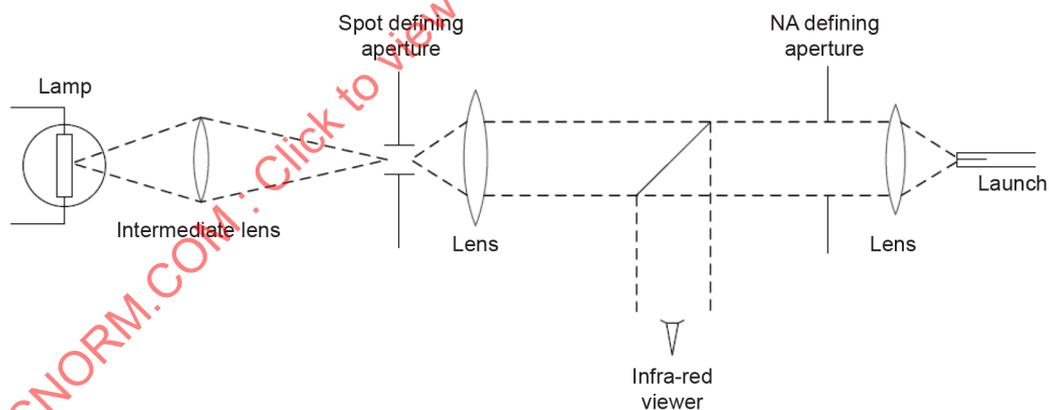
Table A.1 – Size examples

Core diameter μm	Mandrel diameter mm
50	25
62,5	20
100	25

A.2.3.3 Example of geometrical optics launch

A limited phase space (LPS) launch is defined as a geometrically produced launch that uniformly fills 70 % of the test fibre's core diameter and 70 % of the test fibre's numerical aperture. This is the maximum geometrically launched power distribution that does not launch power into leaky, unbounded modes. For a 50/125 μm , 0,2 NA graded-index multimode fibre, the LPS launch condition consists of a uniform 35 μm spot and 0,14 NA.

An example of the optics necessary to produce the LPS launch is given in Figure A.4. It is important to ensure that the axis of the launch beam is coincident with the axis of the fibre so that the spot and incident cone of light are centred on the core of the fibre. Also, set up the optical system at the wavelengths of operation to ensure proper measurement. While mandrels of different size and arrangement can be selected, common mandrel sizes for fibres of different core diameters, are shown in Table A.1.



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Figure A.4 – Limited phase space launch optics

A.2.3.4 Mode scrambler

An essentially uniform power distribution is launched prior to the mode filter. For a source such as an LED or laser, which does not form a uniform power distribution, use a mode scrambler. The mode scrambler shall comprise a suitable fibre arrangement (for example, a step-graded-step index profile sequence).

A "mode scrambler" is a device which is positioned between the light source and test fibre to control launching conditions. A particular mode scrambler design is not specified. It should be emphasized that the performance of these scramblers depends upon the launch optics and fibre sizes (core and NA) used in the actual construction.

EXAMPLE The two designs given in Figure A.5 are for illustration purposes only.

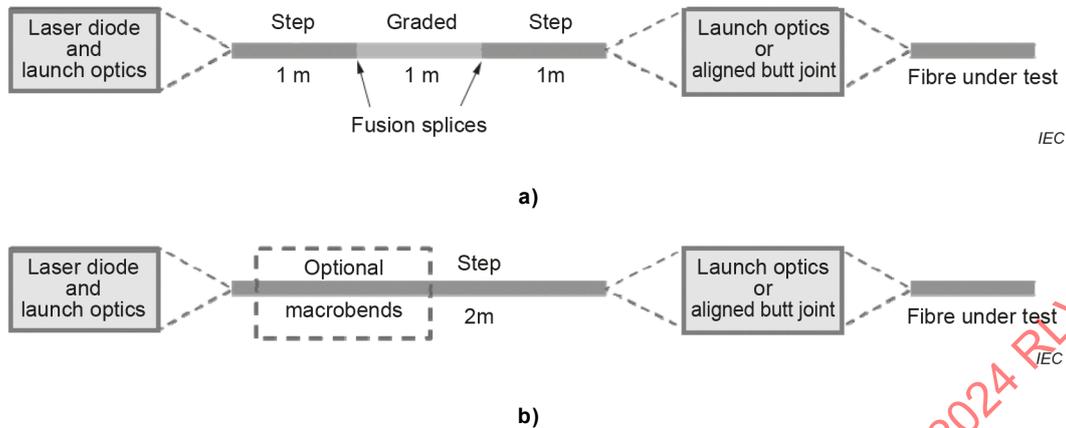


Figure A.5 – Two examples of optical fibre scramblers

A.2.4 Launch apparatus for A2 to A4 multimode fibres

Some examples of generic launching arrangements for short distance fibres are described in Figure A.6, Figure A.7 and Figure A.8.

The reproducibility of the attenuation measurements of multimode fibres is critical. Therefore, a well-defined launching set-up description is necessary. Such a set-up can be achieved by using commercially available optical components and shall be capable of providing for spot sizes and launch NAs as given in Table A.2.

Table A.2 – Launch conditions for A2 to A4 fibres

Attribute	Fibre category		
	A2.2 fibre ^a Glass core/glass cladding	A3 fibre Glass core/plastic cladding	A4 fibre Plastic core/plastic cladding
Spot size	= fibre core size	= fibre core size	= fibre core size with full mode launch (or use mode scrambler with equilibrium mode launch)
Numerical aperture (NA)	= fibre max. Na ^b	= fibre max. NA ^c	= fibre max. NA, with full mode launch
^a Category A2.1 fibre requires further study. ^b This launch condition can be produced by overfilling a mode filter made from 2 m of fibre identical to the fibre under test, with appropriate cladding mode stripping and using the output from this mode filter to launch into the fibre under test. ^c This launch condition can be produced in the same manner as described in footnote b. However, some types of A3 and A4 fibre will not require cladding mode stripping for the mode filter.			

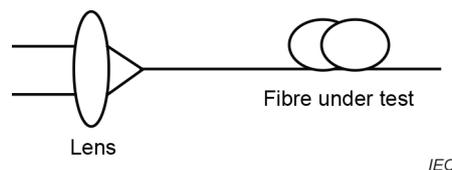


Figure A.6 – Lens system

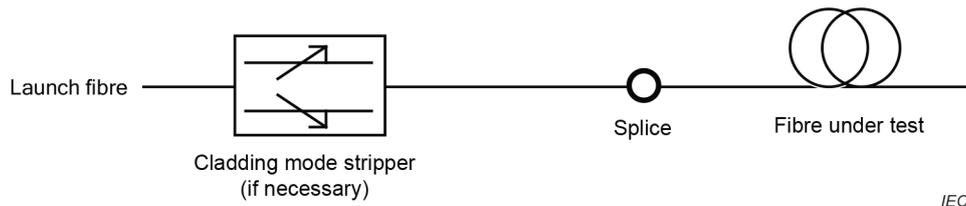


Figure A.7 – Launch fibre

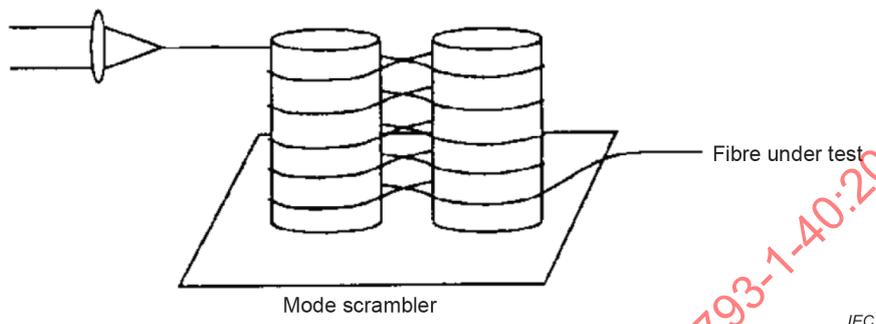


Figure A.8 – Mode scrambler (for A.4 fibre)

A.2.5 Calibration requirements

A.2.5.1 General calibration requirements

Calibrate the optical source's centroidal wavelength to within ± 10 nm.

A.2.5.2 Requirements for A4 fibres

For A4 fibres it is common to perform attenuation measurements at specific wavelengths using an LED as optical source. Owing to characteristic strong sharp variations in attenuation over the wavelength spectrum of some polymeric materials, additional optical characterization measurements should be performed to take into account effects that could affect the measurement when calibrating wide-spectrum sources used for attenuation measurement, especially when the centroidal wavelength is significantly far from the intended wavelength measurement. A full characterization will ensure repeatability of the measurements and avoid the negative influence of the following effects:

– Distortion on the attenuation measurement

An optical source with wide spectrum, for example, an LED, will cause measurement errors on the measurements, since parts of the optical spectrum lie in low-loss wavelengths and other parts lie in higher-loss wavelengths. This is illustrated in Figure A.9 with the Gaussian line "b" showing the spectral response for an LED source used to measure A4 fibres and with the expected spectral attenuation indicated by the line "a". To take proper consideration of the potentially high attenuation variations, the source shall be calibrated both in its centroidal wavelength and spectral width and it should be checked that these two characteristics match the expected wavelength attenuation of the fibre under test.

– Spectral filter effect

Light with a wide spectrum undergoes relatively little attenuation at some wavelengths while other spectral parts suffer higher losses when propagating through A4a fibres. With longer measured fibre lengths, the detected LED spectral maximum shifts towards the fibre attenuation-minimum wavelength. This can be seen in Figure A.9, where the original spectral source is illustrated with the line "b" (characterized through a 0 m fibre length) and the same spectra detected after passing different lengths of an A4 fibre. As the measurement-fibre length increases, a shift on the maximum of the detected Gaussian signal occurs towards the wavelength of minimum attenuation of the fibre (lines "c" to "f" in Figure A.9).

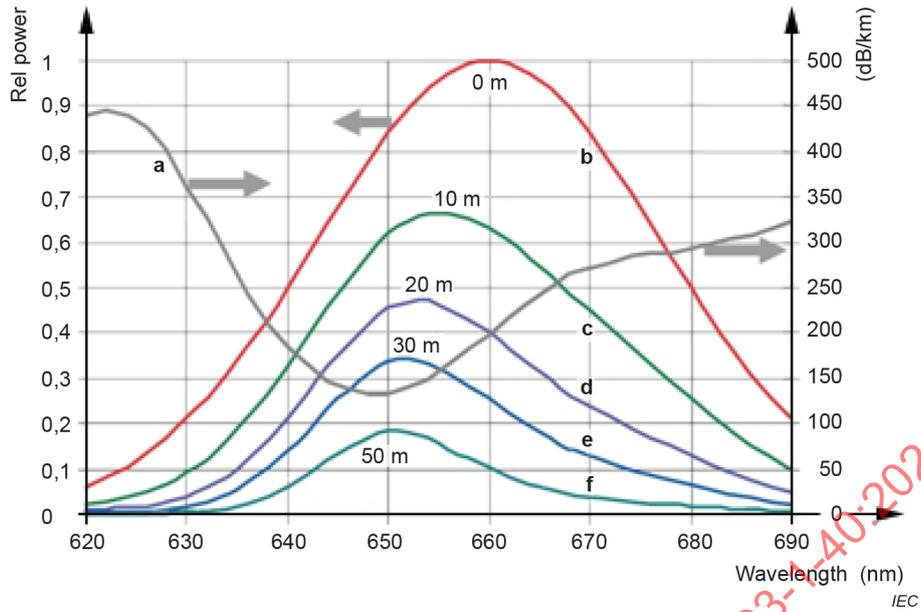


Figure A.9 – A wide-spectrum source (line "b") could lead to attenuation measurement errors due to sharp variations on spectral attenuation of polymer-core fibres (line "a")

A.3 Procedure

A.3.1 Set the fibre under test in the measurement apparatus. Record the output power, $P_2(\lambda)$.

A.3.2 Keeping the launching conditions fixed, cut the fibre to the cut-back length (for example, 2 m from the launching point). Record the output power, $P_1(\lambda)$, of the cut-back length.

A.4 Calculations

A.4.1 Calculate the attenuation between the points where $P_1(\lambda)$ and $P_2(\lambda)$ have been measured using Formula (1) in 3.1.1, or calculate the attenuation coefficient by using Formula (2) in 3.1.2, or both, as required.

A.4.2 Using the attenuation measurement results at discrete wavelengths, a spectral attenuation curve can be calculated with relationships such as those described in Annex D.

Annex B (normative)

Requirements specific to method B – Insertion loss

B.1 General

The insertion loss technique is, in principle, similar to the cut-back technique, but $P_1(\lambda)$ is the power emerging from the output of the launching system.

The insertion loss technique is less accurate than that of the cut-back technique but has the advantage of being non-destructive for the fibre under test and for the terminators possibly fixed at both ends. Therefore, it is suitable for field use, and mainly intended for use with connectorized cable lengths.

This method does not allow for analysis of the attenuation over the length of fibre. Given the previous known power, $P_1(\lambda)$, it is possible with this technique to measure the continuing change in attenuation over changing environmental conditions such as temperature and force.

B.2 Apparatus

B.2.1 General set-ups

Figure B.1 (calibration) and Figure B.2 (measurement) show diagrams of suitable measurement set-ups.

B.2.2 Apparatus common to method A (cut-back)

See the provisions of A.2.1. See also all of the appropriate information on launching conditions in A.2.2 (for single-mode fibre), A.2.3 (for A1 multimode fibre), and A.2.4 (for A2 to A4 multimode fibre).

B.2.3 Additional apparatus specific to method B (insertion-loss)

The insertion-loss technique requires the use of a very precise fibre-to-fibre coupling device to minimize the coupling losses and to ensure reliable results. This coupling device can be a mechanical adjustment that is visually inspected, or a connector with a core-to-core positioning.

B.2.4 Calibration requirements

See A.2.5.

B.3 Procedure

B.3.1 The reference fibre shall be of the same type as that under test. Any connectors and their associated losses are included in the definition of the reference fibre.

B.3.2 Initially calibrate the measurement equipment to obtain an input reference level, $P_1(\lambda)$. Use the same fibre type as a reference fibre at the initial calibration. The length of the reference fibre should be small (for example, 2 m) so that its attenuation can be neglected. (If the attenuation of the reference fibre cannot be neglected, add the value to the calculated value.)

B.3.3 Connect the fibre under test to the measurement apparatus and adjust the coupling to give a maximum level on the optical detector. Record the output power, $P_2(\lambda)$.

B.4 Calculations

Calculate the attenuation by using Formula (1) in 3.1.1, or calculate the attenuation coefficient by using Formula (2) in 3.1.2, or both, as required.

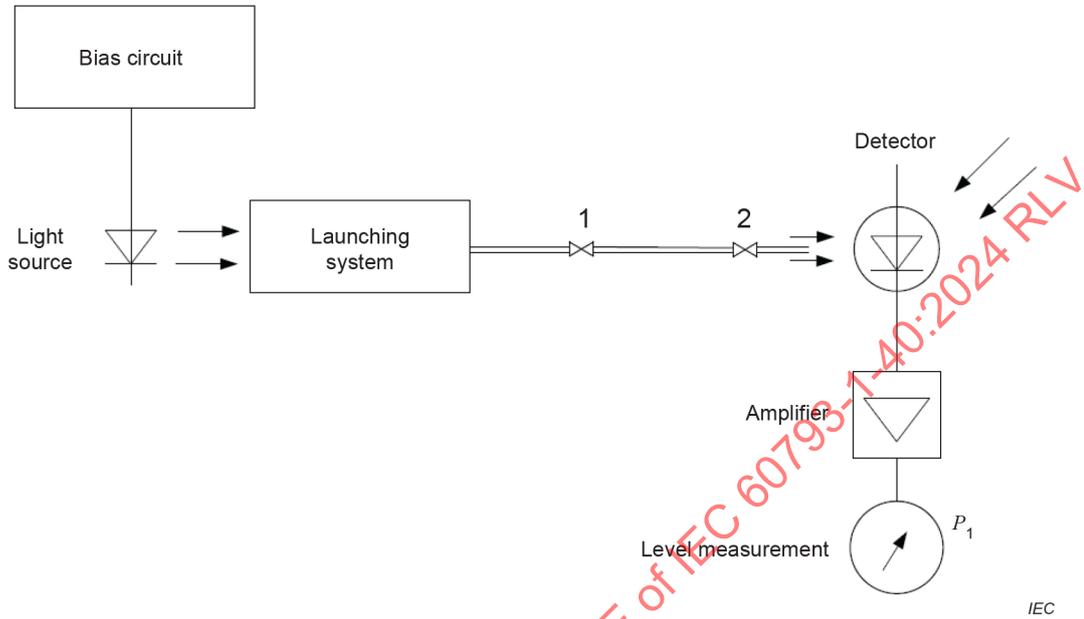


Figure B.1 – Calibration of insertion loss measurement set

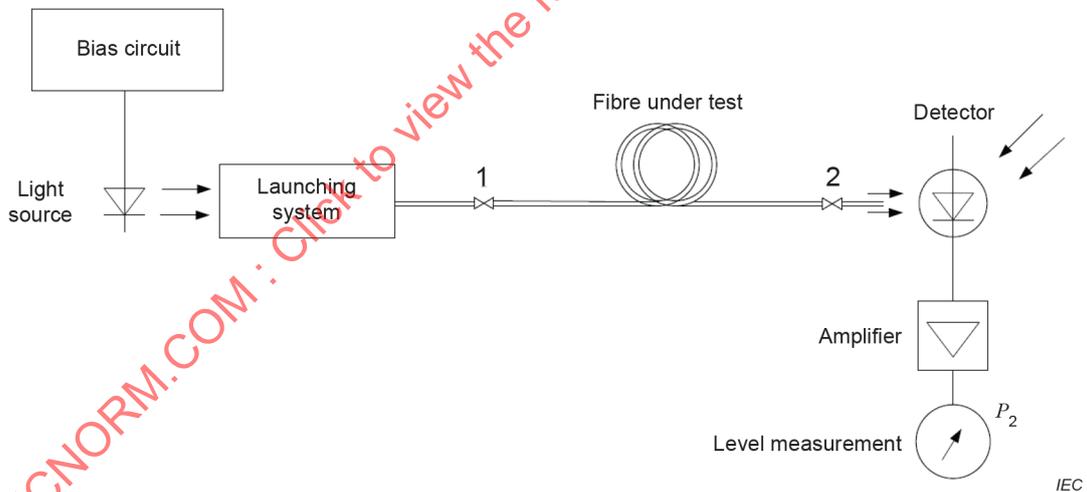


Figure B.2 – Measurement of insertion loss

Annex C (normative)

Requirements specific to method C – Backscattering

C.1 General

The backscattering method, which is a discrete-wavelength, single-sided measurement, measures the optical power backscattered from different points in the fibre to the beginning of the fibre.

The measurement is affected by the propagation speed and the backscattering behaviour of the fibre and it is possible that it will not be accurate for measuring fibre attenuation. The technique can only be used to measure the fibre's attenuation by taking the backscatter measurements from both ends of the fibre under test and averaging the two backscatter traces.

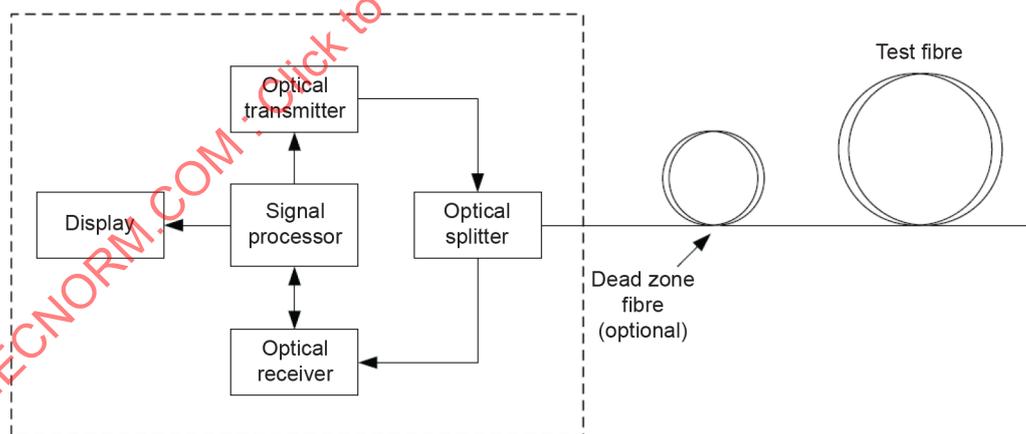
This technique allows analysis of the entire fibre, particularly of longitudinal subsections of the fibre, or even identification of discrete points such as splices. It also permits calculation of the fibre length.

Methods to describe the uniformity of attenuation from the bi-directionally averaged backscattered traces are considered in IEC TR 62316.

C.2 Apparatus

C.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 C.1 for a block diagram.



IEC

Figure C.1 – Block diagram of an OTDR

C.2.2 Optical transmitter

C.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.

C.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.

C.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.

C.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 (RMSW) for wavelengths in the water peak absorption region (e.g. 1 360 nm to 1 430 nm);
- report the actual centroidal wavelength to within 2 nm of the actual value.

C.2.3 Launch conditions

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

For type A fibre, it is possible that optical sources will not produce launch conditions that are well controlled or appropriate to 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 (method A).

C.2.4 Optical splitter

A coupler/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.

C.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.

C.2.6 Pulse duration and repetition rate

The OTDR can provide 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.

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.

C.2.7 Signal processor

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

C.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 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.

C.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.

C.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 specimen.

C.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.

C.3 Sampling and specimens

This is 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.

Care should be taken to ensure that winding does not introduce artificial attenuation for point discontinuity or attenuation measurements. Alternatively, any induced loss confined to the ends of the fibre length (as with the first layer on a reel) can be excluded in a calculation of the attenuation coefficient.

C.4 Procedure

C.4.1 General measurement steps

C.4.1.1 The use of an OTDR for indirect measurement of attenuation or fibre attenuation coefficient of an optical fibre or fibre cable is described below.

For type A1 and A2 optical fibres, more accurate values can be obtained by using spectral attenuation cut-back measurements. If the values obtained by these two techniques differ from each other, the values from the cut-back technique will be accepted as correct, unless otherwise specified in the detail specification.

For type B1 and B2 optical fibres, by performing these measurements at multiple wavelengths, a spectral attenuation curve can be generated using relationships such as those described in method D (see Annex D).

C.4.1.2 Connect the specimen 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.

C.4.1.3 If the attenuation coefficient and accurate distances are to be recorded, the effective group index of the specimen is required. If this value is not known, use the procedure for the OTDR measurement of fibre or cable length (method B of IEC 60793-1-22) to determine it.

C.4.1.4 Enter OTDR parameters such as source wavelength, pulse duration, length range, and signal averaging into the instrument, along with the specimen's effective group index (if required by C.4.1.1.3). The values of some of these parameters can be preset in the instrument.

C.4.1.5 Adjust the instrument to display a backscatter signal from the specimen. It can be advantageous to begin with coarse vertical and horizontal scaling to maximize the length displayed. Figure C.2 and Figure C.3 give examples for use with measuring attenuation and Figure C.4 and Figure C.5 are example schematics for use with measuring point discontinuities.

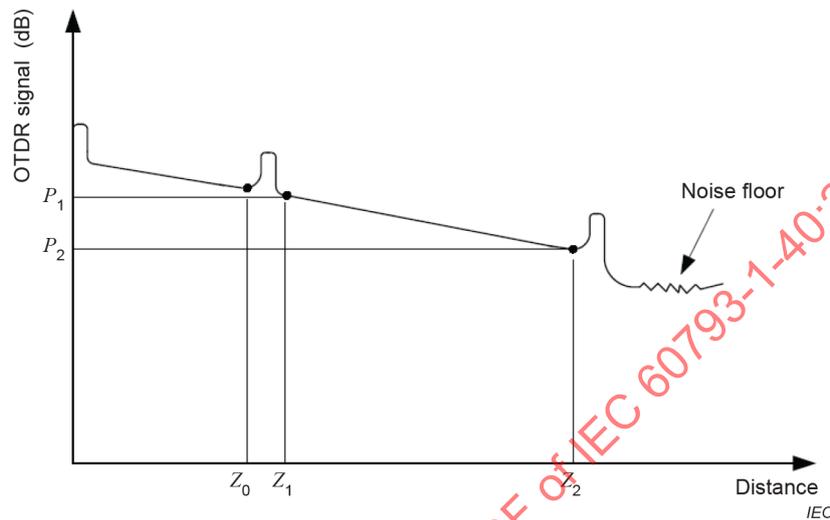


Figure C.2 – Schematic OTDR trace for a "uniform" specimen preceded by a dead-zone fibre

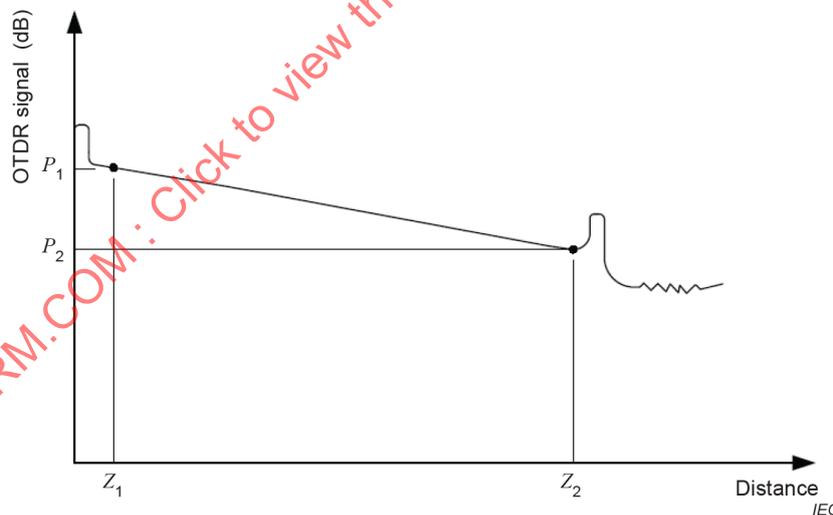


Figure C.3 – Schematic OTDR trace for a "uniform" specimen not preceded by a dead-zone fibre

C.4.2 Further steps for measuring attenuation

C.4.2.1 Step 1

C.4.2.1.1 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).

C.4.2.1.2 (Optional, along with C.5.3) If using a dead-zone fibre, refer to Figure C.2. Place a cursor at the beginning of the trace for the specimen 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 beginning of the trace is not apparent due to minimal discontinuity, apply a tight bend at this location and vary the radius to assist in cursor placement.) Obtain the distance coordinate, z_0 , via the alphanumeric display. If a dead-zone fibre is not used, no cursor placement is required; take $z_0 = 0$.

C.4.2.1.3 Place a cursor on the beginning of the linear portion (after the near end) of the trace for the specimen. If using the dead-zone fibre (Figure C.2), place the cursor beyond the recovery from the small reflection at the end of the dead-zone fibre. If not using the dead-zone fibre (Figure C.3), place the cursor beyond the dead-zone of the OTDR connector. Obtain the distance and power coordinates, $[z_1, P_1(\lambda)]$, via the alphanumeric display.

C.4.2.1.4 Place the same or another cursor at the end of the trace for the specimen at a point by using the methodology described in C.4.2.1.2 for the beginning of the trace. If the end of the trace 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. Obtain the coordinates, $[z_2, P_2(\lambda)]$.

C.4.2.1.5 Repeat the relevant tests of Clause C.4 at each wavelength required.

C.4.2.2 Step 2

Repeat the measurement for a signal launched into the specimen in the opposite direction. To obtain accurate attenuation values, bi-directional traces at the same wavelength are averaged, to eliminate the effects of length varying backscatter properties.

C.4.3 Further steps for measuring point discontinuities

C.4.3.1 Examine the OTDR signal along the specimen for point discontinuities as defined in 3.1.4. 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). See Figure C.5 for an example.

C.4.3.2 To determine that a point discontinuity (rather than an attenuation non-uniformity situation) exists, observe the area in question, using two different pulse durations. If the shape of the loss or gain changes with the pulse duration, the anomaly is a point discontinuity. If the shape does not change, consider the anomaly to be an attenuation non-uniformity to be measured according to the test procedure for measurement of fibre or cable attenuation. Alternatively, if the OTDR pulse shape and duration are known, the resultant shape of the backscatter curve at point discontinuities can be used to determine their existence.

C.4.3.3 Determine the discontinuity location, if required, by placing a cursor at the beginning of a power rise or drop (or at another point specified by the OTDR manufacturer). This can be difficult to do for a power drop. Obtain the coordinate via the alphanumeric display.

C.4.3.4 Obtain the apparent loss or gain of the discontinuity, if required, by the method described by the OTDR manufacturer. Some instruments require placement of a pair of cursors on each side of the discontinuity. Extrapolate the two best-fit straight lines (from a two-point or least-squares fit for each) to the location of the discontinuity. If available, the linear fit method should be chosen. The vertical separation of the lines gives the apparent loss or gain.

Note any reflection peak. The height of a given peak will decrease with increasing pulse width and increase with decreasing pulse width.

C.4.3.5 Repeat the test for a signal launched into the specimen in the opposite direction. Make a loss calculation (and the elimination of apparent gain) by averaging readings taken bi-directionally at the same wavelength. This eliminates the effects of any backscatter differences for the fibre sections on both sides of the discontinuity. Bi-directional measurements are not possible in all cases, thus necessitating unidirectional measurement.

C.4.3.6 Report any point discontinuity deviations that exceed the values specified in the detail specification. Describe the nature of these discontinuities (e.g. apparent loss or gain, reflection, duration, etc.), as required by the detail specification.

C.4.3.7 If required by the detail specification, repeat the test at another wavelength.

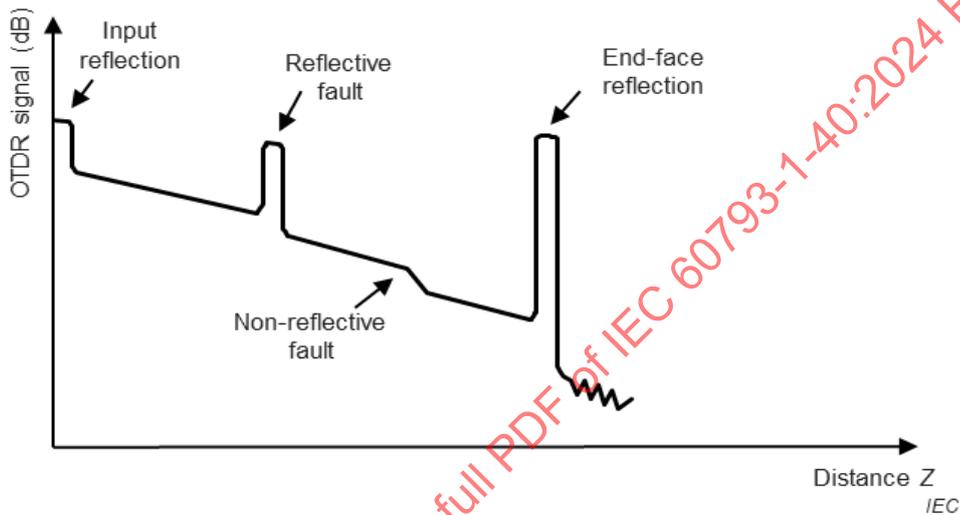


Figure C.4 – Schematic OTDR trace showing apparent loss due to point discontinuities, one reflective and one non-reflective

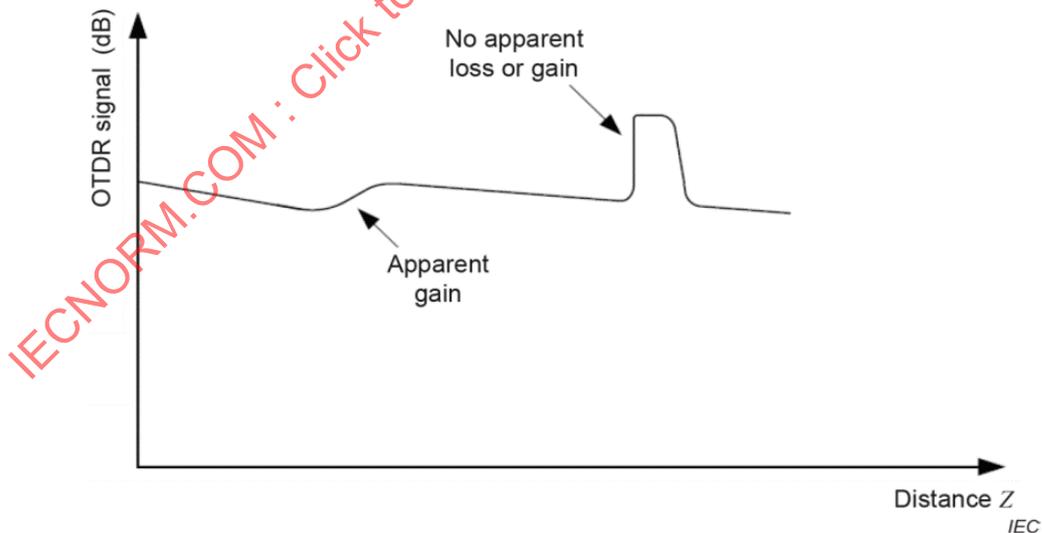


Figure C.5 – Schematic of an expanded OTDR trace showing two point discontinuities, one with apparent gain, and another with no apparent loss or gain

C.4.4 Calibration

Follow the provisions of IEC 61746-1 for the single-mode OTDR calibration method, or of IEC 61746-2 for the multimode OTDR calibration method.

C.5 Calculations

C.5.1 The unidirectional backscatter attenuation of the fibre or cable section beginning after the dead zone is given by $[P_1(\lambda) - P_2(\lambda)]$ in dB.

C.5.2 The unidirectional backscatter attenuation coefficient of the fibre or cable section is given by $\alpha = [P_1(\lambda) - P_2(\lambda)]/(z_2 - z_1)$ in dB/km.

C.5.3 (Optional, along with C.4.2.1.2) The unidirectional backscatter attenuation of the total fibre or cable section is given by $[P_1(\lambda) - P_2(\lambda)] + \alpha(z_1 - z_0)$ in dB (where α is given in C.5.2), or equivalently by $[P_1(\lambda) - P_2(\lambda)](z_2 - z_0)/(z_2 - z_1)$, in dB.

C.5.4 Some OTDRs can automatically perform the two-point subtractions in C.5.1 to C.5.2.

NOTE Some OTDRs can also utilize a least-squares fit to a line, but this can give results that differ from those given by the two-point subtractions. The type of calculation is indicated in the detail specification. While the least-square average (LSA) method can be the more repeatable method due to noise effects, it can err in the presence of inhomogeneities.

C.5.5 Repeat the calculations for the measurements made in the opposite direction. Compute the average of the two calculations made in C.5.2 to arrive at the fibre's attenuation coefficient at that wavelength.

C.5.6 Repeat the calculations of C.5.1 through C.5.5 at each wavelength to determine the attenuation coefficient at each wavelength.

C.6 Results

C.6.1 In addition to the requirements of 10.1, report the following when measuring point defects:

- specimen end where the OTDR was located;
- features of the point discontinuities as required by the detail specification.

C.6.2 In addition to the requirements in 10.2, the following information shall also be available on request:

- fibre or cable specimen, including its type, effective group index, length, and deployment conditions;
- OTDR instrument (including brand, model and manuals);
- pulse duration(s), scale range(s), and signal averaging details;
- centroidal wavelength(s) and spectral width(s) as periodically verified in accordance with C.2.2;
- indication of whether dead-zone fibre is used;
- method of calculation.
- indication of the bi-directional or unidirectional measurement method.

Figure C.4 and Figure C.5 show examples of OTDR traces for several types of point discontinuities: a reflective discontinuity and a non-reflective one, both exhibiting apparent loss (Figure C.4); a discontinuity exhibiting an apparent "gain", and one with no apparent loss or gain (Figure C.5).

Annex D (normative)

Requirements specific to method D – Spectral attenuation modelling

D.1 General

Method D can be demonstrated on class B single-mode fibres.

The attenuation coefficient of a fibre across a spectrum of wavelengths can be calculated by means of a characterizing matrix, M , and a vector, v . The vector v contains the measured attenuation coefficients of a small number (three to five) of wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, or 1 550 nm).

In one approach, the fibre or cable supplier shall provide a matrix characteristic of its product, and the modelled spectral attenuation is a vector, w , calculated from the product of M and v :

$$w = M \times v \quad (\text{D.1})$$

Alternatively, if using a generic matrix, the supplier shall provide a correction factor vector such that the prediction formula becomes

$$W = w + e \quad (\text{D.2})$$

where

W is the modified vector;

w comes from Formula (D.1);

e is the correction factor vector.

A generic matrix is a characterizing matrix which can be applied to a variety of fibres, designs and suppliers (presumably within a single fibre type), and which is either determined or invoked, or both, by a standards body, single customer/end-user, or other industry source to which individual suppliers can compare their products, the difference being resolved by the vector, e .

D.2 Apparatus

Since this technique involves a calculation using predetermined values, no specific apparatus is required. Please refer to the specific technique used to generate the measured values upon which the calculations are made.

D.3 Sampling and specimens

See Clause D.2.

D.4 Procedure

See Clause D.2.

D.5 Calculations

The attenuation coefficient of a fibre across a spectrum of wavelengths can be calculated by means of Formula (D.1). The vector, v , contains the measured attenuation coefficients of a small number (three to five) of predictor wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, or 1 550 nm). Multiplying the matrix, M , times the vector, v , yields another vector, w , which contains the predicted attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1 240 nm to 1 600 nm). The resultant vector, w , contains the predicted attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1 240 nm to 1 600 nm).

The matrix, M , is given by

$$\begin{array}{ccc} A_{11} & A_{12} & A_{1n} \\ A_{21} & A_{22} & A_{2n} \\ \vdots & & \\ A_{m1} & A_{m2} & A_{mn} \end{array}$$

where

m is the number of wavelengths for which the attenuation coefficients have to be estimated;

n is the number of predictor wavelengths.

The standard deviation of the difference between the actual and predicted attenuation coefficients at each wavelength shall be less than a maximum attenuation value (in dB/km) within a stated wavelength range. A different value of maximum attenuation can be necessary if an additional wavelength range is specified. The value(s) of maximum attenuation and the wavelength range(s) should be agreed upon between the user and the manufacturer.

If the estimate is obtained by using the supplier's specific matrix, M , then no correction vector, e , is necessary.

Since the elements of both M and e are achieved on a statistical basis, the w vector elements shall be statistically determined. To indicate the accuracy of the predicted attenuation coefficients, the fibre suppliers shall give a vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients, together with either M or e , or both (see Clause D.6).

In order to facilitate the use of this matrix, the fibre should be routinely measured at the predictor wavelengths. The predictor wavelengths should number from three to five, with a strong preference given to the lower number if sufficient accuracy can be achieved. The specific wavelengths (e.g. 1 310 nm, 1 330 nm, 1 360 nm, 1 380 nm, or 1 550 nm) are an item for further study.

This model considers only uncabled fibre attenuation. An additional vector should be added to w in order to account for cabling and environmental effects.

D.6 Results

D.6.1 In addition to the information required by 10.1, report the predicted attenuation and corresponding wavelength.

D.6.2 In addition to the information required by 10.2, the following shall be available upon request:

- the method used to obtain the measured attenuation values;
- the matrix used to predict the spectral attenuation, or the correction vector if a standard matrix was used;
- the vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients obtained during the development of the matrix.

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Annex E (informative)

Examples of short cable test results on A1 multimode fibres

Figure E.1, Figure E.2, and Figure E.3 represent examples of length-dependent attenuation coefficient measurement results on A1-OM2, A1-OM4 and A1-OM1 multimode fibres at 850 nm and at 1 300 nm, respectively. Each value is an average of measurements repeated 3 times.

Test method: method A, cut-back;

Launch condition: geometrical optics launch (70/70)

Sample configuration: in fibre spool, 30 g winding tension

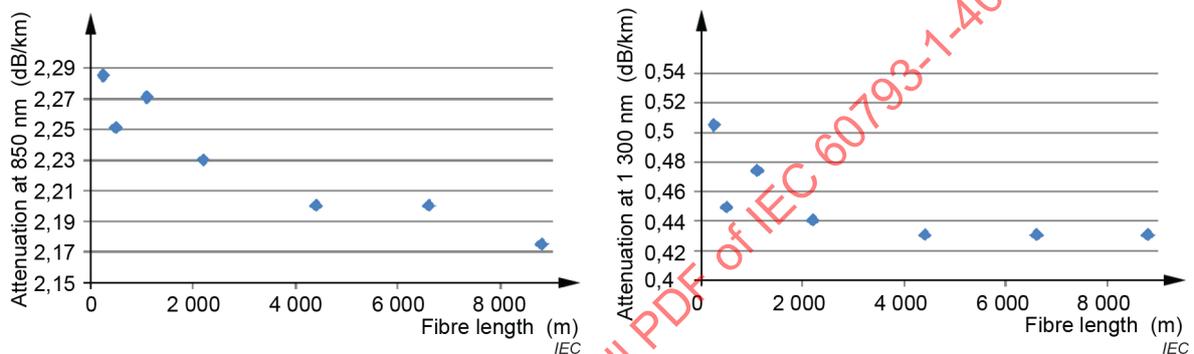


Figure E.1 – Example of attenuation coefficient tests on A1-OM2 fibre

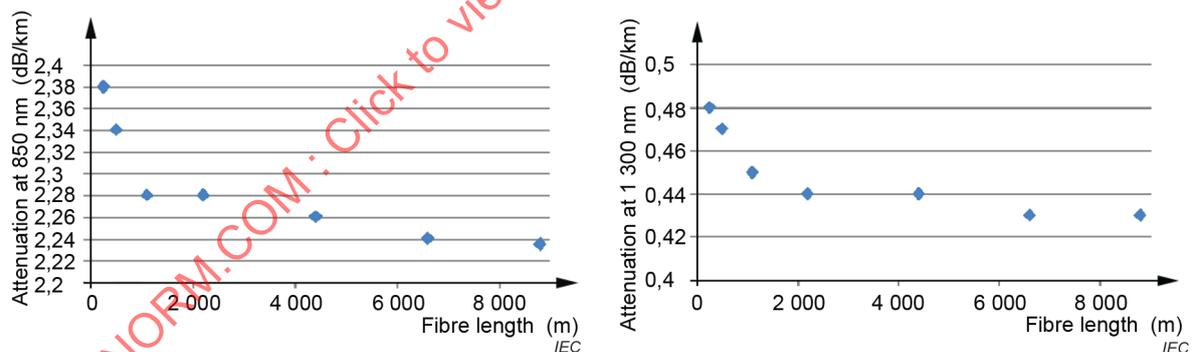


Figure E.2 – Example of attenuation coefficient tests on A1-OM4 fibre

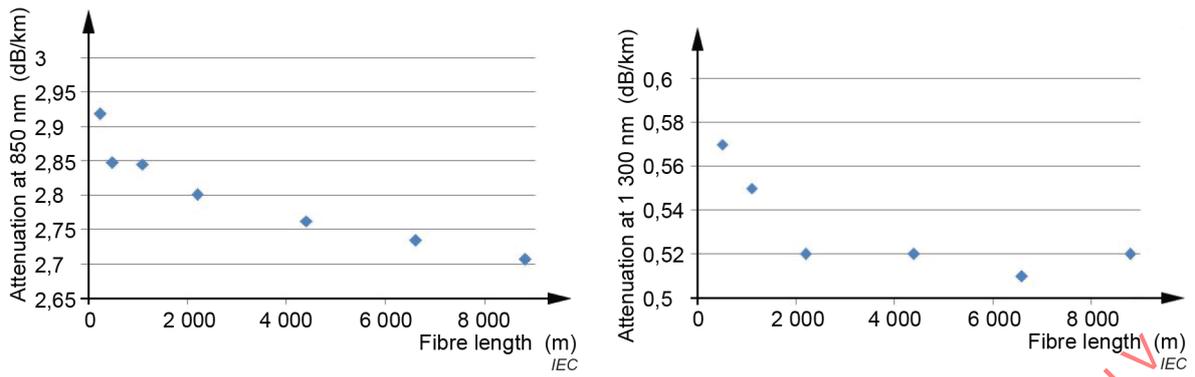


Figure E.3 – Example of attenuation coefficient tests on A1-OM1 fibre

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Bibliography

IEC TR 62316, *Guidance for the interpretation of OTDR backscattering traces for single-mode fibres*

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

FIBRES OPTIQUES –

Partie 1-40: Méthodes de mesure de l'affaiblissement

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L'IEC 60793-1-40 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 troisième édition annule et remplace la deuxième édition parue en 2019. Cette édition constitue une révision technique.

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

- a) modification de la définition de l'affaiblissement pour s'aligner sur la définition du site electropedia.org

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

Projet	Rapport de vote
86A/2355/CDV	86A/2446/RVC

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.

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/.

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FIBRES OPTIQUES –

Partie 1-40: Méthodes de mesure de l'affaiblissement

1 Domaine d'application

La présente partie de l'IEC 60793 établit des exigences harmonisées pour mesurer l'affaiblissement d'une fibre optique, contribuant ainsi au contrôle des fibres et des câbles à des fins commerciales.

Quatre méthodes sont décrites pour mesurer l'affaiblissement, parmi lesquelles une méthode pour modéliser l'affaiblissement spectral:

- méthode A: fibre coupée;
- méthode B: pertes d'insertion;
- méthode C: rétrodiffusion;
- méthode D: modélisation de l'affaiblissement spectral.

Les méthodes A à C s'appliquent au mesurage de l'affaiblissement pour toutes les catégories de fibres suivantes:

- fibres multimodales de classe A;
- fibres unimodales de classe B.

La méthode C, rétrodiffusion, s'applique aussi à la localisation, aux pertes et à la caractérisation des discontinuités ponctuelles.

La méthode D s'applique uniquement aux fibres de classe B.

Les informations communes à ces quatre méthodes sont présentées aux Articles 1 à 11, et les informations propres à chaque méthode individuelle, sont présentées à l'Annexe A, l'Annexe B, l'Annexe C et l'Annexe D, respectivement.

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 60793-1-1, *Fibres optiques – Partie 1-1: Méthodes de mesure et procédures d'essai – Généralités et recommandations*

IEC 60793-1-22, *Fibres optiques – Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur*

IEC 60793-1-43, *Fibres optiques – Partie 1-43: Méthodes de mesure et procédures d'essai – Mesure de l'ouverture numérique*

IEC 61746-1, *Étalonnage des réflectomètres optiques dans le domaine temporel (OTDR) – Partie 1: OTDR pour fibres unimodales*

IEC 61746-2, *Étalonnage des réflectomètres optiques dans le domaine temporel (OTDR) – Partie 2: OTDR pour fibres multimodales*

3 Termes, définitions et abréviations

3.1 Termes et définitions

Pour les besoins du présent document, les termes et les définitions de l'IEC 60793-1-1 ainsi que les suivants s'appliquent.

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 <http://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <http://www.iso.org/obp>

3.1.1

affaiblissement

réduction de la puissance optique le long d'une fibre pour une longueur d'onde λ entre deux sections, 1 et 2, séparées par une certaine distance, et définie comme suit:

$$A(\lambda) = 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \quad (1)$$

où

$A(\lambda)$ est l'affaiblissement, en dB, à la longueur d'onde λ ;

$P_1(\lambda)$ est la puissance optique qui traverse la première section;

$P_2(\lambda)$ est la puissance optique qui traverse la seconde section.

Note 1 à l'article: L'affaiblissement est une mesure de la diminution de la puissance optique dans une fibre à une longueur d'onde donnée. Il dépend de la nature et de la longueur de la fibre et est également influencé par les conditions de mesure.

3.1.2**affaiblissement linéique**

affaiblissement par unité de longueur pour une fibre homogène dans les conditions d'état stable

Note 1 à l'article: Il est possible de définir l'affaiblissement par unité de longueur ou l'affaiblissement linéique par:

$$\alpha(\lambda) = \frac{A(\lambda)}{L} \quad (2)$$

qui est indépendant de la longueur de fibre choisie,

où

$\alpha(\lambda)$ est l'affaiblissement linéique;

$A(\lambda)$ est l'affaiblissement à la longueur d'onde λ ;

L est la longueur, en kilomètres.

Note 2 à l'article: Des conditions d'injection non maîtrisées excitent normalement des modes de fuite d'ordre supérieur qui provoquent des pertes transitoires et entraînent un affaiblissement qui n'est pas proportionnel à la longueur de la fibre. Des conditions d'injection à l'état stable maîtrisées conduisent à un affaiblissement proportionnel à la longueur de la fibre. Dans de telles conditions d'état stable, une valeur d'affaiblissement linéique de la fibre peut être déterminée et les affaiblissements de fibres raccordées peuvent s'additionner de manière linéaire.

3.1.3**modélisation de l'affaiblissement spectral**

technique qui estime l'affaiblissement linéique sur un spectre de longueurs d'onde donné, à partir d'un petit nombre (trois à cinq) de valeurs discrètes mesurées directement à différentes longueurs d'onde

3.1.4**discontinuité ponctuelle**

écart local temporaire ou permanent du signal continu du réflectomètre optique dans le domaine temporel (OTDR – *optical time-domain reflectometer*) dans le sens aller ou retour

Note 1 à l'article: La nature de l'écart peut varier en fonction des conditions d'essai (par exemple, durée d'impulsion, longueur d'onde et sens du signal du réflectomètre optique dans le domaine temporel). Bien que le point de discontinuité puisse être de longueur supérieure à la durée d'impulsion affichée correspondante (y compris les effets de l'émetteur et du récepteur), habituellement cette longueur est sensiblement égale à la durée d'impulsion. Pour une interprétation correcte, il convient de suivre les lignes directrices de l'IEC 60793-1-22 pour le mesurage de la longueur.

3.2 Abréviations

FWHM (full width at half maximum)	largeur d'impulsion à mi-hauteur
LPS (limited phase space)	espace de phase limité
OTDR (optical time-domain reflectometer)	réflectomètre optique dans le domaine temporel
RMSW (root-mean-squared width)	largeur efficace
RTM (reference test method)	méthode d'essai de référence

4 Exigences relatives à l'étalonnage

Voir l'Annexe A, l'Annexe B et l'Annexe C pour les méthodes A, B et C, respectivement.

5 Méthode d'essai de référence

La méthode A, fibre coupée, est la méthode d'essai de référence (RTM – *Reference Test Method*), qui doit être celle utilisée pour régler les litiges.

6 Appareillage

L'Annexe A, l'Annexe B l'Annexe C et l'Annexe D contiennent des dessins et d'autres exigences relatives aux équipements pour chacune des méthodes respectives.

7 Préparation des échantillons

7.1 Longueur d'échantillon

L'échantillon doit avoir une longueur connue de fibre enroulée sur un touret ou à l'intérieur d'un câble, comme cela est indiqué dans la spécification applicable.

7.2 Extrémité d'échantillon

Préparer une section plane perpendiculairement à l'axe de la fibre au niveau des extrémités d'entrée et de sortie de chaque échantillon.

8 Procédure

Voir l'Annexe A, l'Annexe B, l'Annexe C et l'Annexe D pour les méthodes A, B, C et D, respectivement.

9 Calculs

9.1 Méthodes A et B

Les méthodes A, fibre coupée, et B, perte d'insertion, utilisent les Formules (1) et (2) données en 3.1.1 et 3.1.2, respectivement.

9.2 Méthode C

Voir l'Annexe C.

9.3 Méthode D

Voir l'Annexe D.

10 Résultats

10.1 Informations à fournir pour chaque mesurage

Consigner les informations suivantes avec chaque mesurage:

- la date et le titre du mesurage;
- l'identification du spécimen;
- la longueur d'onde de la source optique;
- la longueur du spécimen;
- l'affaiblissement spectral, en dB, ou l'affaiblissement linéique, en dB/km, en fonction de la longueur d'onde ou à une ou plusieurs longueurs d'onde spécifiques, comme l'exige la spécification applicable.

10.2 Informations à fournir sur demande

Les informations suivantes doivent être fournies sur demande:

- la méthode de mesure utilisée: A, B, C ou D;
- le type de source optique utilisée: la ou les longueurs d'onde centroïdales et la ou les largeurs spectrales;
- la technique et les conditions d'injection utilisées;
- l'indication concernant l'utilisation d'une fibre qui couvre la zone morte (uniquement pour la méthode C);
- la description de tous les équipements clés;
- pour les fibres de type B: les dimensions et le nombre de spires du filtre de modes ou de l'embrouilleur de modes;
- la ou les durées d'impulsion, la ou les plages d'échelle et les détails de calcul de la moyenne du signal;
- les informations détaillées de la technique de calcul (méthode de calcul);
- tout écart par rapport à la procédure;
- la date du dernier étalonnage de l'équipement de mesure.

10.3 Informations supplémentaires spécifiques aux méthodes

Pour les méthodes C et D, se reporter aux exigences supplémentaires indiquées à l'Article C.6 et à l'Article D.6, respectivement. Ceci s'applique en particulier lorsque la méthode C est utilisée pour mesurer des discontinuités ponctuelles.

11 Informations à mentionner dans la spécification

La spécification applicable doit préciser les informations suivantes:

- le type de fibre (ou de câble) à mesurer;
- les critères de défaillance ou d'acceptation à la longueur d'onde ou dans la plage de longueurs d'onde;
- tout écart par rapport à la procédure applicable;
- les informations à consigner.

Annexe A (normative)

Exigences spécifiques à la méthode A – Fibre coupée

A.1 Généralités

La technique de la fibre coupée est la seule méthode directement dérivée de la définition de l'affaiblissement de fibre, dans laquelle les niveaux de puissance, $P_1(\lambda)$ et $P_2(\lambda)$, sont mesurés en deux points de la fibre sans modification des conditions d'entrée. $P_2(\lambda)$ est la puissance qui sort de l'extrémité de la fibre et $P_1(\lambda)$ est la puissance qui sort d'un point situé à proximité de l'entrée lorsque la fibre est coupée. Cela explique pourquoi cette méthode est largement acceptée comme méthode d'essai de référence pour l'affaiblissement.

Le principe du mesurage ne permet pas de fournir une indication quant au comportement de l'affaiblissement le long de la fibre. Il rend également difficile le mesurage des variations de l'affaiblissement lorsque les conditions ne sont pas stables. Dans certaines circonstances, la nature destructive de cette méthode est un inconvénient.

A.2 Appareillage

A.2.1 Appareillage général pour toutes les fibres

A.2.1.1 Généralités

La Figure A.1 et la Figure A.2 représentent des schémas de montages d'essai appropriés.

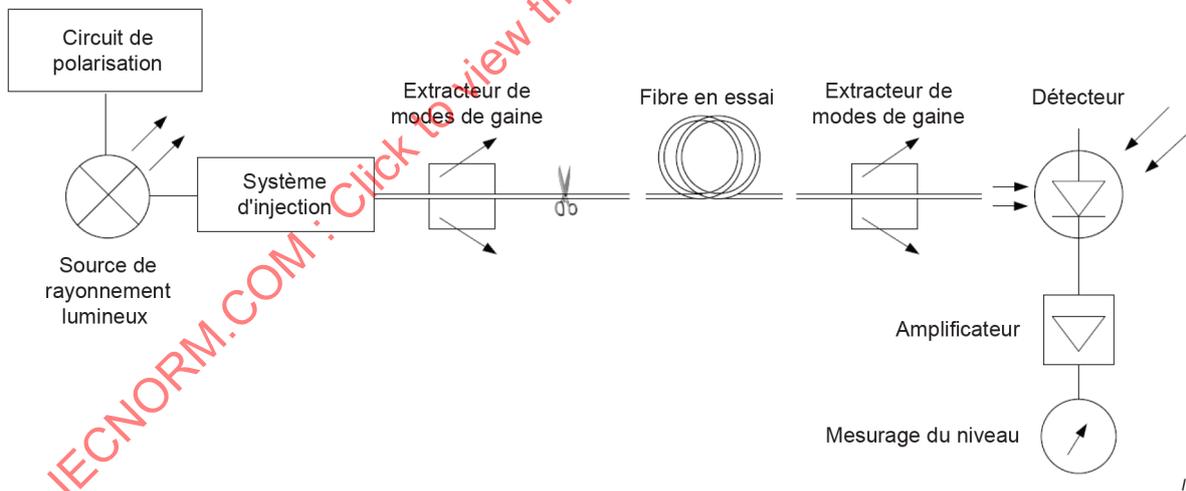


Figure A.1 – Disposition de l'équipement de mesure des pertes à une longueur d'onde spécifiée

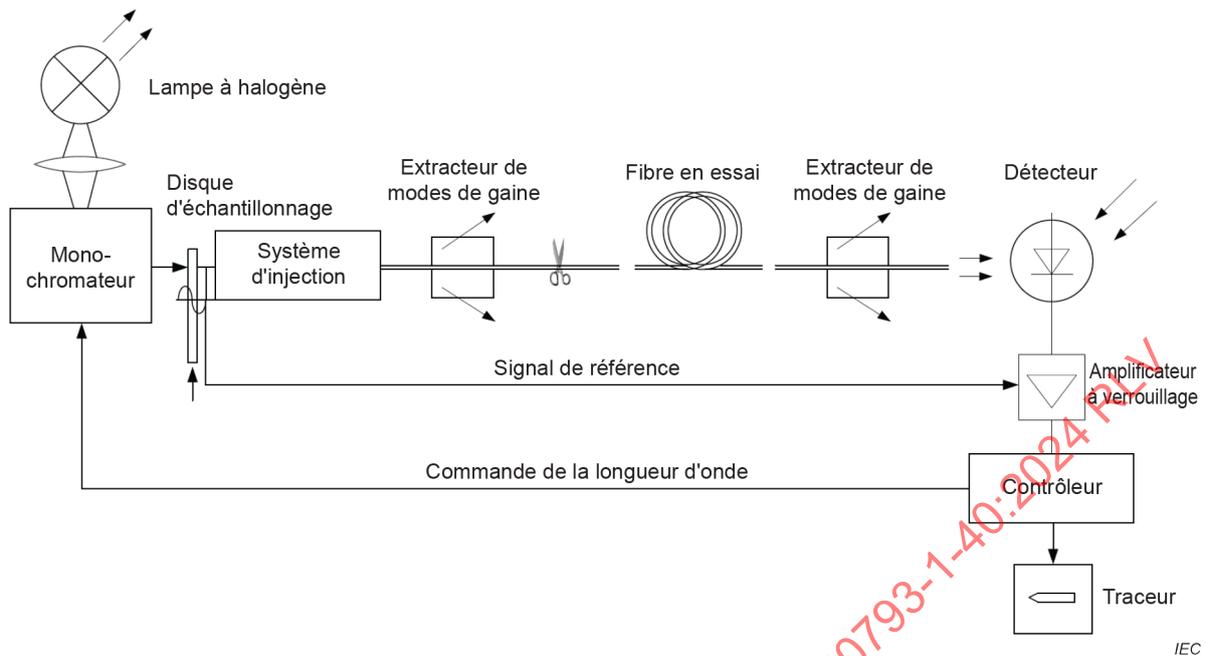


Figure A.2 – Disposition de l'équipement utilisé pour obtenir le spectre des pertes

A.2.1.2 Montage général d'injection

La Figure A.3 représente le montage général d'injection utilisé pour toutes les fibres. Des informations détaillées sont présentées de A.2.2 à A.2.4 en ce qui concerne les catégories spécifiques de fibres unimodales et multimodales.

A.2.1.3 Source optique

Utiliser une source de rayonnement appropriée, telle qu'une lampe, un laser ou une diode électroluminescente. Le choix de la source dépend du type de mesure. La source doit avoir une position, une intensité et une longueur d'onde stables pendant une durée suffisamment longue pour terminer la procédure de mesure. Spécifier la largeur de raie spectrale (entre les points à 50 % de l'intensité de la puissance optique des sources utilisées) de sorte que la raie soit étroite, par exemple inférieure à 10 nm par rapport à une quelconque caractéristique d'affaiblissement spectral de la fibre. Aligner la fibre sur le cône d'injection, ou connecter la fibre à une fibre d'injection.

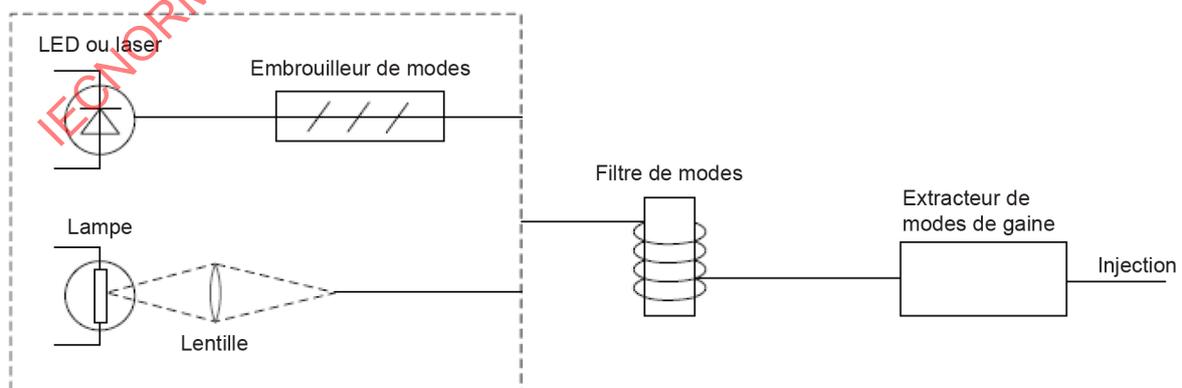


Figure A.3 – Montage général d'injection

A.2.1.4 Longueur d'onde de la source

Les mesurages peuvent être effectués à une ou plusieurs longueurs d'onde. En variante, une réponse spectrale peut être obtenue sur une plage de longueurs d'onde donnée.

A.2.1.5 Ensemble de détection optique

Un moyen doit être prévu pour coupler la totalité de la puissance émise par le spécimen vers la zone active du détecteur. Par exemple, un système de lentilles optiques, une épissure en bout à une fibre amorce ou un couplage direct avec le détecteur peut être utilisé(e). Si le détecteur est déjà équipé d'une fibre amorce, le diamètre du cœur et l'ouverture numérique de la fibre amorce doivent être suffisamment larges pour capturer tout le rayonnement lumineux sortant des fibres de référence et des spécimens de fibres.

Utiliser un détecteur optique linéaire et stable sur la plage des intensités et des durées de mesure rencontrées au cours du mesurage. Un système type peut inclure une photodiode en mode photovoltaïque amplifiée par un amplificateur de courant en entrée, avec détection synchrone par un amplificateur à verrouillage.

A.2.1.6 Traitement du signal

Il est d'usage de moduler la source de rayonnement lumineux pour améliorer le rapport signal/bruit au niveau du récepteur. Si un tel procédé est utilisé, lier le détecteur à un système de traitement du signal synchronisé sur la fréquence de modulation de la source. Il convient que le système de détection soit essentiellement linéaire ou qu'il ait été complètement caractérisé avec une fonction de réponse.

A.2.1.7 Extracteur de modes de gaine

Utiliser des techniques appropriées pour supprimer la puissance optique qui se propage dans la gaine dès lors qu'elle risque de considérablement influencer sur le signal reçu.

A.2.2 Appareillage d'injection pour toutes les fibres unimodales

A.2.2.1 Généralités

Un système de lentilles optiques ou une fibre amorce peuvent être utilisés pour exciter la fibre d'essai. La puissance couplée dans la fibre doit être stable pendant toute la durée du mesurage. Voir la Figure A.1.

A.2.2.2 Fibre amorce

Si une fibre amorce est utilisée, il peut être nécessaire d'utiliser une substance adaptatrice d'indice entre la fibre amorce source et la fibre d'essai afin d'éliminer les phénomènes d'interférence.

A.2.2.3 Système de lentilles optiques

Si un système de lentilles optiques est utilisé, prévoir un moyen pour maintenir de manière stable l'extrémité d'entrée de la fibre, par exemple un plateau de serrage à vide. Monter ce support sur un dispositif de positionnement de sorte que l'extrémité de la fibre puisse être positionnée de manière répétée dans le faisceau d'entrée. Une méthode qui vise à réduire la sensibilité vis-à-vis du positionnement de la fibre consiste à saturer spatialement et angulairement l'extrémité de la fibre.

A.2.2.4 Filtre de modes d'ordre élevé

Utiliser une méthode pour supprimer les modes de propagation d'ordre élevé dans la plage de longueurs d'onde concernée. Un exemple de tel filtre de modes d'ordre élevé est une seule boucle de rayon suffisamment faible pour décaler la longueur d'onde de coupure sous la longueur d'onde minimale concernée. Pour les fibres unimodales insensibles aux pertes par courbure, plusieurs boucles de rayon plus faible ou un spécimen de fibre coupée plus long peuvent être utilisés. Il convient de veiller à ce que le rayon ne soit pas faible au point d'induire des oscillations qui dépendent de la longueur d'onde. Il convient de tenir compte de l'augmentation de la longueur du spécimen de fibre coupée dans le calcul de l'affaiblissement.

A.2.2.5 Extracteur de modes de gaine

L'extracteur de modes de gaine assure qu'aucun mode de rayonnement, se propageant dans la région de la gaine, n'est détectable après une courte distance le long de la fibre. L'extracteur de modes de gaine est souvent constitué d'un matériau dont l'indice de réfraction est supérieur ou égal à celui de la gaine de la fibre. Il peut s'agir d'un fluide d'adaptation d'indice appliqué directement à la fibre non revêtue à proximité de ses extrémités. Dans certains cas, le revêtement de la fibre assure cette fonction.

A.2.3 Appareillage d'injection pour les fibres multimodales A1

A.2.3.1 Généralités

Les conditions d'injection sont d'une importance capitale pour satisfaire aux objectifs définis à l'Article 1. Elles sont définies pour empêcher d'injecter de la puissance dans des modes transitoires d'ordre supérieur. En n'injectant pas de puissance dans ces modes transitoires de la fibre d'essai, les affaiblissements, s'additionnant alors de façon approximativement linéaire, sont mesurés. Étant donné que ces répartitions de puissance ne sont quasiment pas altérées par la fibre, elles sont appelées "répartitions à l'état stable".

Deux techniques sont communément utilisées pour créer des conditions d'injection stables pour les mesurages de l'affaiblissement: en utilisant des filtres de modes ou en réalisant l'injection par système optique géométrique. Lorsqu'elles sont réalisées avec soin, ces deux techniques donnent des résultats comparables.

Veiller à ce que la répartition des modes tienne compte de la longueur des spécimens. Pour les câbles à fibres multimodales A1 courts (moins de 1 km), il est possible que la répartition des modes n'atteigne pas un état stable. Ceci entraîne une augmentation des valeurs d'affaiblissement pour les longueurs de fibres plus courtes, dans lesquelles l'importance de la dépendance à la longueur dépend du type de fibre, de la condition d'injection, etc. Dans ces cas, il convient que les valeurs d'affaiblissement soient obtenues avec des câbles suffisamment longs pour atteindre un état stable, ou les valeurs d'affaiblissement peuvent être celles du câble plus long dans lequel elles ont été prélevées. Les exemples de résultats d'essai sur des câbles pour des fibres multimodales A1 présentés à l'Annexe E constituent des recommandations sur les longueurs de câbles suffisantes.

La Figure A.3 représente un exemple générique de montage d'injection qui utilise un filtre de modes. Des exemples de chaque filtre de modes sont donnés ci-dessous.

A.2.3.2 Exemples de filtres de modes

A.2.3.2.1 Filtre de modes par fibre inerte

Choisir une fibre de type similaire à celui de la fibre d'essai. Il convient que la fibre soit suffisamment longue (généralement supérieure ou égale à 1 km) pour que la répartition de la puissance transmise par cette fibre soit à l'état stable, lorsque la source d'injection utilisée est celle de A.2.1.2.

A.2.3.2.2 Filtre de modes du type enroulement sur mandrin

Un autre type de filtre de modes se présente sous la forme d'un mandrin autour duquel quelques spires (généralement trois à cinq spires) de la fibre en essai sont réalisées avec une faible tension. Choisir le diamètre du mandrin de manière à assurer que les modes transitoires excités dans la fibre d'essai ont été atténués jusqu'à obtenir un état stable. Effectuer un mesurage en champ lointain pour comparer la répartition de puissance en sortie d'une grande longueur de la fibre d'essai (supérieure à 1 km), lorsqu'elle est excitée par une source qui assure une saturation uniforme, avec la répartition de puissance en sortie d'une courte longueur de la fibre lorsque le mandrin est appliqué. Choisir le diamètre du mandrin de manière à obtenir une répartition de puissance en champ lointain dans la courte longueur qui correspond approximativement à la répartition de puissance en champ lointain dans la grande longueur de fibre.

L'ouverture numérique (mesurée selon la méthode de l'IEC 60793-1-43) du diagramme de rayonnement en sortie de la courte longueur doit être comprise entre 94 % et 100 % de l'ouverture numérique du diagramme qui correspond à la grande longueur.

Le diamètre du mandrin peut être différent d'une fibre à l'autre, en fonction du type de fibre et de revêtement. Des diamètres dans la plage comprise entre 15 mm et 40 mm, avec cinq spires de fibre réalisées dans une longueur de mandrin de 20 mm sont couramment prescrits. Bien que des mandrins de tailles et de dispositions différentes puissent être sélectionnés, le Tableau A.1 donne des tailles courantes de mandrin pour des fibres de différents diamètres du cœur.

Tableau A.1 – Exemples de tailles de mandrin

Diamètre du cœur μm	Diamètre du mandrin mm
50	25
62,5	20
100	25

A.2.3.3 Exemple d'injection par système optique géométrique

Une injection à espace de phase limité (LPS – *limited phase space*) est définie comme une injection produite de manière géométrique qui remplit uniformément 70 % du diamètre du cœur et 70 % de l'ouverture numérique de la fibre d'essai. Il s'agit de la répartition de puissance géométrique maximale injectée qui n'injecte pas de puissance dans les modes évanescents. Dans le cas d'une fibre multimodale à gradient d'indice 50/125 μm, d'ouverture numérique 0,2, les conditions d'injection LPS correspondent à un diamètre de champ uniforme de 35 μm et à une ouverture numérique de 0,14.

La Figure A.4 est un exemple de système optique nécessaire pour produire l'injection LPS. Il est important d'assurer que l'axe du faisceau d'injection coïncide avec celui de la fibre, de manière que le champ et le cône de rayonnement lumineux incident soient centrés sur le cœur de la fibre. Installer également le système optique aux longueurs d'onde de fonctionnement, afin de garantir un mesurage correct. Bien que des mandrins de tailles et de dispositions différentes puissent être sélectionnés, le Tableau A.1 donne des tailles courantes de mandrin pour des fibres de différents diamètres du cœur.