

INTERNATIONAL STANDARD



**Optical fibres –
Part 1-47: Measurement methods and test procedures – Macrobending loss**

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**Optical fibres –
Part 1-47: Measurement methods and test procedures – Macrobending loss**

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OPTICAL FIBRES –

Part 1-47: Measurement methods and test procedures – Macrobending loss

FOREWORD

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International Standard IEC 60793-1-47 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This fourth edition cancels and replaces the third edition published in 2009. It constitutes a technical revision.

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

- a) former Annex A has been renumbered to Annex D;
- b) introduction of new Annex A on the transmitted power monitoring technique;
- c) introduction of Annex B on the cut-back technique;
- d) introduction of Annex C on the requirements for the optical source characteristics of A1 multimode measurement;
- e) introduction of Annex E on parallel plate (2-point) macrobend loss approximation.

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

FDIS	Report on voting
86A/1823/FDIS	86A/1828/RVD

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

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

This standard is to be read in conjunction with IEC 60793-1-1:2017.

A list of all parts of 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 "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

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

Within the same series, several different areas are grouped, but all numbers are possibly not used, as follows:

Parts 1-10 to 1-19:	General
Parts 1-20 to 1-29:	Measurement methods and test procedures for dimensions
Parts 1-30 to 1-39:	Measurement methods and test procedures for mechanical characteristics
Parts 1-40 to 1-49:	Measurement methods and test procedures for transmission and optical characteristics
Parts 1-50 to 1-59:	Measurement methods and test procedures for environmental characteristics

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OPTICAL FIBRES –

Part 1-47: Measurement methods and test procedures – Macrobending loss

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the macrobending loss of single-mode fibres (category class B) at 1 550 nm or 1 625 nm, category A1 multimode fibres at 850 nm or 1 300 nm, and category A3 and A4 multimode fibres at 650 nm, 850 nm or 1 300 nm, thereby assisting in the inspection of fibres and cables for commercial purposes.

This document gives two methods for measuring macrobending sensitivity:

- Method A – Fibre winding, pertains to category class B single-mode fibres and category A1 multimode fibres.
- Method B – Quarter circle bends, pertains to category A3 and A4 multimode fibres.

For both of these methods, the optical power is measured using either the macrobending loss can be measured utilizing general fibre attenuation techniques, for example the power monitoring technique (see Annex A) or the cut-back technique (see Annex B). Methods A and B are expected to produce different results if they are applied to the same fibre. This is because the key difference between the two methods is the deployment, including the bend radius and amount length of fibre that is bent. The reason for the difference is that A3 and A4 multimode fibres are expected to be deployed in short lengths with relatively fewer a smaller number of bends per unit fiber length compared to single-mode and category A1 multimode fibres.

In this document, the "curvature radius" is defined as the radius of the suitable circular shaped support (e.g. mandrel or guiding groove on a flat surface) on which the fibre can be bent.

In addition, informative Annex E has been added to approximate bend loss for class B single-mode fibres across a broad wavelength range at various effective bends.

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 (all parts), *Optical fibres – Measurement methods and test procedures*

IEC 60793-1-1:2017, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

~~IEC 60793-1-40: Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation~~

~~IEC 60793-1-46: Optical fibres – Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance~~

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-2, IEC 60793-1 (all parts) and IEC 60793-1-1 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>

NOTE General definitions for fibres are provided in IEC 60793-2, definitions of the specified attributes are contained in the relevant test methods standard of IEC 60793-1 (all parts), and general definitions for testing are provided in IEC 60793-1-1.

4 Apparatus

4.1 Method A – Fibre winding

The apparatus consists of a tool (e.g. a mandrel or a guiding groove on a flat surface) able to hold the sample bent with a radius as stated in the **appropriate optical fibre sectional product specification** (~~e.g. 30 mm for single mode fibres and 37,5 mm for multimode fibres~~) and a loss measurement instrument. Determine the macrobending loss at the wavelength as stated in the **appropriate sectional product specification** (~~e.g. 850 nm or 1 300 nm for multimode fibres, 1 550 nm or 1 625 nm for single mode fibre~~) by using either the transmitted power monitoring technique (~~method A of IEC 60793-1-46 Annex A~~) or the cut-back technique (~~method A of IEC 60793-1-40 Annex B~~), taking care of the appropriate launch condition for the specific fibre type.

4.2 Method B – Quarter circle bends

The apparatus consists of one or more plates, each containing one or more "guide grooves", and a loss measurement instrument. The plates shall be designed to be stacked during the test without contacting the sample fibre in a lower or higher plate; such contact will affect the measurement results. Each guide groove shall have a quarter circle segment (i.e. 90°) as shown in Figure 1. The bend radius r , i.e. the radius of the quarter circle segment, shall be stated in the detail specification. The width of each guide groove ~~shall be at least 0,4 mm greater than the diameter of the fibre~~ is recommended to be 40 % broader than the outer fibre diameter.

Determine the macrobending loss at the wavelength as stated in the **appropriate sectional product specification** (~~e.g. 650 nm, 850 nm, or 1 300 nm~~) by using either the transmitted power monitoring technique (~~method A of IEC 60793-1-46 Annex A~~) or the cut-back technique (~~method A of IEC 60793-1-40 Annex B~~), taking care of the appropriate launch condition for the specific fibre type.

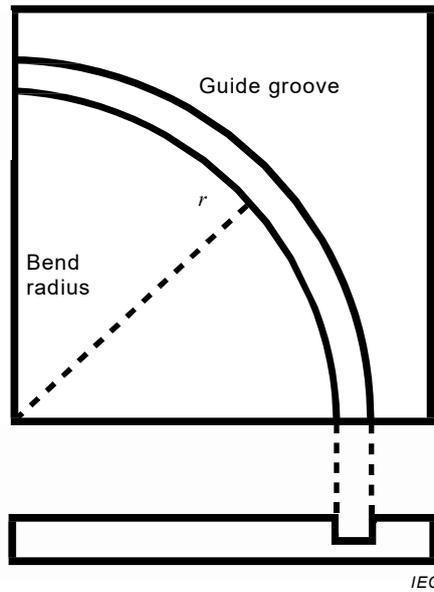


Figure 1 – Quarter circle guide groove in plate

4.3 Input system

4.3.1 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 less than 10 nm, compared with any features of the fibre spectral attenuation. Align the fibre to the launch cone, or connect it coaxially to a launch fibre.

4.3.2 Optical launch arrangement

4.3.2.1 General

Figure 2 shows the general launch arrangement used for all fibres. Apply the appropriate launch arrangement to produce a full or restricted launch, depending on the parameter being measured. See 4.3.2.3 to 4.3.2.4 for further details as they apply to specific categories of single-mode and multimode fibres.

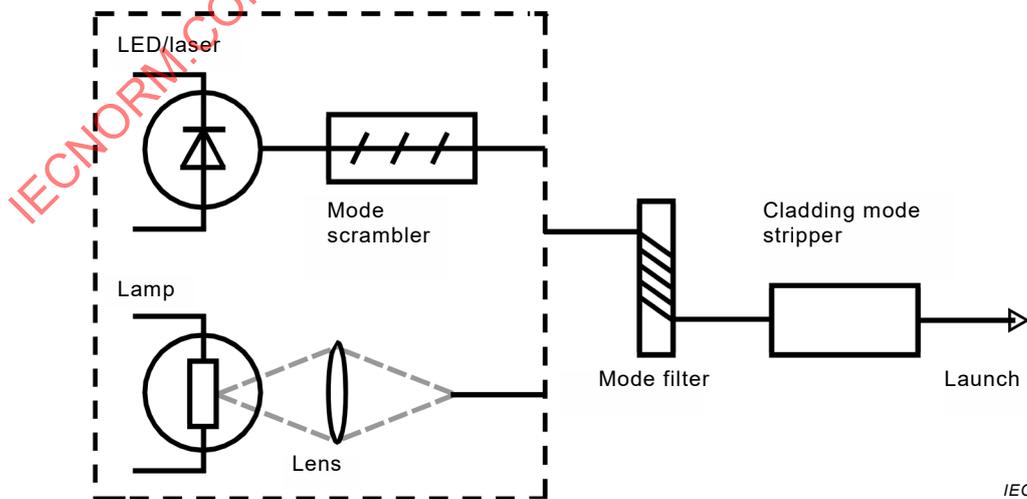


Figure 2 – General launch arrangement

4.3.2.2 Launch arrangement for single-mode fibres

4.3.2.2.1 General

An optical lens system or fibre pigtail may 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 or Figure B.1).

4.3.2.2.2 Fibre pigtail

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

4.3.2.2.3 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.

4.3.2.2.4 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, but not so small as to induce wavelength-dependent oscillations.

Another option commonly employed on bend insensitive single mode fibres and other single mode fibres with little or no cut-off response to bend is the use of a standard single mode fibre as a mode filter.

4.3.2.2.5 Cladding mode stripper

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

4.3.2.3 Launch arrangement for A1 multimode fibres

The required launch for measuring the macrobending loss of A1 multimode fibres shall be an encircled flux launch. The requirements for the optical source characteristics for A1 multimode measurement are included in Annex C.

The encircled flux emitted by the launching cord depends on the characteristic of the light source emerging from the face of the socket, the connection of the launching cord to the socket, the optical fibre within the launch cord, and any applied mode conditioning.

The test equipment manufacturer should provide specifications for the test cord that are compatible with the particular source implementation used. When the specification on the cord is met and used with the test equipment, the encircled flux (EF) requirements should be assured.

4.3.2.4 Launch arrangements for A2 to A4 multimode fibres

Below are some examples of generic launching arrangements for short-distance fibres described in Figure 3, Figure 4 and Figure 5.

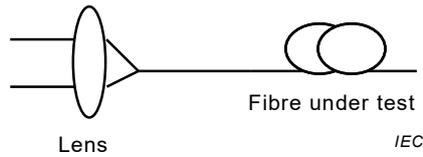


Figure 3 – Lens system

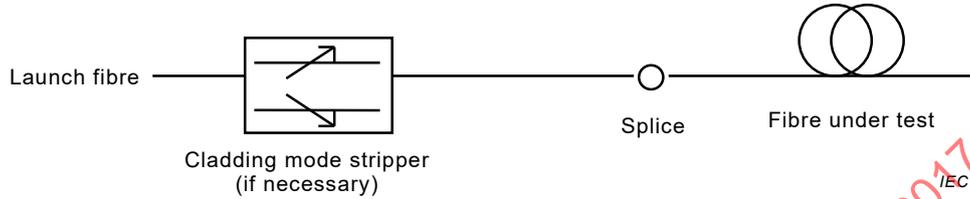


Figure 4 – Launch fibre

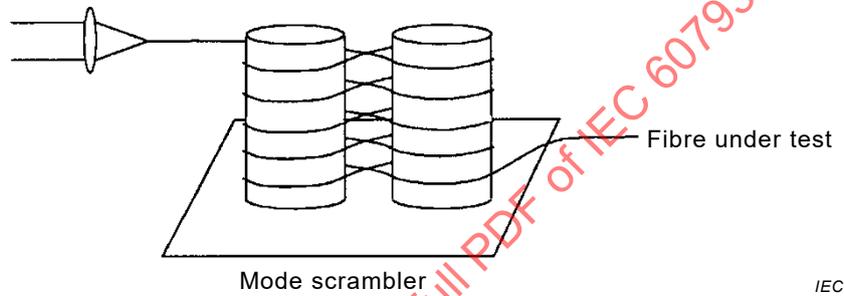


Figure 5 – Mode scrambler (for A4 fibre)

The reproducibility of the attenuation measurements of step-index 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 able to provide spot sizes and launch numerical apertures (NAs) as given in Table 1. In addition, the measurement wavelength shall be calibrated to within ± 10 nm.

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Table 1 – Launch conditions for A2 to A4 fibres

Attribute	Fibre category		
	A2 Glass core/glass cladding	A3 Glass core/plastic cladding	A4 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 ^a	= fibre max NA ^b	= fibre max NA, with full mode launch ^b
<p>^a This launch condition can be produced by overfilling a mode filter made from 2 m of fibre identical to the fibre under test (FUT), with appropriate cladding mode stripping and using the output from this mode filter to launch into the FUT.</p> <p>^b This launch condition can be produced in the same manner as described in Note a. However, some types of A3 and A4 fibre will not require cladding mode stripping for the mode filter.</p>			

4.4 Output system and detection

4.4.1 Optical divider

When an optical divider is required, it shall have a splitting ratio that remains constant during the test. The splitting ratio and temperature stability shall be as shown in the relevant detail specification. Commercially available or custom built devices may be used.

4.4.2 Optical detector

The optical detector shall be of sufficient area to intercept all of the radiated power in the output cone and shall be sufficiently linear over the optical powers encountered.

The optical detector shall have a sufficiently uniform response over the active area and range of incidence angle at the measurement wavelength to ensure the movement of the output cone in position or angle relative to the detector. This shall be within the limits determined by the mechanical design of the measurement equipment and shall not significantly affect the results.

Where more than one detector is used, as in the arrangement shown in Figure A.1, the detectors shall be of the same manufacturer and model and be of comparable linearity.

4.4.3 Optical detection assembly

All power emitted from the specimen should be coupled to the active region of the detector by an appropriate means. For example, an optical lens system, a butt spliced fibre pigtail, or direct coupling to the detector may 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 can include a photovoltaic mode photodiode amplified by a current input amplifier, with synchronous detection by a lock-in amplifier.

4.4.4 Signal processing

It is customary to modulate the light source in order to improve the signal-to-noise ratio (SNR) 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 known characteristics.

When low loss is expected, more test bends may be added provided there are separate grooves for each additional bend to improve the SNR; however, the approximation of the bend diameter along with the bend control may be further degraded.

5 Specimen

5.1 Specimen length

5.1.1 Method A – Fibre winding

The specimen shall be a known length of fibre, as specified in the detail specification. In particular, the length of the sample tested for loss is determined by the measurement set-up, i.e. curvature radius (R) and number of turns (N); any further fibre length does not affect the measurement results, provided that the ~~signal to noise (S/N) ratio~~ SNR is optimised.

5.1.2 Method B – Quarter circle bends

The specimen length shall be determined according to the details shown in 6.2.

5.2 Specimen end face

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

6 Procedure

6.1 Method A – Fibre winding

6.1.1 General consideration

Loosely wind the fibre on the tool, avoiding excessive fibre twist. The number of turns, curvature radius and wavelength at which loss is to be measured are discussed below in 6.1.1 and in 6.1.2 and 6.1.3.

Since the actual curvature radius is critical, a maximum tolerance of $\pm 0,1$ mm (for radii lower than or equal to 15 mm) or \pm ~~0,5 mm to~~ 1,0 mm (for larger radii) is accepted: a tighter tolerance on small radii is required for higher measurement sensitivity.

Both for single-mode and for multimode fibres, two optical powers can be measured using

- the power-monitoring technique, which measures the fibre attenuation increase due to a change from the straight condition to a bent condition, or
- the cut-back technique, which measures the total attenuation of the fibre in the bent condition. In order to determine the induced attenuation due to macrobending, this value should be corrected for the intrinsic attenuation of the fibre.

The fibre length outside the mandrel and the reference cut-back length shall be free of bends that ~~might can~~ introduce a significant change in the measurement result. ~~Collection of excess fibre in a bend radius of at least 140 mm is recommended.~~

It is also possible to rewind the fibre from a mandrel with a large radius (introducing negligible macrobend loss) to the mandrel with the required radius. In this case, the macrobend loss can be determined directly by using the power-monitoring technique (without the correction for the intrinsic attenuation of the fibre).

Care ~~must shall~~ be taken in order not to introduce torsion on any fibre part during the measurements, as this would affect the result.

6.1.2 Single-mode fibres

Different applications may require different deployment conditions: fibre types have been developed which exhibit bending performances optimised for each condition.

Two typical environments are recognised for (possibly) different fibre types, for which different measurement set-ups should be considered when characterising fibre performances.

- a) Long distance networks: far from urban areas, space occupancy is not typically an issue, and bends imposed on the fibres can be limited to relatively large radii. Fibres designed for this application should be tested in similar conditions, i.e. with the samples wrapped around relatively large radius mandrels, for example in the range 25 mm to 30 mm.

This measurement set-up is mainly affected by errors related to low ~~S/N ratio~~ SNR and by unwanted tension, torsions or kinks on the relatively long fibre length used for the measurement.

- b) Access networks: operating conditions require bending radii as small as possible, compatible with lifetime expectations and acceptable bend losses. For more information on lifetime expectations please refer to ITU-T G Suppl.59:2016. Fibres designed for this application should be tested in similar conditions, i.e. with the samples bent at small radii, for example in the range 7,5 mm to 15 mm (see Annex C).

The measurement can be affected by different sources, i.e. reflections, which may occur at the coating-air or coating-glass interface, at surrounding surfaces (including, when used, the mandrel surface), or at connectors.

The test can be carried out on samples either making complete (360°) turn(s), in open air or around a suitable support (mandrel), or making an equivalent number of partial turns, for example U-turns (180°) or quarter turns (90°), in open air or around suitable supports. The length under test is different for complete and partial turns; for example, the length of a complete turn being twice the length of a U-turn or four times the length of a quarter turn. In this document, the term "coil" refers to one complete turn. One coil could also be made of, for example, two consecutive U-turns¹ or four consecutive quarter turns. This should be taken into account while normalising the results to the length of the sample (number of coils).

The following recommendations apply to test conditions in both cases (items a) and b) above):

Number of turns

- The number of turns should be in accordance with the values stated in the product specification.
- For single-mode fibres, the attenuation increases in a linear fashion with the number of turns.
- For each radius, the number of turns shall be chosen in such a way that:
 - the induced loss is significantly higher than the detection limit of the set-up; when necessary, for example for low bend loss fibres, tests may be carried out with more turns than the specification requires – followed by linear normalization to the specified number;
 - the induced loss is significantly lower than the onset of the non-linear region in the set-up; for bending radii in the range 5 mm to 10 mm, this may imply that not more than 5 to 10 turns should be used.

Bend radius

The value of bend radius shall be in accordance with the values stated in the product specification².

Wavelength

The measurement wavelength shall be 1 550 nm or 1 625 nm, in accordance with the relevant product specification; it should be considered that bending losses increase exponentially with the wavelength.

NOTE The homogeneity of bend loss in different angular positions over the cross section needs to be verified either by multiple angular position tests or by verifying the homogeneity of the effective refractive index profile, establishing the guiding properties of the bent FUT.

6.1.3 Multimode (A1) fibres

Macrobending loss in A1 multimode fibres varies with bend radius and number of turns around a mandrel, ~~but is rather independent of the measuring wavelength, except for possible~~ and is

¹ If there is excessive displacement between successive U-turns, the length of the sample arranged on two U-turns can be shorter than one coil. A maximum displacement between adjacent U-turns of 0,5 mm is therefore suggested.

² Bending loss on single-mode fibre increases exponentially as wavelength increases and as radius decreases (see Annex D).

less sensitive to wavelength than with single-mode fibres. Still, oscillating effects with wavelength may occur which are related to successive mode groups passing cut-off and having increased bend loss at these wavelengths.

The values of bend radius and number of turns shall be in accordance with the values stated in the specification. When testing multiple turns, the attenuation that occurs over a specific turn depends on the attenuation of the preceding turns. The incremental macrobending added loss decreases with each added turn. Macrobending added loss produced by multiple turns should not be expressed in the units of "dB/turn" by dividing the total added loss by the number of turns. Instead, it ~~must~~ shall be reported in dB for the specified number of bends. An extrapolation to more than the specified number of turns will result in an overestimation of the overall loss.

For multimode fibres only, the launching characteristics of the light source at the launching position of the fibre being tested shall be consistent with the expected fibre application. Further details on ~~MM~~ multimode launching conditions can be found in ~~IEC 61280-4-1~~ Annex C.

6.2 Method B – Quarter circle bends

This method applies to category A3 and A4 multimode fibres. The fibre to be tested should be carefully set in the guide groove(s) (see Figure 1). The beginning of each controlled bend shall be s metres apart from the beginning of the next controlled bend. The beginning of the controlled bend closest to the launch end shall be 1 m from the launch. The end of the controlled bend closest to the detector end shall be 1 m from the detector (see Figure 6).

The minimum specimen length shall be determined according to Equations (1) and (2).

$$L = (n - 1) \times s + 2 \quad (1)$$

$$s = \frac{3}{2} \pi \times R + 2 \times R \quad (2)$$

where

- L is the minimum sample length, in m;
- n is the number of quarter-turn bends;
- s is the interval between each bend, in m;
- R is the slack bend radius, in m.

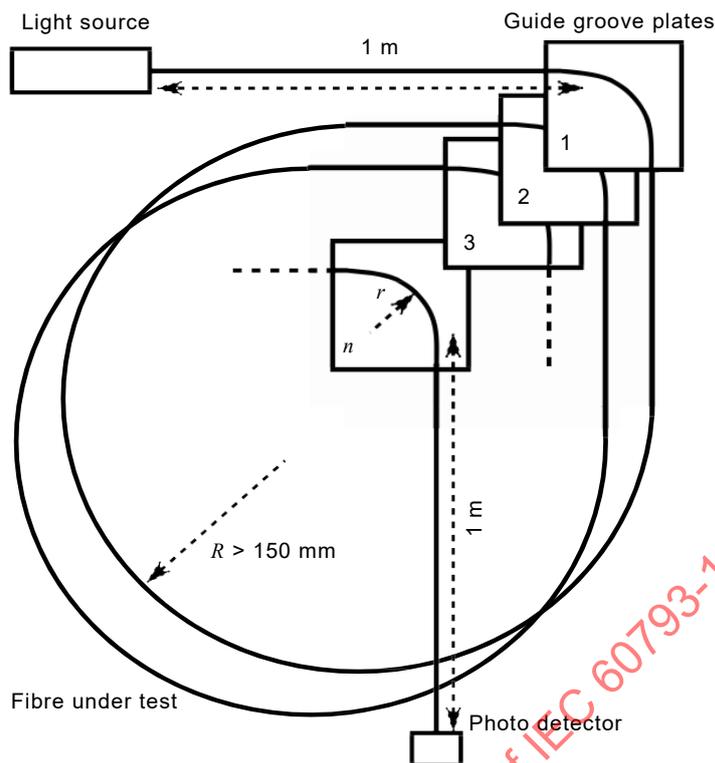


Figure 6 – Multiple bends using stacked plates

Macrobending loss caused by multiple bends of various radii can be measured simultaneously by stacking plates cut with grooves of various specified bend radii (see Figure 6).

Unless otherwise specified in the detail specification, the default values for the test are as follows:

- macrobend radius: $r = 25$ mm;
- number of macrobends: $n = 10$;
- slack bend radius, $R \geq 150$ mm;
- wavelengths: 650 nm, 850 nm or 1 300 nm.

These parameters correspond to the interval between each macrobend being $s \geq 1$ m, and a sample length $L \geq 11$ m.

The added fibre loss caused by bending shall be measured using either the transmitted power monitoring technique (~~method A of IEC 60793-1-46 Annex A~~) or the cut-back technique (~~method A of IEC 60793-1-40 Annex B~~). Use cladding mode strippers at the source and detector ends of the specimen. A suitable cladding mode stripper consists of three turns of the FUT around a 15 mm radius mandrel.

Perform the test using the following procedure:

- cut the fibre to the appropriate length and wrap it on a spool or lay it on a flat surface so that the fibre has a bend radius ≥ 150 mm;
- measure the transmitted power;
- place the fibre in the measurement apparatus (Figure 1 and Figure 6);
- measure the transmitted power.

NOTE When testing multiple macrobends, such as using the default value of $n = 10$, the mode distribution encountered at a specific macrobend may depend on how many macrobends precede it. For example, the first bend ~~might~~ can influence the launch condition at the second bend, and the second bend ~~might~~ can influence the launch condition at the third bend, etc.

Consequently, the macrobending added loss at a given bend ~~may~~ can be different ~~than~~ from the macrobending added loss at another bend. In particular, the first bend ~~may~~ can have the largest influence on following bends. Consequently, the macrobending added loss produced by multiple bends should not be expressed in the units of "dB/bend" (by dividing the total added loss by the number of bends). Therefore, the specification for macrobend added loss should not be stated in the units of "dB/bend".

7 Calculations

The results are reported in dB as:

$$\gamma = 10 \log_{10} \left(\frac{P_{\text{str}}}{P_{\text{Bend}}} \right) \quad (3)$$

where

γ is the loss, in dB;

P_{str} is the power measured without the bend;

P_{Bend} is the power measured with the bend present³.

NOTE For single-mode fibre, the loss can be reported in dB/turn.

8 Results

8.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of specimen;
- length of specimen;
- curvature ~~radius~~ as ~~macro~~bend radius and measurement set-up (method A);
- macrobend radius (method B);
- number of turns (method A);
- number of macrobends (method B);
- wavelength(s) of interest;
- launching conditions (MM fibres only);
- macrobending loss (dB).

8.2 Information available upon request

The following information shall be available upon request:

- measurement method used: A or B;
- power measurement method: power monitoring or cut-back;
- description of measurement apparatus arrangement;
- details of computation technique;
- date of latest calibration of equipment.

9 Specification information

The detail specification shall specify the following information:

- type of fibre to be measured;

³ The power through the straight fibre can be calculated from the fibre attenuation coefficient, the length tested, and the output power of the source.

- launching conditions (MM fibres only);
- radius of curvature **as macrobend radius** (method A);
- macrobend radius (method B);
- number of turns (method A);
- number of macrobends (method B);
- failure or acceptance criteria;
- information to be reported;
- wavelength(s) of interest;
- any deviations ~~to~~ **from** the procedure that apply.

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Annex A (normative)

Change in transmittance by transmitted power technique

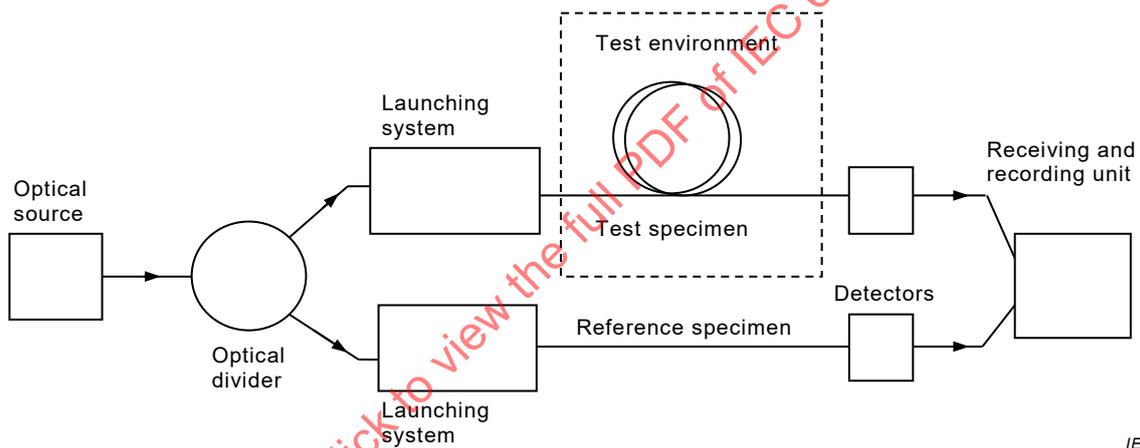
A.1 Apparatus

A.1.1 General

The arrangement shall provide a monitoring for optical transmittance with high resolution and good stability over the time and temperature changes given in the relevant product specification.

Figure A.1 is an example of a typical arrangement suitable for use when carrying out mechanical or environmental tests in a laboratory or factory. By comparison with a reference sample, it provides a measurement of the change in optical transmittance, corrected for any changes that can occur in the optical source. Connections shall have stable coupling conditions.

Figure A.2 is an example of a typical arrangement suitable for use in the field, laboratory or factory where long-term tests are required, in cases where it is possible to stabilise the optical source by optical feedback.



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Figure A.1 – Measurement of change in optical transmittance using reference specimen

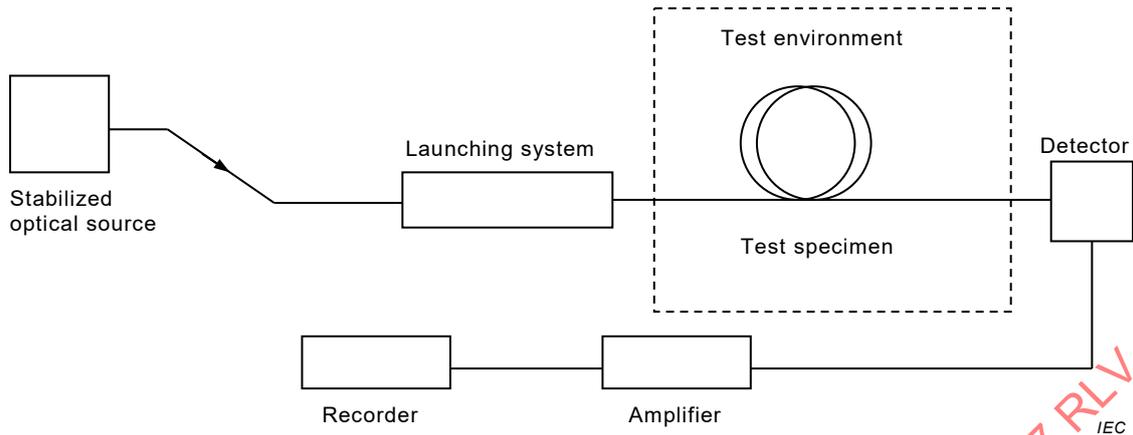


Figure A.2 – Measurement of change in optical transmittance using stabilized source

A.2 Procedure

Before the test sequence, measure the initial optical power, P_{0t} , from the test specimen and, in the case of Figure A.1, the initial optical output power, P_{0r} , from the reference specimen.

During the test sequence specified in the appropriate mechanical, environmental, or other test being carried out, measure the subsequent optical output powers, P_{nt} ($n = 1, 2, 3, \dots$), from the test specimen and, in the case of Figure A.1, the subsequent powers, P_{nr} , from the reference specimen.

In the above measurements, quantities proportional to the absolute power, rather than the absolute powers themselves, may be measured. In the case of Figure A.1, the proportionality factor may differ between the test and reference channels. The proportionality factor(s) shall remain constant for the duration of the test sequence.

A.3 Calculations

Calculate the changes in optical transmittance during the test sequence (in decibels).

According to Figure A.1:

$$D_n(\lambda) = 10 \log_{10} \frac{P_{0r}(\lambda) \times P_{nt}(\lambda)}{P_{0t}(\lambda) \times P_{nr}(\lambda)} \quad (\text{A.1})$$

According to Figure A.2:

$$D_n(\lambda) = 10 \log_{10} \frac{P_{nt}(\lambda)}{P_{0t}(\lambda)} \quad (\text{A.2})$$

where

$D_n(\lambda)$ is the change in optical transmittance during the sequence, in dB at wavelength λ ;

$P_{0t}(\lambda)$ is the initial optical output power from the test specimen, in mW;

$P_{0r}(\lambda)$ is the initial optical output power from the reference specimen, in mW;

$P_{nt}(\lambda)$ is the subsequent optical output power from the test specimen, in mW;

$P_{nr}(\lambda)$ is the subsequent optical output power from the reference specimen, in mW;

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Annex B (normative)

Cut-back technique

B.1 General

The cut-back technique is 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.

B.2 Apparatus

B.2.1 General apparatus for all fibres

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

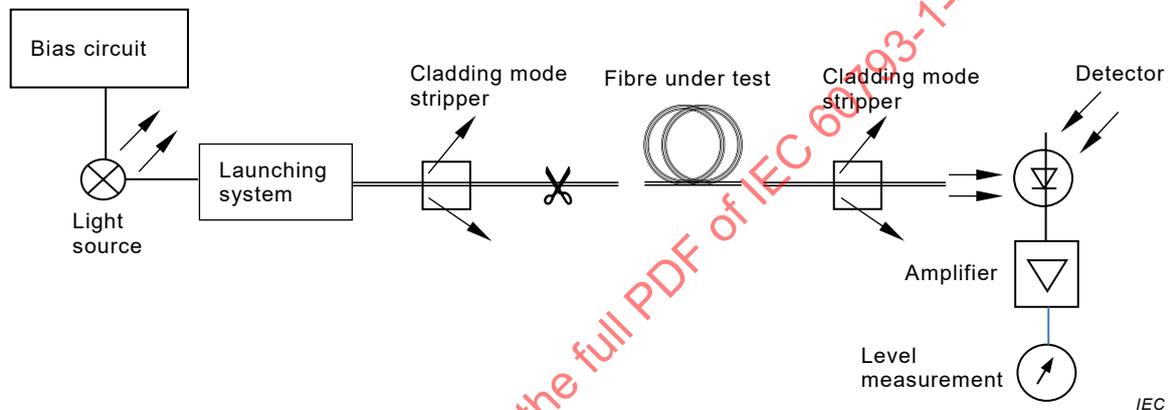


Figure B.1 – Arrangement of equipment to perform loss measurement at one specified wavelength

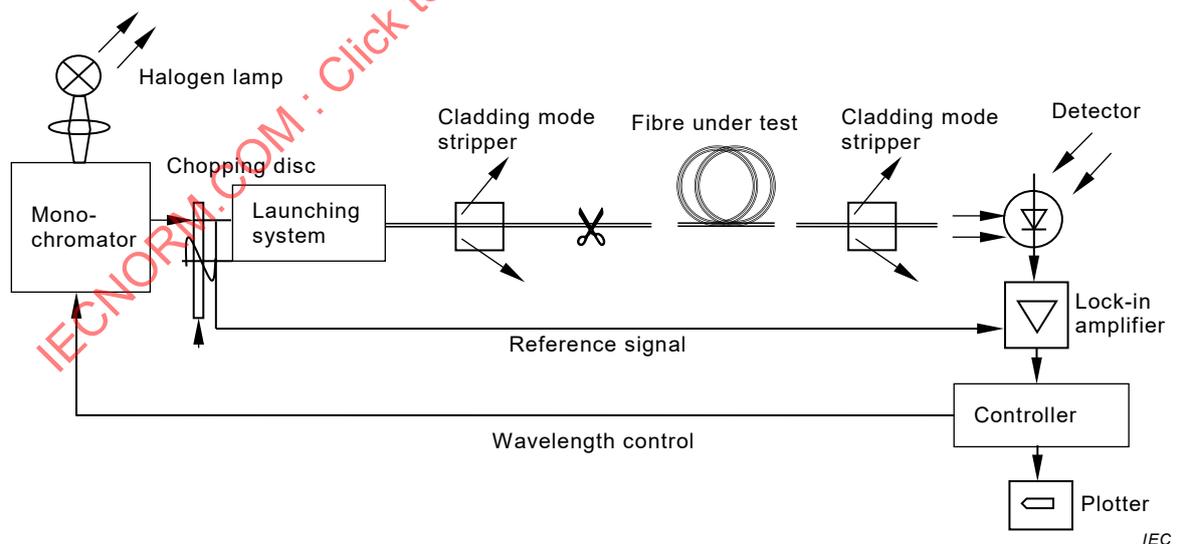


Figure B.2 – Arrangement of equipment used to obtain a loss spectrum

B.3 Procedure

Set the FUT in the measurement apparatus. Record the output power, $P_2(\lambda)$.

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.

B.4 Calculations

Calculate the attenuation between the points where $P_1(\lambda)$ and $P_2(\lambda)$ have been measured, using Equation (B.1), or attenuation coefficient by using Equation (B.2), or both, as required.

The attenuation of a fibre at wavelength λ between two cross-sections, 1 and 2, separated by a distance is defined as

$$A(\lambda) = \left| 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \right| \quad (\text{B.1})$$

where

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

$P_1(\lambda)$ is the optical power traversing cross-section 1;

$P_2(\lambda)$ is the optical power traversing cross-section 2.

For a uniform fibre under steady state conditions, it is possible to define the attenuation per unit length or the attenuation coefficient as follows:

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

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 km.

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Annex C (normative)

Requirements for the optical source characteristics for A1 multimode measurement

C.1 Encircled flux (EF)

The EF is the ratio of the cumulative near field power to the total output power as a function of radial distance from the optical centre of the fibre core. It is determined from the near field measurement of the light coming from the end of the launching cord.

The near field measurement is conducted in accordance with IEC 61280-1-4. The measured near field result is a function, $I(r)$, of radius, r , away from the optical centre of the core, which is used to generate the encircled flux (EF) function as:

$$EF(r) = \frac{\int_0^r xI(x)dx}{\int_0^R xI(x)dx} \quad (\text{C.1})$$

where R is an integration limit defined in IEC 61280-1-4.

C.2 Limits on encircled flux

These requirements are suitable for cabling using category A1a and A1b multimode fibres that are defined in IEC 60793-2-10 as 50 μm and 62,5 μm core fibres, both with 125 μm cladding diameter. The requirement for other categories of multimode fibres is under study.

The limits for the encircled flux are derived from a target near field and a set of boundary conditions designed to constrain the variation in attenuation due to variations in the source launch distribution to within $\pm 10\%$ or $\pm X$ dB, whichever is largest, of the value that would be obtained if the target launch were used. Only coupling losses are taken into account for these attenuation values.

The theory leading to the EF limits is based on assumptions that include

- fibre core refractive index dimension and shape,
- spectral width, and
- Hermite-Gauss model for mode fields.

Deviation from these assumptions can lead to additional attenuation variance. One assumption is that the attenuation is measured with a light source and power meter (LSPM) method in which the light is coupled forward through the connections, and the backscattered light is not considered. The OTDR method is based on backscattered light, which propagates different paths in the fibre compared to the LSPM method. Accordingly, coupling is different at connections. As a consequence, the understanding of the relationship of the attenuation variance obtained from an OTDR to the encircled flux limits is incomplete.

The source launch conditions are described at the output of the launch cord. It is understood that the source, as supplied, has been verified by the test equipment manufacturer to produce the specified launch using a test cord with certain specifications. In the event that the launch cord needs to be replaced, obtain one that is compatible with the recommendation of the test equipment supplier or verify its compatibility by one of the procedures in IEC 61280-4-1.

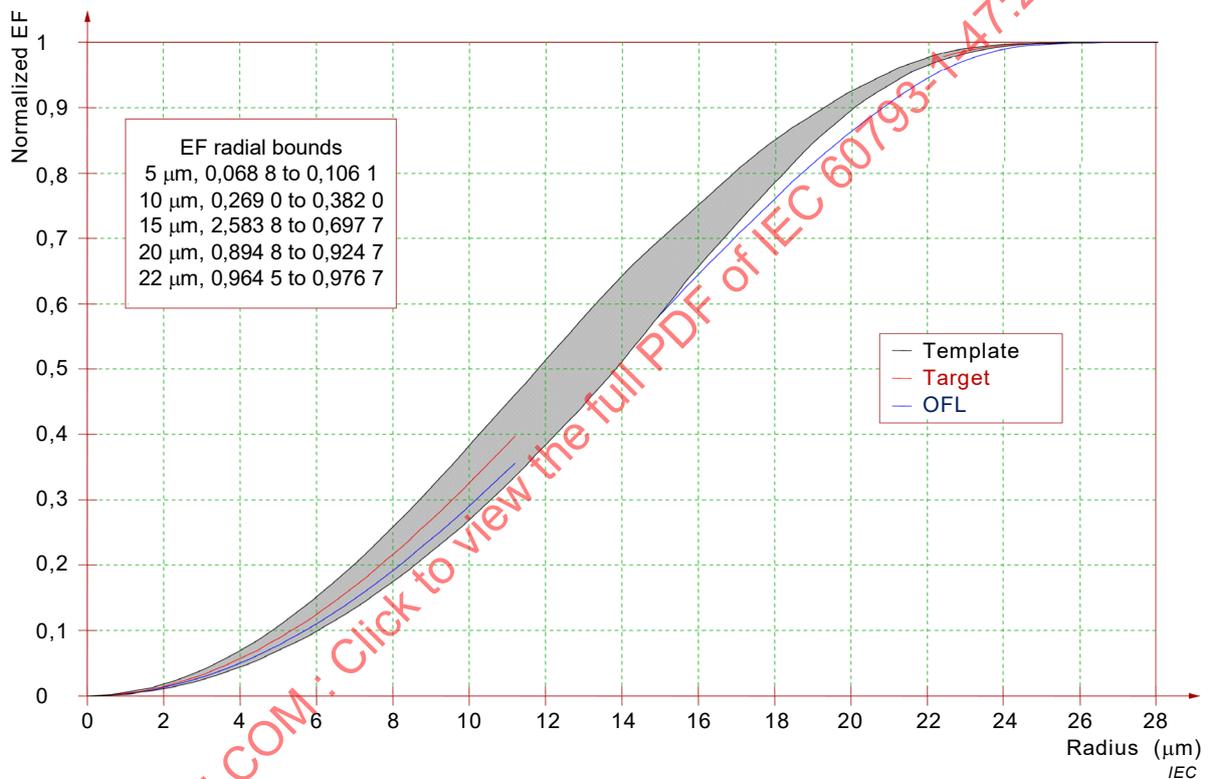
The variable X is a tolerance threshold that varies with fibre core size and wavelength according to the values in Table C.1.

Table C.1 – Threshold tolerance

Threshold dB	Wavelength nm	
Fibre nominal core diameter (µm)	850	1 300
50	0,08	0,12
62,5	0,10	0,15

Table C.1 is referenced to nominal core diameter. The core diameter of the fibre in the actual launch cord is critical to good performance. A tolerance of better than $\pm 1,0 \mu\text{m}$, i.e., $\pm 0,7 \mu\text{m}$, is recommended.

An example of the encircled flux template for A1a fibre at 850 nm is shown in Figure C.1. The target EF along with the EF that would be obtained by an overfilled launch is also shown.



NOTE Attenuation deviation constraints, 850 nm, 50 µm. 75 % shape tol, link constraints ($\mu\text{M SHIFT} \times \#\text{CMPTS}$, dB Tol) = (2,0 dB \times 2,08 dB), (3,0 dB \times 2,08 dB), (4,0 dB \times 2,08 dB), (5,0 dB \times 2,10 %), (2,0 dB \times 5,08 dB), (3,0 dB \times 5,10%), (4,0 dB \times 5,10 %), (5,0 dB \times 5,10 %).

Figure C.1 – Encircled flux template example

The EF requirements are defined as a table of limiting values for each of a set of particular radial values for each combination of fibre core size and wavelength. These limiting values are given in Table C.2 through Table C.5.

Table C.2 – EF requirements for 50 μm core fibre cabling at 850 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,278 5	0,335 0	0,391 5
15	0,598 0	0,655 0	0,711 9
20	0,910 5	0,919 3	0,929 5
22	0,969 0	0,975 1	0,981 2

Table C.3 – EF requirements for 50 μm core fibre cabling at 1 300 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,279 2	0,336 6	0,394 0
15	0,599 6	0,656 7	0,713 8
20	0,907 2	0,918 6	0,930 0
22	0,966 3	0,972 8	0,979 3

Table C.4 – EF requirements for 62,5 μm core fibre cabling at 850 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,168 3	0,210 9	0,253 5
15	0,369 5	0,439 0	0,508 5
20	0,633 7	0,692 3	0,750 9
26	0,924 5	0,935 0	0,945 5
28	0,971 0	0,978 3	0,985 6

Table C.5 – EF requirements for 62,5 μm core fibre cabling at 1 300 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,168 0	0,211 9	0,255 8
15	0,369 9	0,440 9	0,511 9
20	0,636 9	0,694 5	0,752 1
26	0,925 4	0,935 7	0,946 0
28	0,970 8	0,978 2	0,985 6

Annex D (informative)

Small bend radius phenomena

D.1 General

Annex D illustrates some features of single-mode fibre behaviour when bent to particularly small radii, depending on the fibre construction. It is based on practical experience of several fibre manufacturers.

The phenomena described in Annex D ~~might~~ can affect the quality of transmission. It is therefore recommended that fibre performances are confirmed under actual operating conditions, for example wavelength, bend radii and bent fibre length.

D.2 Interference between propagating and radiating modes

When measuring macrobending loss at low bend radii, a secondary effect due to interference among the fundamental propagating mode in the core and radiating modes can occur if the length of the sample under bend is not sufficient to suppress radiating modes. In this phenomenon, the propagating optical signal is irradiated from the bent fibre core and back reflected at curved interfaces outside the core (e.g. core-cladding or cladding-coating or coating-air, similar to the so called "whispering gallery modes phenomenon"), thus interfering with the propagating mode. Under certain deployment conditions, constructive and destructive ~~effects~~ interference can occur, leading to ~~wavelength dependent losses at a certain bend radius~~ oscillations in the spectral loss.

In case these effects occur ~~in the wavelength dependent loss~~, curve fitting can be applied for ~~processing~~ evaluating the spectral loss curve; the fit shall be based on the exponential behaviour of loss vs. wavelength. It is expected that the fitting will produce values that would be obtained with the interference effects substantially reduced, as would be the case if the test was carried out on a number of turns sufficiently large to suppress interference effects or if index-matching materials were used. The fitting technique, however, allows the measurement to be carried out and completed, preventing the need of unpractical set-ups and measurement conditions.

An example of this oscillating behaviour and of a possible fitting curve (A) is shown in Figure D.1. Two consecutive deployments in a $R = 7,5$ mm test set-up with 18x a 180° bend (U-turn deployment) result in different loss curves but with coincident curve fits.

NOTE When fitting in the presence of peaks and valleys, verify that there are enough of them, for example four, so that their ~~effect~~ impact on the fit is balanced.

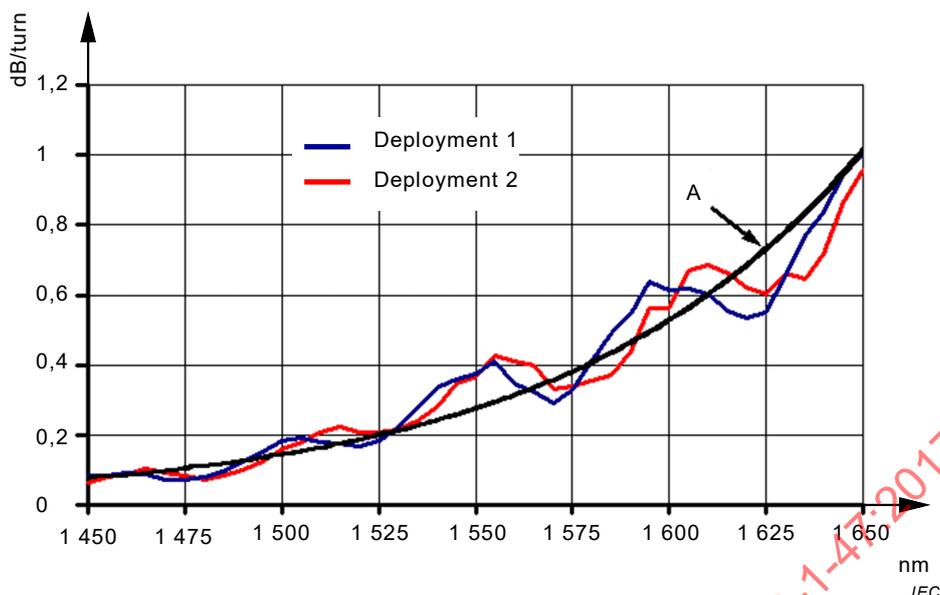


Figure D.1 – Loss curves versus curve fits

A similar oscillatory behaviour can be observed at a fixed wavelength for changing radii and/or for changing temperature: fitting techniques are also possible applicable in this case.

~~Regarding the fitting curve, several different models have been developed and can be found in scientific literature; two simplified models are given in the following as an example.~~

~~For a fixed bend, loss variations with wavelength can be represented by~~

$$\underline{Bend Loss(dB) = Ae^{\alpha \cdot \lambda}}$$

~~where A and α are coefficients depending on fibre design.~~

~~At a fixed wavelength and for restricted regions around a certain value of the radius (e.g. 15 mm or 30 mm for B1 fibres) the loss trends with bend radius may be represented by~~

$$\underline{Bend Loss(dB) = Be^{-\beta R}}$$

~~where R is the bend radius of the circularly deployed fibre and again where B and β are coefficients which depend on fibre design.~~

~~Due to the statistical nature (to some extent) of the interference phenomenon, it is recommended that the fit is carried out:~~

- ~~a) on data represented on a y-axis log scale;~~
- ~~b) by minimizing the median vs. mean difference, instead of the root mean square error.~~

Due to the statistical nature (to some extent) of the interference phenomenon, it is recommended that a curve fit is carried out from which bending loss values at specified wavelengths are derived.

For optimizing the fitted curve to the measurement data, various methods are available. Well known is the "least square method" that minimizes the sum of squared differences between measured and fitted values. Other possibilities are for example to minimize "mean minus median" of differences between measured and fitted values, or to minimize "mean" or "median" of differences between measured and fitted values. To perform the curve fitting, facilities like the Solver in Excel⁴ can be used.

⁴ Excel is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

Other methods become available when we do not fit with the curve

$$\gamma = A^{\alpha\lambda} \quad (D.1)$$

where

γ is the bend loss, in dB.

but fit with a linear curve which is obtained by taking the natural logarithm of both sides of this formula:

$$\ln[\gamma] = \alpha\lambda \times \ln A \quad (D.2)$$

where

γ is the bend loss, in dB.

Fitting with this linear curve using the least square method enables the use of a relatively simple analytical expression. This expression facilitates real time calculation of fitting coefficients during the measurement. Drawback of this method is that, due to the natural logarithm, preference is given to lower wavelength measurement values where in general the real interest is for the higher wavelengths, for example 1 550 nm and 1 625 nm. This can be compensated by using "weighted least square methods" that give more weight to the higher wavelength points.

All methods described enable fitted curves with very good correlation to the measured values. Most important however is the accuracy of the bend loss values at specific wavelengths that will be derived from it, for example at 1 550 nm and 1625 nm.

The interference between the fundamental mode and lossy cladding and coating modes can be eliminated by measuring loss of a bent fibre when immersed in a high index fluid (refractive index higher than the refractive index of the outer fibre coating). Measurements in this situation can give a good impression of the intrinsic bend loss of the fibre and can be used to evaluate specific curve fitting optimization methods.

The accuracy of the curve fit further depends on the wavelength range of used measurement points and the total number of points taken. A larger number of points increase accuracy. Care should be taken that selected measurement points are not influenced by injected higher order modes.

D.3 Polarization effects

When measuring macrobending loss at very low bend radii, polarization of the propagating or radiating light may affect the results. Since the light leaving the fibre is subjected to several reflections from different interfaces (e.g. cladding to coating, coating to air, coating to contact materials), some degree of polarization may be present even for un-polarized sources. These polarization ~~depending~~ dependent losses (PDL) are functions of the wavelength and should be taken into account when comparing results from different measurements or laboratories.

D.4 High power damage

In some extreme conditions (very high power, very tight bends), the temperature of the coating and of the glass can rise to very high values, eventually causing the coating to break down and the glass to collapse. These extreme conditions, however, are not typical of standard telecom networks deployment and operations. Detailed information about this phenomenon can be found in IEC TR 62547.

Annex E (informative)

Parallel plate (2-point) macrobend loss approximation

E.1 General

Annex E describes a 2-point macrobending loss measurement for estimating a macrobending loss of single mode fibres only. This measurement is not an alternative to the normative macrobend tests. The 2-point macrobending loss measurement can be utilized to approximate the effective macrobending loss for a broad wavelength range at various effective bends. The term "effective" is used because the fibre is not shaped circularly with this technique, but rather approximates a parabola.

This measurement can be used to compare different single mode fibre types, although care should be taken to ensure that optical attributes are approximately matched. Compared with the normative macrobend test, the 2-point macrobend loss measurement results differ from the normative test, tending to be a higher loss value with larger variability.

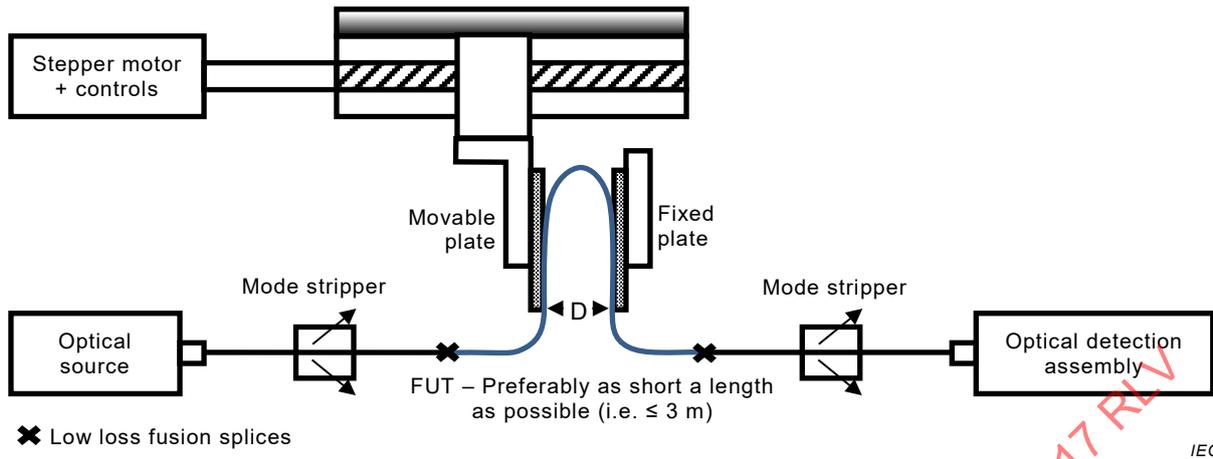
E.2 Specimen

The specimen should be of sufficient length to allow adequate coupling to the measurement system and positioning in the apparatus. Any further fibre length should not affect the measurement results, provided that the SNR is optimised.

E.3 Apparatus

E.3.1 General

A possible test apparatus is provided in Figure E.1. The test setup is designed to measure the optical signal response through the FUT under different controlled bent conditions. The launch characteristics can be found in 4.3.2.2.



a) Possible test setup for parallel plate (2-point) macrobend loss measurement

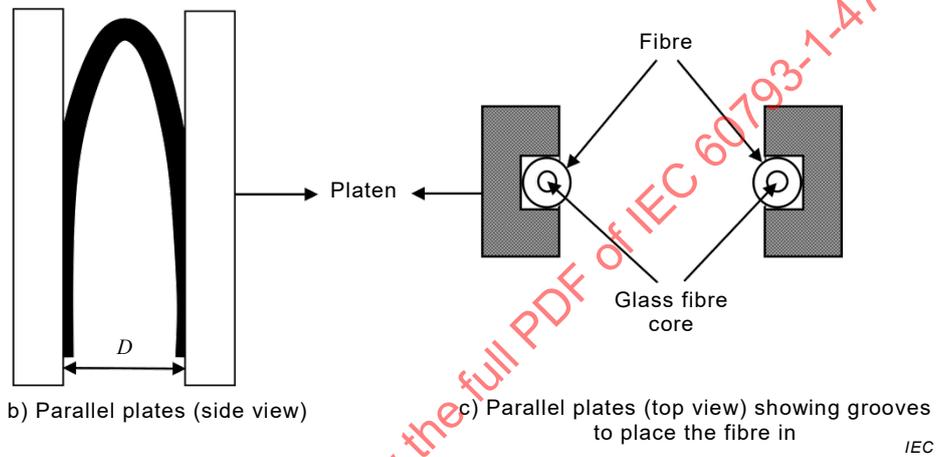


Figure E.1 – Schematic of possible (two-point bend) apparatus

The effective bend radius, R_{eff} , can be approximated by the following expression:

$$R_{\text{eff}} = \frac{D - d}{2(1,198)} \tag{E.1}$$

where

D is the separation of the surfaces making contact with the fibre;

d is the fibre diameter.

NOTE This approximation, however, is not equivalent to the bend radius determined by the normative macrobending loss methods.

E.3.2 Stepper motor control

This device allows accurate, reliable, repeatable motorized control of the linear table. The repeatability of the stepper motor should be matched to the requirements of the bend deployment.

E.3.3 Movable plate

The movable plate converts the stepper motor rotation to linear translation by means of a lead screw.

E.3.4 Fixed plate

This device holds the fibre against the movable plate.

E.4 Procedure

- a) Couple the optical source to one end of the fibre and measure the reference optical power using a detection system coupled to the other end.
 - The FUT should be in a loosely coiled deployment which does not induce macrobending.
- b) Place the FUT between two parallel plates with the section of FUT between the plates deployed in a half loop.
 - Each plate may have a shallow groove machined in it along its longitudinal axis to serve as a fibre guide. The fibre should be deployed between the plates resting in the bottom of the grooves. By using grooves, as the distance between the plates is changed, the length of fibre between the plates naturally changes to maintain a half loop under bend. This eliminates the need to manually adjust the length of sample under bend to maintain a half loop. The section of fibre under bend is otherwise unconstrained, forming a natural curvature.
 - One additional advantage of this approach is that it facilitates the loading of the fibre after a reference measurement without disturbing the source or detector connections.
 - V-grooves can also be used, but care shall be taken to ensure that the distance between the two sides of the deployed fibre satisfies the desired bend diameter.
- c) Measure the power level through the FUT.
 - The optical bending loss can be measured by spectral attenuation over a designated wavelength range. This provides data at any wavelengths of interest. The loss as a function of wavelength can be plotted to assess the fibre's response at each effective bend radius. An example of one of these plots can be seen in Figure B.2.
- d) Adjust the movable plate to the next predetermined increment. At each additional increment, make sure the FUT is positioned correctly and measure the power level.
 - At each increment, the fibre length between the plates is adjusted to provide a half turn of approximate constant radius.
 - The effective bend radius can be approximated by Equation (E.1).
- e) Repeat until all the positions have been evaluated.

E.5 Calculation

Refer to Clause 7 for loss calculation.

E.6 Results

- a) The measured values should be reported as dB/turn.
- b) The measured values then could be fit to any suitable method.

EXAMPLE 1 The calculated loss data as a function of effective bend diameter, $2R_{\text{eff}} = D_{\text{eff}}$, can be fitted with a simple exponential function and plotted on a log scale, as depicted in Figure E.2, for particular wavelength of interest.

NOTE Noise can cause fitting problems at low bend losses.

The extrapolation to effective bending diameters outside the range of tested diameters is not recommended.

EXAMPLE 2 The spectral calculated loss data can be plotted as a function of wavelength for a given effective bend to evaluate the approximate loss as shown in Figure E.3.

- c) The data may be fitted to an exponential curve to smooth the variability associated with the presence of the usual whispering gallery modes.

Additional statistical treatments such as implementing a confidence interval may also be utilized.

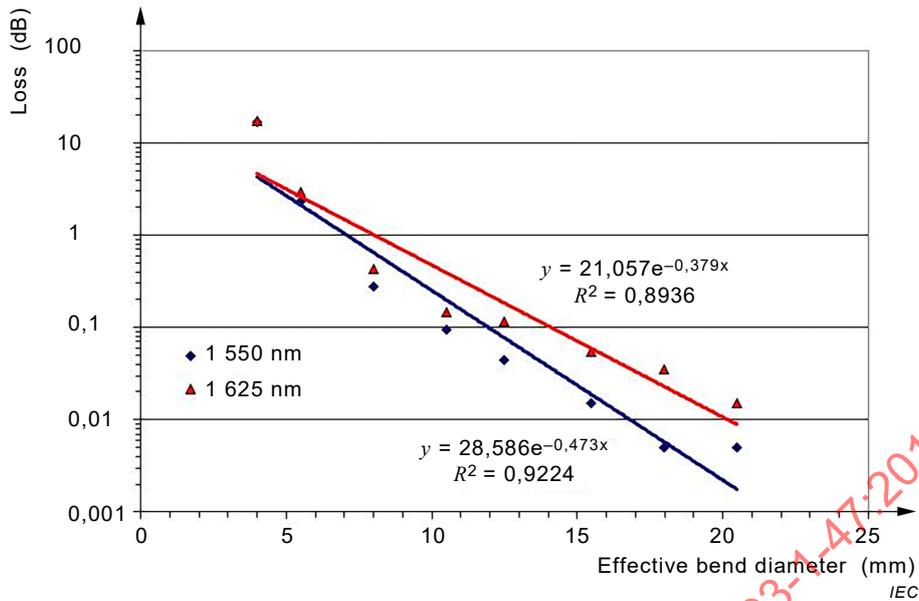


Figure E.2 – Example of applying an exponential fit to the spectral data of a B6_a2 fibre

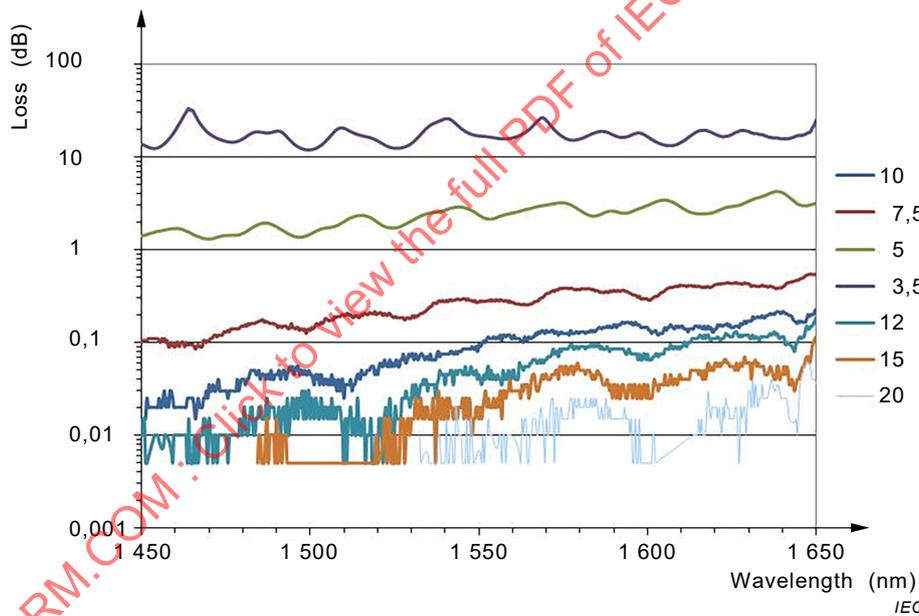


Figure E.3 – Example of 2-point bend test data for a B6_a2 fibre

E.7 Comparison of results with normative test

It should be considered that results from this measurement are not equivalent to ones obtained from the normative macrobend tests. Table E.1 illustrates the differences that can occur between the two test methodologies. The 2-point measurement provides different results from the normative test.

It should also be considered that a 2-point measurement should not be applied to measure low bend loss; for example, bend loss of less than 0,5 dB, such as the bend loss at a large bend and/or of bend-insensitive fibres. The 2-point method results in a large variability of measured macrobend losses.

Table E.1 – Comparison of parallel plate (2-point) versus method A macrobend loss measurement for a B6_b3 fibre at 10 mm diameter (ratio of mandrel / 2-point)

Fibre	1 550 nm	1 625 nm
A	0,99	0,93
B	0,89	0,90
C	1,07	0,97
D	1,21	1,17
E	0,82	0,89
F	0,97	1,07
G	0,84	0,84
H	1,06	1,07
I	1,08	1,05
J	1,15	1,24
K	1,51	1,21
L	1,10	1,04
NOTE Each data point represents an average of five measurements.		

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IEC TR 62547, *Guidelines for the measurement of high-power damage sensitivity of single-mode fibre to bends – Guidance for interpretation of results*

ITU-T G Suppl. 59:2016, *Guidance on optical fibre and cable reliability*

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INTERNATIONAL STANDARD

NORME INTERNATIONALE



Optical fibres –

Part 1-47: Measurement methods and test procedures – Macrobending loss

Fibres optiques –

Partie 1-47: Méthodes de mesure et procédures d'essai – Pertes par macrocourbures

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL FIBRES –

**Part 1-47: Measurement methods and test procedures –
Macrobending loss**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60793-1-47 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This fourth edition cancels and replaces the third edition published in 2009. It constitutes a technical revision.

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

- a) former Annex A has been renumbered to Annex D;
- b) introduction of new Annex A on the transmitted power monitoring technique;
- c) introduction of Annex B on the cut-back technique;
- d) introduction of Annex C on the requirements for the optical source characteristics of A1 multimode measurement;
- e) introduction of Annex E on parallel plate (2-point) macrobend loss approximation.

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

FDIS	Report on voting
86A/1823/FDIS	86A/1828/RVD

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

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

This standard is to be read in conjunction with IEC 60793-1-1:2017.

A list of all parts of 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 "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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

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

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INTRODUCTION

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

Within the same series, several different areas are grouped, but all numbers are possibly not used, as follows:

Parts 1-10 to 1-19:	General
Parts 1-20 to 1-29:	Measurement methods and test procedures for dimensions
Parts 1-30 to 1-39:	Measurement methods and test procedures for mechanical characteristics
Parts 1-40 to 1-49:	Measurement methods and test procedures for transmission and optical characteristics
Parts 1-50 to 1-59:	Measurement methods and test procedures for environmental characteristics

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OPTICAL FIBRES –

Part 1-47: Measurement methods and test procedures – Macrobending loss

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the macrobending loss of single-mode fibres (class B) at 1 550 nm or 1 625 nm, category A1 multimode fibres at 850 nm or 1 300 nm, and category A3 and A4 multimode fibres at 650 nm, 850 nm or 1 300 nm, thereby assisting in the inspection of fibres and cables for commercial purposes.

This document gives two methods for measuring macrobending sensitivity:

- Method A – Fibre winding, pertains to class B single-mode fibres and category A1 multimode fibres.
- Method B – Quarter circle bends, pertains to category A3 and A4 multimode fibres.

For both of these methods, the macrobending loss can be measured utilizing general fibre attenuation techniques, for example the power monitoring technique (see Annex A) or the cut-back technique (see Annex B). Methods A and B are expected to produce different results if they are applied to the same fibre. This is because the key difference between the two methods is the deployment, including the bend radius and length of fibre that is bent. The reason for the difference is that A3 and A4 multimode fibres are expected to be deployed in short lengths with a smaller number of bends per unit fiber length compared to single-mode and category A1 multimode fibres.

In this document, the "curvature radius" is defined as the radius of the suitable circular shaped support (e.g. mandrel or guiding groove on a flat surface) on which the fibre can be bent.

In addition, informative Annex E has been added to approximate bend loss for class B single-mode fibres across a broad wavelength range at various effective bends.

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 (all parts), *Optical fibres – Measurement methods and test procedures*

IEC 60793-1-1:2017, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-2, IEC 60793-1 (all parts) and IEC 60793-1-1 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>

NOTE General definitions for fibres are provided in IEC 60793-2, definitions of the specified attributes are contained in the relevant test methods standard of IEC 60793-1 (all parts), and general definitions for testing are provided in IEC 60793-1-1.

4 Apparatus

4.1 Method A – Fibre winding

The apparatus consists of a tool (e.g. a mandrel or a guiding groove on a flat surface) able to hold the sample bent with a radius as stated in the appropriate optical fibre sectional product specification and a loss measurement instrument. Determine the macrobending loss at the wavelength as stated in the appropriate sectional product specification by using either the transmitted power monitoring technique (Annex A) or the cut-back technique (Annex B), taking care of the appropriate launch condition for the specific fibre type.

4.2 Method B – Quarter circle bends

The apparatus consists of one or more plates, each containing one or more "guide grooves", and a loss measurement instrument. The plates shall be designed to be stacked during the test without contacting the sample fibre in a lower or higher plate; such contact will affect the measurement results. Each guide groove shall have a quarter circle segment (i.e. 90°) as shown in Figure 1. The bend radius r , i.e. the radius of the quarter circle segment, shall be stated in the detail specification. The width of each guide groove is recommended to be 40 % broader than the outer fibre diameter.

Determine the macrobending loss at the wavelength as stated in the appropriate sectional product specification by using either the transmitted power monitoring technique (Annex A) or the cut-back technique (Annex B), taking care of the appropriate launch condition for the specific fibre type.

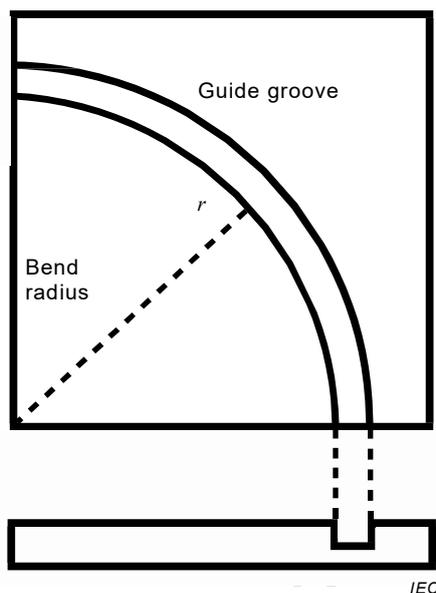


Figure 1 – Quarter circle guide groove in plate

4.3 Input system

4.3.1 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 less than 10 nm, compared with any features of the fibre spectral attenuation. Align the fibre to the launch cone, or connect it coaxially to a launch fibre.

4.3.2 Optical launch arrangement

4.3.2.1 General

Figure 2 shows the general launch arrangement used for all fibres. Apply the appropriate launch arrangement to produce a full or restricted launch, depending on the parameter being measured. See 4.3.2.3 to 4.3.2.4 for further details as they apply to specific categories of single-mode and multimode fibres.

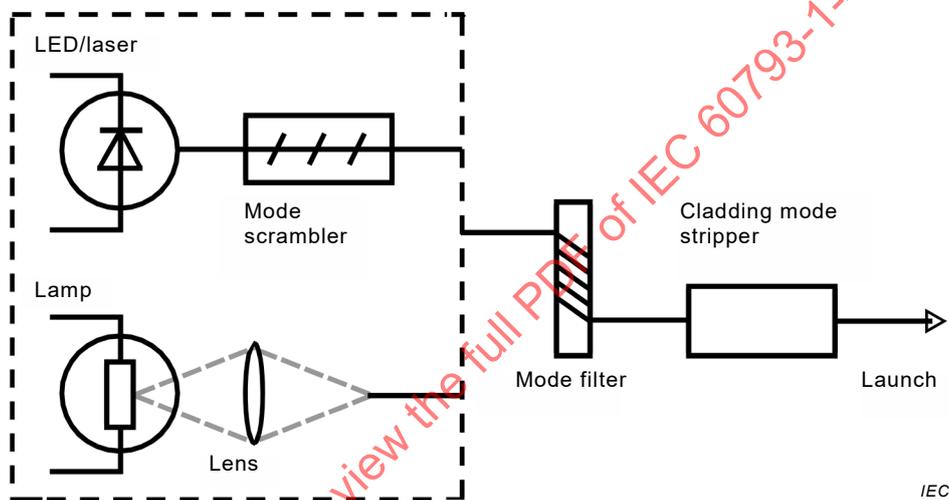


Figure 2 – General launch arrangement

4.3.2.2 Launch arrangement for single-mode fibres

4.3.2.2.1 General

An optical lens system or fibre pigtail may 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 or Figure B.1).

4.3.2.2.2 Fibre pigtail

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

4.3.2.2.3 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.

4.3.2.2.4 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, but not so small as to induce wavelength-dependent oscillations.

Another option commonly employed on bend insensitive single mode fibres and other single mode fibres with little or no cut-off response to bend is the use of a standard single mode fibre as a mode filter.

4.3.2.2.5 Cladding mode stripper

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

4.3.2.3 Launch arrangement for A1 multimode fibres

The required launch for measuring the macrobending loss of A1 multimode fibres shall be an encircled flux launch. The requirements for the optical source characteristics for A1 multimode measurement are included in Annex C.

The encircled flux emitted by the launching cord depends on the characteristic of the light source emerging from the face of the socket, the connection of the launching cord to the socket, the optical fibre within the launch cord, and any applied mode conditioning.

The test equipment manufacturer should provide specifications for the test cord that are compatible with the particular source implementation used. When the specification on the cord is met and used with the test equipment, the encircled flux (EF) requirements should be assured.

4.3.2.4 Launch arrangements for A2 to A4 multimode fibres

Below are some examples of generic launching arrangements for short-distance fibres described in Figure 3, Figure 4 and Figure 5.

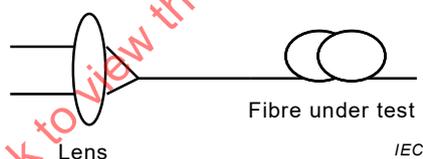


Figure 3 – Lens system

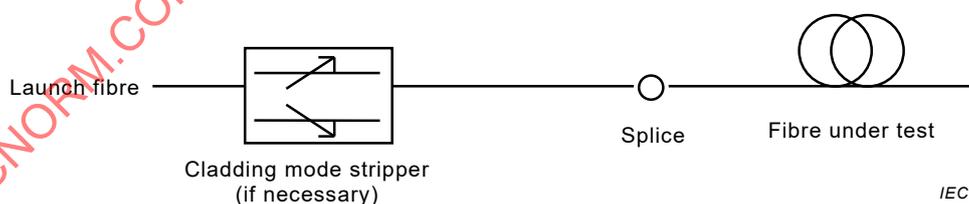


Figure 4 – Launch fibre

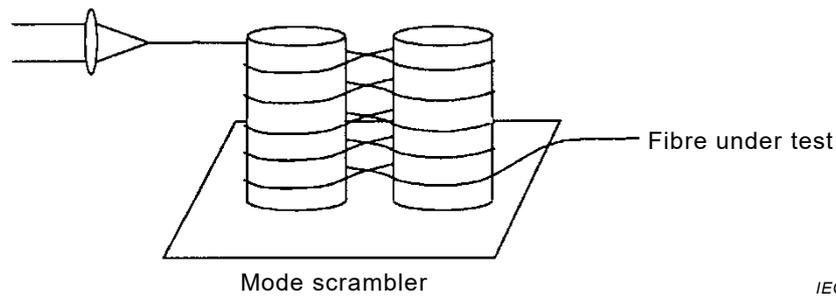


Figure 5 – Mode scrambler (for A4 fibre)

The reproducibility of the attenuation measurements of step-index 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 able to provide spot sizes and launch numerical apertures (NAs) as given in Table 1. In addition, the measurement wavelength shall be calibrated to within ± 10 nm.

Table 1 – Launch conditions for A2 to A4 fibres

Attribute	Fibre category		
	A2 Glass core/glass cladding	A3 Glass core/plastic cladding	A4 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 ^a	= fibre max NA ^b	= fibre max NA, with full mode launch ^b
<p>^a This launch condition can be produced by overfilling a mode filter made from 2 m of fibre identical to the fibre under test (FUT), with appropriate cladding mode stripping and using the output from this mode filter to launch into the FUT.</p> <p>^b This launch condition can be produced in the same manner as described in Note a. However, some types of A3 and A4 fibre will not require cladding mode stripping for the mode filter.</p>			

4.4 Output system and detection

4.4.1 Optical divider

When an optical divider is required, it shall have a splitting ratio that remains constant during the test. The splitting ratio and temperature stability shall be as shown in the relevant detail specification. Commercially available or custom built devices may be used.

4.4.2 Optical detector

The optical detector shall be of sufficient area to intercept all of the radiated power in the output cone and shall be sufficiently linear over the optical powers encountered.

The optical detector shall have a sufficiently uniform response over the active area and range of incidence angle at the measurement wavelength to ensure the movement of the output cone in position or angle relative to the detector. This shall be within the limits determined by the mechanical design of the measurement equipment and shall not significantly affect the results.

Where more than one detector is used, as in the arrangement shown in Figure A.1, the detectors shall be of the same manufacturer and model and be of comparable linearity.

4.4.3 Optical detection assembly

All power emitted from the specimen should be coupled to the active region of the detector by an appropriate means. For example, an optical lens system, a butt spliced fibre pigtail, or direct coupling to the detector may 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 can include a photovoltaic mode photodiode amplified by a current input amplifier, with synchronous detection by a lock-in amplifier.

4.4.4 Signal processing

It is customary to modulate the light source in order to improve the signal-to-noise ratio (SNR) 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 known characteristics.

When low loss is expected, more test bends may be added provided there are separate grooves for each additional bend to improve the SNR; however, the approximation of the bend diameter along with the bend control may be further degraded.

5 Specimen

5.1 Specimen length

5.1.1 Method A – Fibre winding

The specimen shall be a known length of fibre, as specified in the detail specification. In particular, the length of the sample tested for loss is determined by the measurement set-up, i.e. curvature radius (R) and number of turns (N); any further fibre length does not affect the measurement results, provided that the SNR is optimised.

5.1.2 Method B – Quarter circle bends

The specimen length shall be determined according to the details shown in 6.2.

5.2 Specimen end face

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

6 Procedure

6.1 Method A – Fibre winding

6.1.1 General consideration

Loosely wind the fibre on the tool, avoiding excessive fibre twist. The number of turns, curvature radius and wavelength at which loss is to be measured are discussed below in 6.1.1 and in 6.1.2 and 6.1.3.

Since the actual curvature radius is critical, a maximum tolerance of $\pm 0,1$ mm (for radii lower than or equal to 15 mm) or $\pm 1,0$ mm (for larger radii) is accepted: a tighter tolerance on small radii is required for higher measurement sensitivity.

Both for single-mode and for multimode fibres, two optical powers can be measured using

- the power-monitoring technique, which measures the fibre attenuation increase due to a change from the straight condition to a bent condition, or
- the cut-back technique, which measures the total attenuation of the fibre in the bent condition. In order to determine the induced attenuation due to macrobending, this value should be corrected for the intrinsic attenuation of the fibre.

The fibre length outside the mandrel and the reference cut-back length shall be free of bends that can introduce a significant change in the measurement result. It is also possible to rewind

the fibre from a mandrel with a large radius (introducing negligible macrobend loss) to the mandrel with the required radius. In this case, the macrobend loss can be determined directly by using the power-monitoring technique (without the correction for the intrinsic attenuation of the fibre).

Care shall be taken in order not to introduce torsion on any fibre part during the measurements, as this would affect the result.

6.1.2 Single-mode fibres

Different applications may require different deployment conditions: fibre types have been developed which exhibit bending performances optimised for each condition.

Two typical environments are recognised for (possibly) different fibre types, for which different measurement set-ups should be considered when characterising fibre performances.

- a) Long distance networks: far from urban areas, space occupancy is not typically an issue, and bends imposed on the fibres can be limited to relatively large radii. Fibres designed for this application should be tested in similar conditions, i.e. with the samples wrapped around relatively large radius mandrels, for example in the range 25 mm to 30 mm.

This measurement set-up is mainly affected by errors related to low SNR and by unwanted tension, torsions or kinks on the relatively long fibre length used for the measurement.

- b) Access networks: operating conditions require bending radii as small as possible, compatible with lifetime expectations and acceptable bend losses. For more information on lifetime expectations please refer to ITU-T G Suppl.59:2016. Fibres designed for this application should be tested in similar conditions, i.e. with the samples bent at small radii, for example in the range 7,5 mm to 15 mm (see Annex C).

The measurement can be affected by different sources, i.e. reflections, which may occur at the coating-air or coating-glass interface, at surrounding surfaces (including, when used, the mandrel surface), or at connectors.

The test can be carried out on samples either making complete (360°) turn(s), in open air or around a suitable support (mandrel), or making an equivalent number of partial turns, for example U-turns (180°) or quarter turns (90°), in open air or around suitable supports. The length under test is different for complete and partial turns; for example, the length of a complete turn being twice the length of a U-turn or four times the length of a quarter turn. In this document, the term "coil" refers to one complete turn. One coil could also be made of, for example, two consecutive U-turns¹ or four consecutive quarter turns. This should be taken into account while normalising the results to the length of the sample (number of coils).

The following recommendations apply to test conditions in both cases (items a) and b) above):

Number of turns

- The number of turns should be in accordance with the values stated in the product specification.
- For single-mode fibres, the attenuation increases in a linear fashion with the number of turns.
- For each radius, the number of turns shall be chosen in such a way that:
 - the induced loss is significantly higher than the detection limit of the set-up; when necessary, for example for low bend loss fibres, tests may be carried out with more turns than the specification requires – followed by linear normalization to the specified number;
 - the induced loss is significantly lower than the onset of the non-linear region in the set-up; for bending radii in the range 5 mm to 10 mm, this may imply that not more than 5 to 10 turns should be used.

¹ If there is excessive displacement between successive U-turns, the length of the sample arranged on two U-turns can be shorter than one coil. A maximum displacement between adjacent U-turns of 0,5 mm is therefore suggested.

Bend radius

The value of bend radius shall be in accordance with the values stated in the product specification².

Wavelength

The measurement wavelength shall be 1 550 nm or 1 625 nm, in accordance with the relevant product specification; it should be considered that bending losses increase exponentially with the wavelength.

The homogeneity of bend loss in different angular positions over the cross section needs to be verified either by multiple angular position tests or by verifying the homogeneity of the effective refractive index profile, establishing the guiding properties of the bent FUT.

6.1.3 Multimode (A1) fibres

Macro-bending loss in A1 multimode fibres varies with bend radius and number of turns around a mandrel and is less sensitive to wavelength than with single-mode fibres. Still, oscillating effects with wavelength may occur which are related to successive mode groups passing cut-off and having increased bend loss at these wavelengths.

The values of bend radius and number of turns shall be in accordance with the values stated in the specification. When testing multiple turns, the attenuation that occurs over a specific turn depends on the attenuation of the preceding turns. The incremental macro-bending added loss decreases with each added turn. Macro-bending added loss produced by multiple turns should not be expressed in the units of "dB/turn" by dividing the total added loss by the number of turns. Instead, it shall be reported in dB for the specified number of bends. An extrapolation to more than the specified number of turns will result in an overestimation of the overall loss.

For multimode fibres only, the launching characteristics of the light source at the launching position of the fibre being tested shall be consistent with the expected fibre application. Further details on multimode launching conditions can be found in Annex C.

6.2 Method B – Quarter circle bends

This method applies to category A3 and A4 multimode fibres. The fibre to be tested should be carefully set in the guide groove(s) (see Figure 1). The beginning of each controlled bend shall be s metres apart from the beginning of the next controlled bend. The beginning of the controlled bend closest to the launch end shall be 1 m from the launch. The end of the controlled bend closest to the detector end shall be 1 m from the detector (see Figure 6).

The minimum specimen length shall be determined according to Equations (1) and (2).

$$L = (n - 1) \times s + 2 \quad (1)$$

$$s = \frac{3}{2} \pi \times R + 2 \times R \quad (2)$$

where

L is the minimum sample length, in m;

n is the number of quarter-turn bends;

s is the interval between each bend, in m;

R is the slack bend radius, in m.

² Bending loss on single-mode fibre increases exponentially as wavelength increases and as radius decreases (see Annex D).

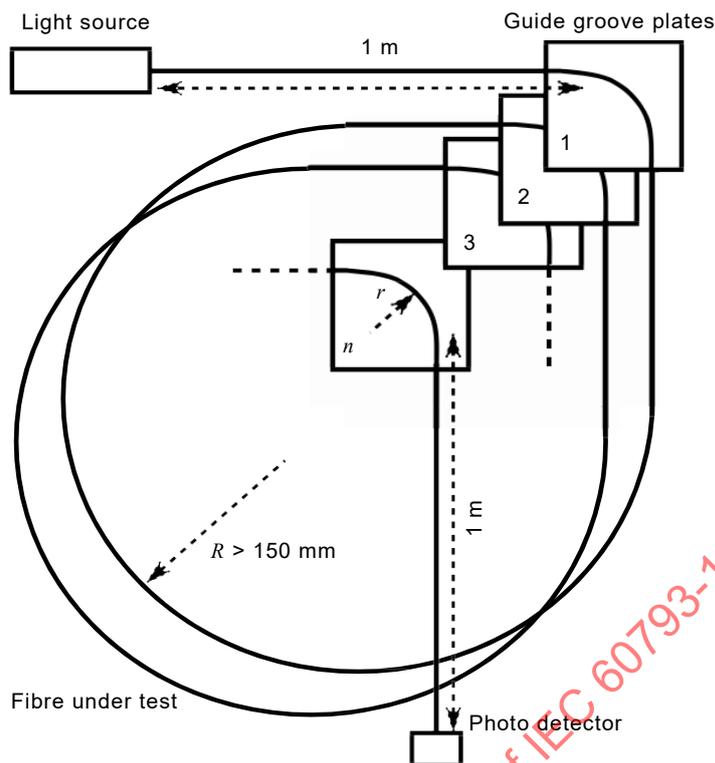


Figure 6 – Multiple bends using stacked plates

Macrobending loss caused by multiple bends of various radii can be measured simultaneously by stacking plates cut with grooves of various specified bend radii (see Figure 6).

Unless otherwise specified in the detail specification, the default values for the test are as follows:

- macrobend radius: $r = 25$ mm;
- number of macrobends: $n = 10$;
- slack bend radius, $R \geq 150$ mm;
- wavelengths: 650 nm, 850 nm or 1 300 nm.

These parameters correspond to the interval between each macrobend being $s \geq 1$ m, and a sample length $L \geq 11$ m.

The added bend loss caused by bending shall be measured using either the transmitted power monitoring technique (Annex A) or the cut-back technique (Annex B). Use cladding mode strippers at the source and detector ends of the specimen. A suitable cladding mode stripper consists of three turns of the FUT around a 15 mm radius mandrel.

Perform the test using the following procedure:

- a) cut the fibre to the appropriate length and wrap it on a spool or lay it on a flat surface so that the fibre has a bend radius ≥ 150 mm;
- b) measure the transmitted power;
- c) place the fibre in the measurement apparatus (Figure 1 and Figure 6);
- d) measure the transmitted power.

When testing multiple macrobends, such as using the default value of $n = 10$, the mode distribution encountered at a specific macrobend may depend on how many macrobends precede it. For example, the first bend can influence the launch condition at the second bend, and the second bend can influence the launch condition at the third bend, etc. Consequently, the macrobending added loss at a given bend can be different from the macrobending added

loss at another bend. In particular, the first bend can have the largest influence on following bends. Consequently, the macrobending added loss produced by multiple bends should not be expressed in the units of "dB/bend" (by dividing the total added loss by the number of bends). Therefore, the specification for macrobend added loss should not be stated in the units of "dB/bend".

7 Calculations

The results are reported in dB as:

$$\gamma = 10 \log_{10} \left(\frac{P_{\text{str}}}{P_{\text{Bend}}} \right) \quad (3)$$

where

γ is the loss, in dB;

P_{str} is the power measured without the bend;

P_{Bend} is the power measured with the bend present³.

NOTE For single-mode fibre, the loss can be reported in dB/turn.

8 Results

8.1 Information available with each measurement

Report the following information with each measurement:

- date and title of measurement;
- identification of specimen;
- length of specimen;
- curvature radius as macrobend radius and measurement set-up (method A);
- macrobend radius (method B);
- number of turns (method A);
- number of macrobends (method B);
- wavelength(s) of interest;
- launching conditions (MM fibres only);
- macrobending loss (dB).

8.2 Information available upon request

The following information shall be available upon request:

- measurement method used: A or B;
- power measurement method: power monitoring or cut-back;
- description of measurement apparatus arrangement;
- details of computation technique;
- date of latest calibration of equipment.

9 Specification information

The detail specification shall specify the following information:

- type of fibre to be measured;
- launching conditions (MM fibres only);

³ The power through the straight fibre can be calculated from the fibre attenuation coefficient, the length tested, and the output power of the source.

- radius of curvature as macrobend radius (method A);
- macrobend radius (method B);
- number of turns (method A);
- number of macrobends (method B);
- failure or acceptance criteria;
- information to be reported;
- wavelength(s) of interest;
- any deviations from the procedure that apply.

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Annex A (normative)

Change in transmittance by transmitted power technique

A.1 Apparatus

A.1.1 General

The arrangement shall provide a monitoring for optical transmittance with high resolution and good stability over the time and temperature changes given in the relevant product specification.

Figure A.1 is an example of a typical arrangement suitable for use when carrying out mechanical or environmental tests in a laboratory or factory. By comparison with a reference sample, it provides a measurement of the change in optical transmittance, corrected for any changes that can occur in the optical source. Connections shall have stable coupling conditions.

Figure A.2 is an example of a typical arrangement suitable for use in the field, laboratory or factory where long-term tests are required, in cases where it is possible to stabilise the optical source by optical feedback.

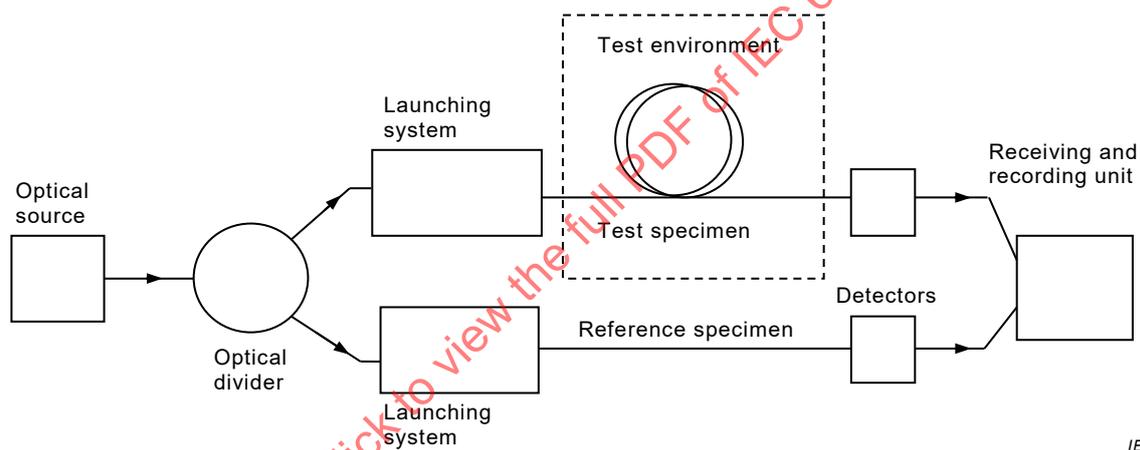


Figure A.1 – Measurement of change in optical transmittance using reference specimen

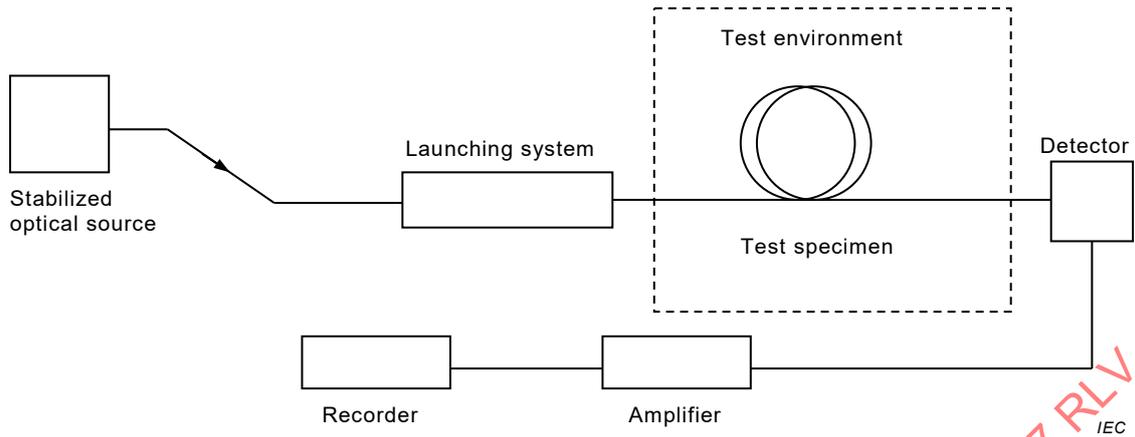


Figure A.2 – Measurement of change in optical transmittance using stabilized source

A.2 Procedure

Before the test sequence, measure the initial optical power, P_{0t} , from the test specimen and, in the case of Figure A.1, the initial optical output power, P_{0r} , from the reference specimen.

During the test sequence specified in the appropriate mechanical, environmental, or other test being carried out, measure the subsequent optical output powers, P_{nt} ($n = 1, 2, 3, \dots$), from the test specimen and, in the case of Figure A.1, the subsequent powers, P_{nr} , from the reference specimen.

In the above measurements, quantities proportional to the absolute power, rather than the absolute powers themselves, may be measured. In the case of Figure A.1, the proportionality factor may differ between the test and reference channels. The proportionality factor(s) shall remain constant for the duration of the test sequence.

A.3 Calculations

Calculate the changes in optical transmittance during the test sequence (in decibels).

According to Figure A.1:

$$D_n(\lambda) = 10 \log_{10} \frac{P_{0r}(\lambda) \times P_{nt}(\lambda)}{P_{0t}(\lambda) \times P_{nr}(\lambda)} \tag{A.1}$$

According to Figure A.2:

$$D_n(\lambda) = 10 \log_{10} \frac{P_{nt}(\lambda)}{P_{0t}(\lambda)} \tag{A.2}$$

where

$D_n(\lambda)$ is the change in optical transmittance during the sequence, in dB at wavelength λ ;

$P_{0t}(\lambda)$ is the initial optical output power from the test specimen, in mW;

$P_{0r}(\lambda)$ is the initial optical output power from the reference specimen, in mW;

$P_{nt}(\lambda)$ is the subsequent optical output power from the test specimen, in mW;

$P_{nr}(\lambda)$ is the subsequent optical output power from the reference specimen, in mW;

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Annex B (normative)

Cut-back technique

B.1 General

The cut-back technique is 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.

B.2 Apparatus

B.2.1 General apparatus for all fibres

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

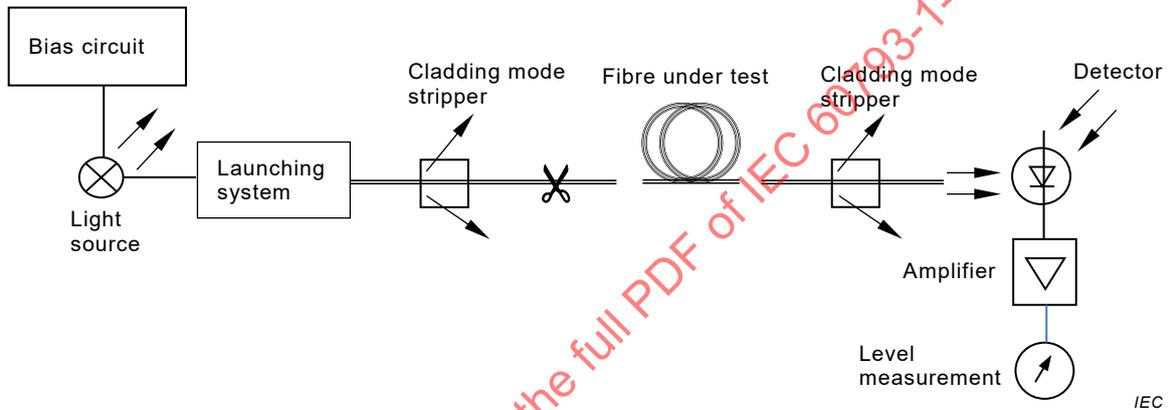


Figure B.1 – Arrangement of equipment to perform loss measurement at one specified wavelength

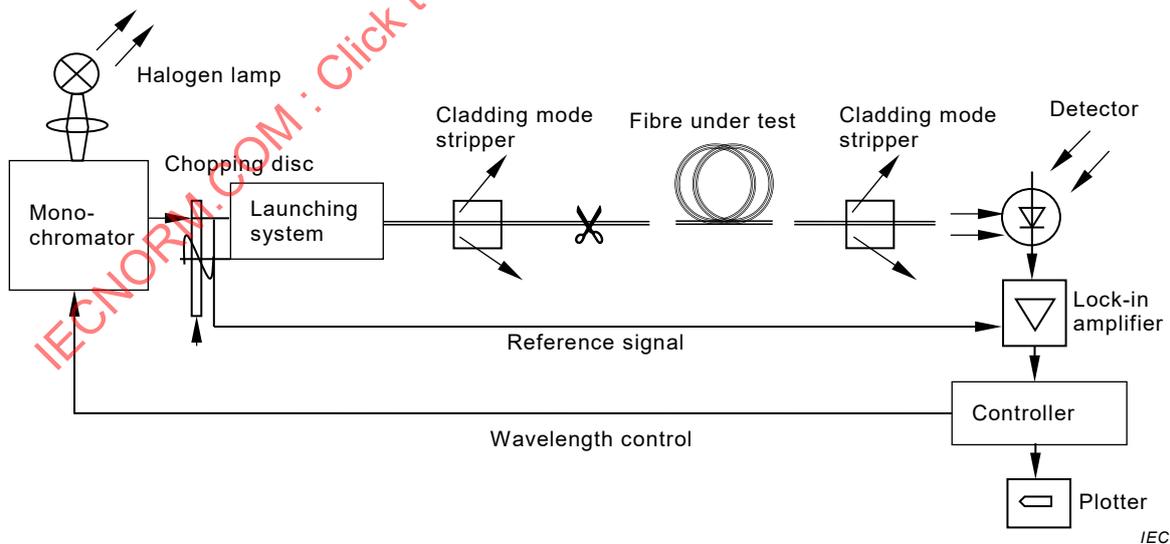


Figure B.2 – Arrangement of equipment used to obtain a loss spectrum

B.3 Procedure

Set the FUT in the measurement apparatus. Record the output power, $P_2(\lambda)$.

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.

B.4 Calculations

Calculate the attenuation between the points where $P_1(\lambda)$ and $P_2(\lambda)$ have been measured, using Equation (B.1), or attenuation coefficient by using Equation (B.2), or both, as required.

The attenuation of a fibre at wavelength λ between two cross-sections, 1 and 2, separated by a distance is defined as

$$A(\lambda) = \left| 10 \log_{10} \frac{P_1(\lambda)}{P_2(\lambda)} \right| \quad (\text{B.1})$$

where

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

$P_1(\lambda)$ is the optical power traversing cross-section 1;

$P_2(\lambda)$ is the optical power traversing cross-section 2.

For a uniform fibre under steady state conditions, it is possible to define the attenuation per unit length or the attenuation coefficient as follows:

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

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 km.

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Annex C (normative)

Requirements for the optical source characteristics for A1 multimode measurement

C.1 Encircled flux (EF)

The EF is the ratio of the cumulative near field power to the total output power as a function of radial distance from the optical centre of the fibre core. It is determined from the near field measurement of the light coming from the end of the launching cord.

The near field measurement is conducted in accordance with IEC 61280-1-4. The measured near field result is a function, $I(r)$, of radius, r , away from the optical centre of the core, which is used to generate the encircled flux (EF) function as:

$$EF(r) = \frac{\int_0^r xI(x)dx}{\int_0^R xI(x)dx} \quad (C.1)$$

where R is an integration limit defined in IEC 61280-1-4.

C.2 Limits on encircled flux

These requirements are suitable for cabling using category A1a and A1b multimode fibres that are defined in IEC 60793-2-10 as 50 μm and 62,5 μm core fibres, both with 125 μm cladding diameter. The requirement for other categories of multimode fibres is under study.

The limits for the encircled flux are derived from a target near field and a set of boundary conditions designed to constrain the variation in attenuation due to variations in the source launch distribution to within $\pm 10\%$ or $\pm X$ dB, whichever is largest, of the value that would be obtained if the target launch were used. Only coupling losses are taken into account for these attenuation values.

The theory leading to the EF limits is based on assumptions that include

- fibre core refractive index dimension and shape,
- spectral width, and
- Hermite-Gauss model for mode fields.

Deviation from these assumptions can lead to additional attenuation variance. One assumption is that the attenuation is measured with a light source and power meter (LSPM) method in which the light is coupled forward through the connections, and the backscattered light is not considered. The OTDR method is based on backscattered light, which propagates different paths in the fibre compared to the LSPM method. Accordingly, coupling is different at connections. As a consequence, the understanding of the relationship of the attenuation variance obtained from an OTDR to the encircled flux limits is incomplete.

The source launch conditions are described at the output of the launch cord. It is understood that the source, as supplied, has been verified by the test equipment manufacturer to produce the specified launch using a test cord with certain specifications. In the event that the launch cord needs to be replaced, obtain one that is compatible with the recommendation of the test equipment supplier or verify its compatibility by one of the procedures in IEC 61280-4-1.

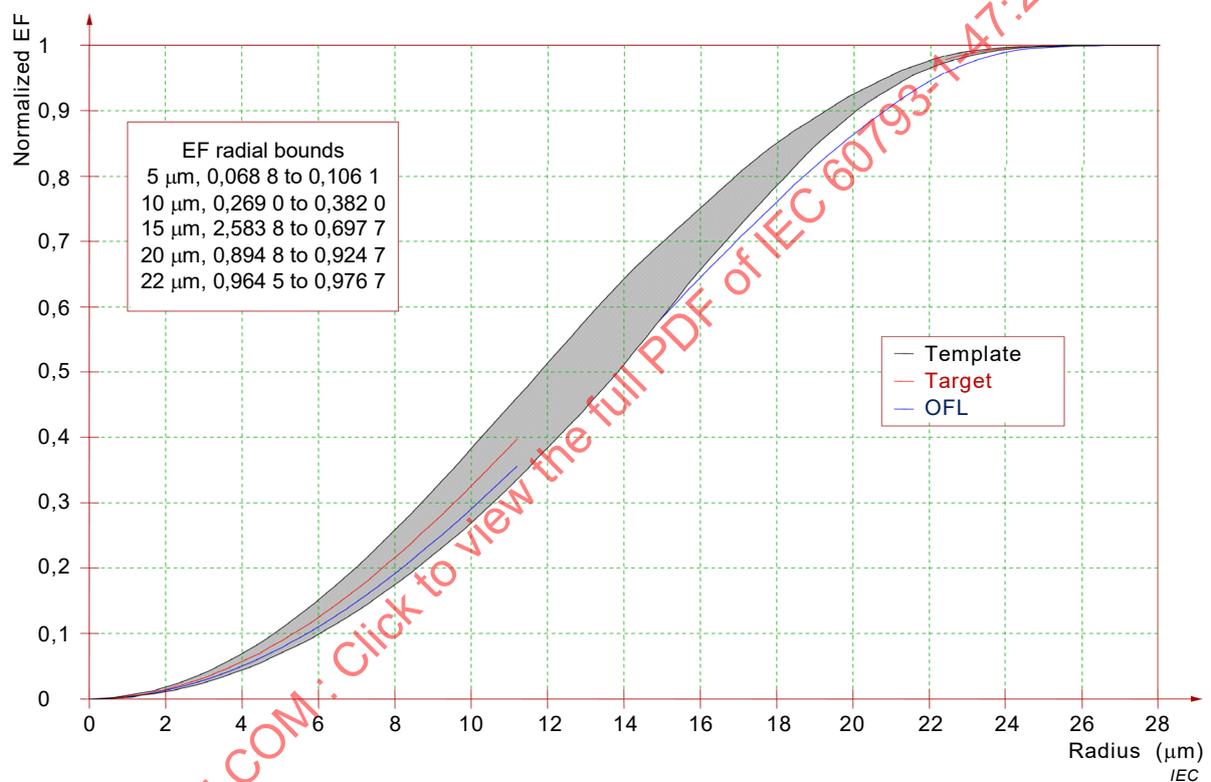
The variable X is a tolerance threshold that varies with fibre core size and wavelength according to the values in Table C.1.

Table C.1 – Threshold tolerance

Threshold dB	Wavelength nm	
Fibre nominal core diameter (μm)	850	1 300
50	0,08	0,12
62,5	0,10	0,15

Table C.1 is referenced to nominal core diameter. The core diameter of the fibre in the actual launch cord is critical to good performance. A tolerance of better than $\pm 1,0 \mu\text{m}$, i.e., $\pm 0,7 \mu\text{m}$, is recommended.

An example of the encircled flux template for A1a fibre at 850 nm is shown in Figure C.1. The target EF along with the EF that would be obtained by an overfilled launch is also shown.



NOTE Attenuation deviation constraints, 850 nm, 50 μm . 75 % shape tol, link constraints (μM SHIFT \times #CMPTS, dB Tol) = (2,0 dB \times 2,08 dB), (3,0 dB \times 2,08 dB), (4,0 dB \times 2,08 dB), (5,0 dB \times 2,10 %), (2,0 dB \times 5,08 dB), (3,0 dB \times 5,10 %), (4,0 dB \times 5,10 %), (5,0 dB \times 5,10 %).

Figure C.1 – Encircled flux template example

The EF requirements are defined as a table of limiting values for each of a set of particular radial values for each combination of fibre core size and wavelength. These limiting values are given in Table C.2 through Table C.5.

Table C.2 – EF requirements for 50 μm core fibre cabling at 850 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,278 5	0,335 0	0,391 5
15	0,598 0	0,655 0	0,711 9
20	0,910 5	0,919 3	0,929 5
22	0,969 0	0,975 1	0,981 2

Table C.3 – EF requirements for 50 μm core fibre cabling at 1 300 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,279 2	0,336 6	0,394 0
15	0,599 6	0,656 7	0,713 8
20	0,907 2	0,918 6	0,930 0
22	0,966 3	0,972 8	0,979 3

Table C.4 – EF requirements for 62,5 μm core fibre cabling at 850 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,168 3	0,210 9	0,253 5
15	0,369 5	0,439 0	0,508 5
20	0,633 7	0,692 3	0,750 9
26	0,924 5	0,935 0	0,945 5
28	0,971 0	0,978 3	0,985 6

Table C.5 – EF requirements for 62,5 μm core fibre cabling at 1 300 nm

Radius μm	EF lower bound	Target	EF upper bound
10	0,168 0	0,211 9	0,255 8
15	0,369 9	0,440 9	0,511 9
20	0,636 9	0,694 5	0,752 1
26	0,925 4	0,935 7	0,946 0
28	0,970 8	0,978 2	0,985 6

Annex D (informative)

Small bend radius phenomena

D.1 General

Annex D illustrates some features of single-mode fibre behaviour when bent to particularly small radii, depending on the fibre construction. It is based on practical experience of several fibre manufacturers.

The phenomena described in Annex D can affect the quality of transmission. It is therefore recommended that fibre performances are confirmed under actual operating conditions, for example wavelength, bend radii and bent fibre length.

D.2 Interference between propagating and radiating modes

When measuring macrobending loss at low bend radii, a secondary effect due to interference among the fundamental propagating mode in the core and radiating modes can occur if the length of the sample under bend is not sufficient to suppress radiating modes. In this phenomenon, the propagating optical signal is irradiated from the bent fibre core and back reflected at curved interfaces outside the core (e.g. core-cladding or cladding-coating or coating-air, similar to the so called "whispering gallery modes phenomenon"), thus interfering with the propagating mode. Under certain deployment conditions, constructive and destructive interference can occur, leading to oscillations in the spectral loss.

In case these effects occur, curve fitting can be applied for evaluating the spectral loss curve; the fit shall be based on the exponential behaviour of loss vs. wavelength. It is expected that the fitting will produce values that would be obtained with the interference effects substantially reduced, as would be the case if the test was carried out on a number of turns sufficiently large to suppress interference effects or if index-matching materials were used. The fitting technique, however, allows the measurement to be carried out and completed, preventing the need of unpractical set-ups and measurement conditions.

An example of this oscillating behaviour and of a possible fitting curve (A) is shown in Figure D.1. Two consecutive deployments in a $R = 7,5$ mm test set-up with 18x a 180° bend (U-turn deployment) result in different loss curves but with coincident curve fits.

When fitting in the presence of peaks and valleys, verify that there are enough of them, for example four, so that their impact on the fit is balanced.

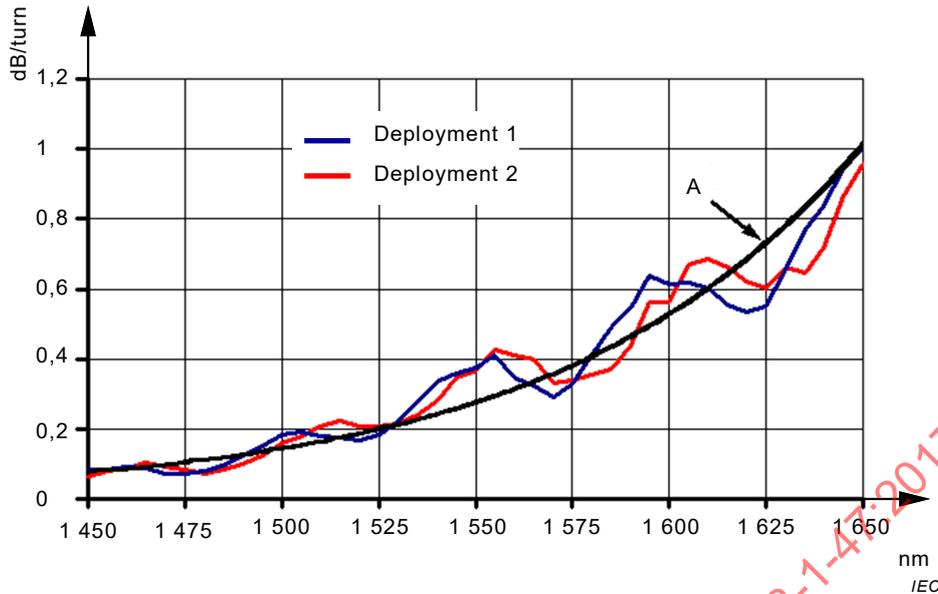


Figure D.1 – Loss curves versus curve fits

A similar oscillatory behaviour can be observed at a fixed wavelength for changing radii and/or for changing temperature: fitting techniques are also applicable in this case.

Due to the statistical nature (to some extent) of the interference phenomenon, it is recommended that a curve fit is carried out from which bending loss values at specified wavelengths are derived.

For optimizing the fitted curve to the measurement data, various methods are available. Well known is the "least square method" that minimizes the sum of squared differences between measured and fitted values. Other possibilities are for example to minimize "mean minus median" of differences between measured and fitted values, or to minimize "mean" or "median" of differences between measured and fitted values. To perform the curve fitting, facilities like the Solver in Excel⁴ can be used.

Other methods become available when we do not fit with the curve

$$\gamma = A^{\alpha\lambda} \tag{D.1}$$

where

γ is the bend loss, in dB.

but fit with a linear curve which is obtained by taking the natural logarithm of both sides of this formula:

$$\ln[\gamma] = \alpha\lambda \times \ln A \tag{D.2}$$

where

γ is the bend loss, in dB.

Fitting with this linear curve using the least square method enables the use of a relatively simple analytical expression. This expression facilitates real time calculation of fitting coefficients during the measurement. Drawback of this method is that, due to the natural logarithm, preference is given to lower wavelength measurement values, where in general the real interest is for the higher wavelengths, for example 1 550 nm and 1 625 nm. This can be compensated by using "weighted least square methods" that give more weight to the higher wavelength points.

⁴ Excel is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

All methods described enable fitted curves with very good correlation to the measured values. Most important however is the accuracy of the bend loss values at specific wavelengths that will be derived from it, for example at 1 550 nm and 1625 nm.

The interference between the fundamental mode and lossy cladding and coating modes can be eliminated by measuring loss of a bent fibre when immersed in a high index fluid (refractive index higher than the refractive index of the outer fibre coating). Measurements in this situation can give a good impression of the intrinsic bend loss of the fibre and can be used to evaluate specific curve fitting optimization methods.

The accuracy of the curve fit further depends on the wavelength range of used measurement points and the total number of points taken. A larger number of points increase accuracy. Care should be taken that selected measurement points are not influenced by injected higher order modes.

D.3 Polarization effects

When measuring macrobending loss at very low bend radii, polarization of the propagating or radiating light may affect the results. Since the light leaving the fibre is subjected to several reflections from different interfaces (e.g. cladding to coating, coating to air, coating to contact materials), some degree of polarization may be present even for unpolarized sources. These polarization dependent losses (PDL) are functions of the wavelength and should be taken into account when comparing results from different measurements or laboratories.

D.4 High power damage

In some extreme conditions (very high power, very tight bends), the temperature of the coating and of the glass can rise to very high values, eventually causing the coating to break down and the glass to collapse. These extreme conditions, however, are not typical of standard telecom networks deployment and operations. Detailed information about this phenomenon can be found in IEC TR 62547.

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Annex E (informative)

Parallel plate (2-point) macrobend loss approximation

E.1 General

Annex E describes a 2-point macrobending loss measurement for estimating a macrobending loss of single mode fibres only. This measurement is not an alternative to the normative macrobend tests. The 2-point macrobending loss measurement can be utilized to approximate the effective macrobending loss for a broad wavelength range at various effective bends. The term "effective" is used because the fibre is not shaped circularly with this technique, but rather approximates a parabola.

This measurement can be used to compare different single mode fibre types, although care should be taken to ensure that optical attributes are approximately matched. Compared with the normative macrobend test, the 2-point macrobend loss measurement results differ from the normative test, tending to be a higher loss value with larger variability.

E.2 Specimen

The specimen should be of sufficient length to allow adequate coupling to the measurement system and positioning in the apparatus. Any further fibre length should not affect the measurement results, provided that the SNR is optimised.

E.3 Apparatus

E.3.1 General

A possible test apparatus is provided in Figure E.1. The test setup is designed to measure the optical signal response through the FUT under different controlled bent conditions. The launch characteristics can be found in 4.3.2.2.

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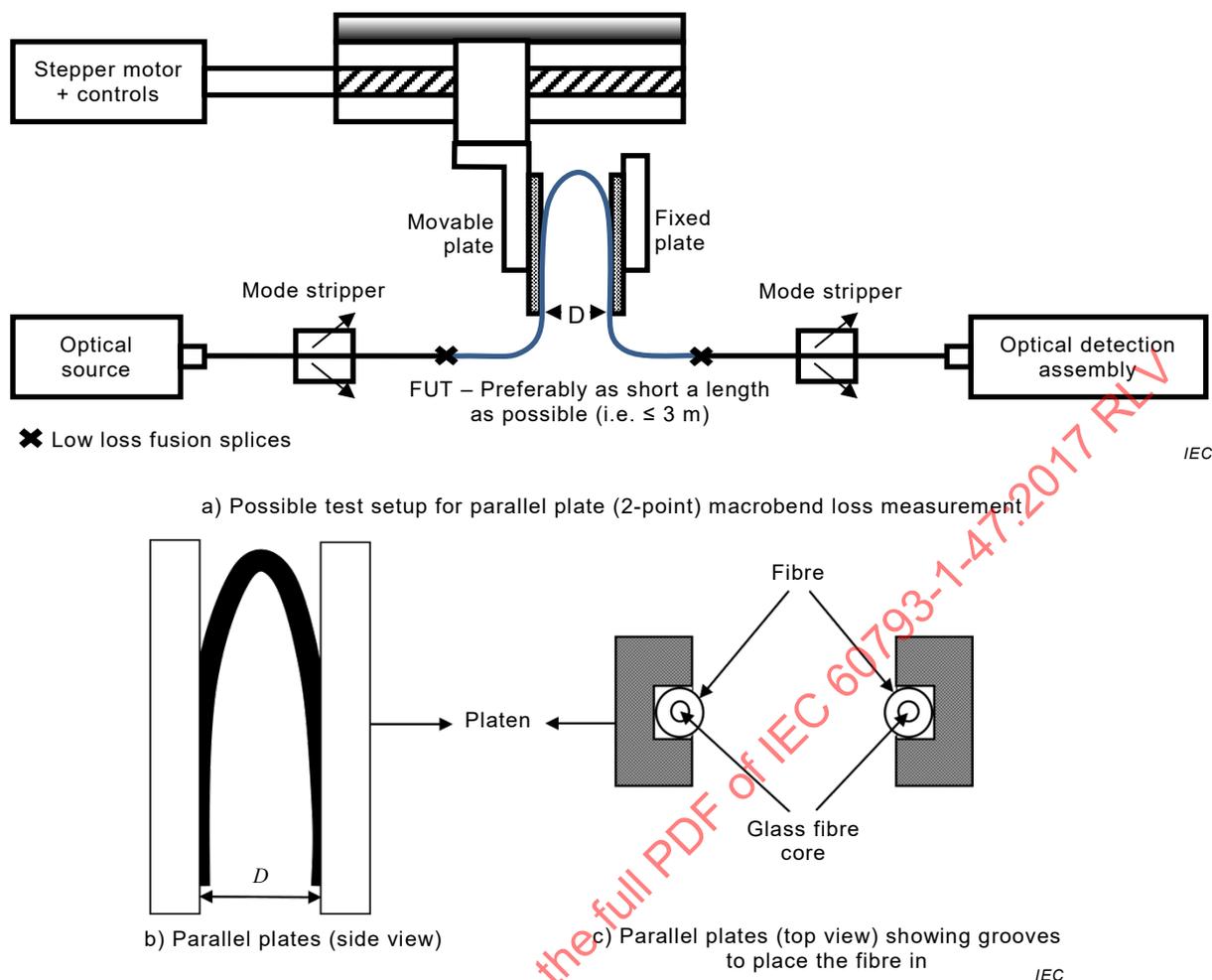


Figure E.1 – Schematic of possible (two-point bend) apparatus

The effective bend radius, R_{eff} , can be approximated by the following expression:

$$R_{\text{eff}} = \frac{D - d}{2(1,198)} \quad (\text{E.1})$$

where

D is the separation of the surfaces making contact with the fibre;

d is the fibre diameter.

NOTE This approximation, however, is not equivalent to the bend radius determined by the normative macrobending loss methods.

E.3.2 Stepper motor control

This device allows accurate, reliable, repeatable motorized control of the linear table. The repeatability of the stepper motor should be matched to the requirements of the bend deployment.

E.3.3 Movable plate

The movable plate converts the stepper motor rotation to linear translation by means of a lead screw.

E.3.4 Fixed plate

This device holds the fibre against the movable plate.

E.4 Procedure

- a) Couple the optical source to one end of the fibre and measure the reference optical power using a detection system coupled to the other end.
 - The FUT should be in a loosely coiled deployment which does not induce macrobending.
- b) Place the FUT between two parallel plates with the section of FUT between the plates deployed in a half loop.
 - Each plate may have a shallow groove machined in it along its longitudinal axis to serve as a fibre guide. The fibre should be deployed between the plates resting in the bottom of the grooves. By using grooves, as the distance between the plates is changed, the length of fibre between the plates naturally changes to maintain a half loop under bend. This eliminates the need to manually adjust the length of sample under bend to maintain a half loop. The section of fibre under bend is otherwise unconstrained, forming a natural curvature.
 - One additional advantage of this approach is that it facilitates the loading of the fibre after a reference measurement without disturbing the source or detector connections.
 - V-grooves can also be used, but care shall be taken to ensure that the distance between the two sides of the deployed fibre satisfies the desired bend diameter.
- c) Measure the power level through the FUT.
 - The optical bending loss can be measured by spectral attenuation over a designated wavelength range. This provides data at any wavelengths of interest. The loss as a function of wavelength can be plotted to assess the fibre's response at each effective bend radius. An example of one of these plots can be seen in Figure B.2.
- d) Adjust the movable plate to the next predetermined increment. At each additional increment, make sure the FUT is positioned correctly and measure the power level.
 - At each increment, the fibre length between the plates is adjusted to provide a half turn of approximate constant radius.
 - The effective bend radius can be approximated by Equation (E.1).
- e) Repeat until all the positions have been evaluated.

E.5 Calculation

Refer to Clause 7 for loss calculation.

E.6 Results

- a) The measured values should be reported as dB/turn.
- b) The measured values then could be fit to any suitable method.

EXAMPLE 1 The calculated loss data as a function of effective bend diameter, $2R_{\text{eff}} = D_{\text{eff}}$, can be fitted with a simple exponential function and plotted on a log scale, as depicted in Figure E.2, for particular wavelength of interest.

NOTE Noise can cause fitting problems at low bend losses.

The extrapolation to effective bending diameters outside the range of tested diameters is not recommended.

EXAMPLE 2 The spectral calculated loss data can be plotted as a function of wavelength for a given effective bend to evaluate the approximate loss as shown in Figure E.3.

- c) The data may be fitted to an exponential curve to smooth the variability associated with the presence of the usual whispering gallery modes.

Additional statistical treatments such as implementing a confidence interval may also be utilized.

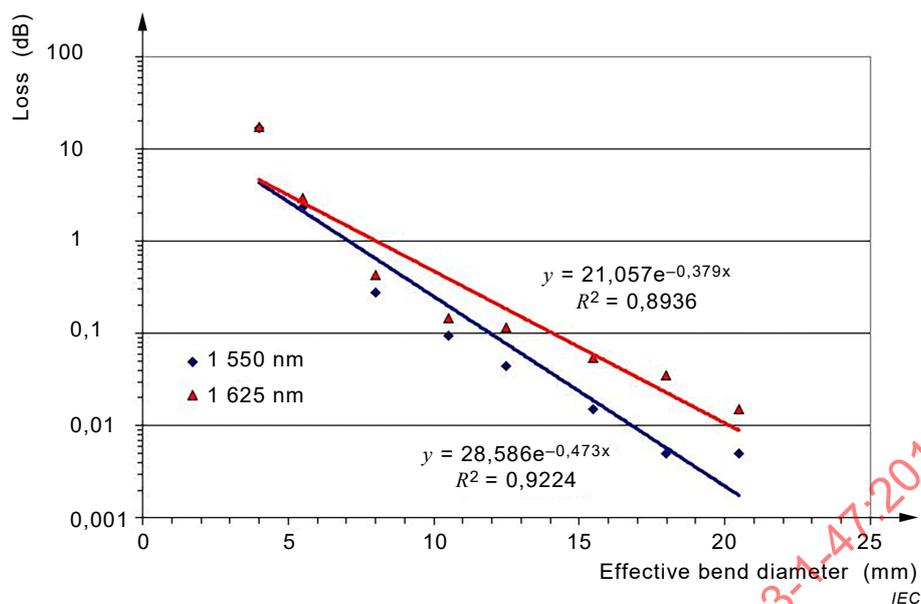


Figure E.2 – Example of applying an exponential fit to the spectral data of a B6_a2 fibre

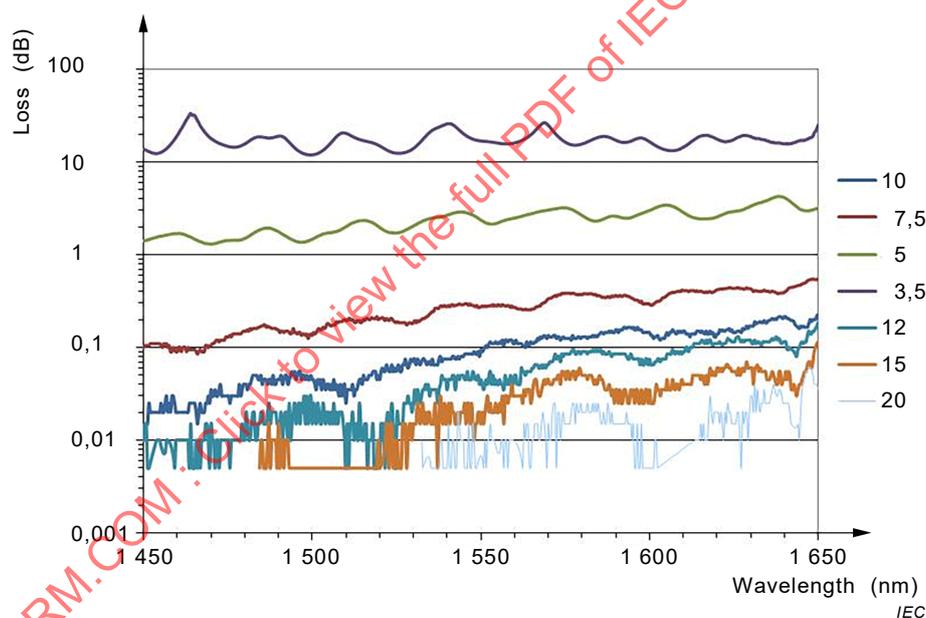


Figure E.3 – Example of 2-point bend test data for a B6_a2 fibre

E.7 Comparison of results with normative test

It should be considered that results from this measurement are not equivalent to ones obtained from the normative macrobend tests. Table E.1 illustrates the differences that can occur between the two test methodologies. The 2-point measurement provides different results from the normative test.

It should also be considered that a 2-point measurement should not be applied to measure low bend loss; for example, bend loss of less than 0,5 dB, such as the bend loss at a large bend and/or of bend-insensitive fibres. The 2-point method results in a large variability of measured macrobend losses.

Table E.1 – Comparison of parallel plate (2-point) versus method A macrobend loss measurement for a B6_b3 fibre at 10 mm diameter (ratio of mandrel / 2-point)

Fibre	1 550 nm	1 625 nm
A	0,99	0,93
B	0,89	0,90
C	1,07	0,97
D	1,21	1,17
E	0,82	0,89
F	0,97	1,07
G	0,84	0,84
H	1,06	1,07
I	1,08	1,05
J	1,15	1,24
K	1,51	1,21
L	1,10	1,04
NOTE Each data point represents an average of five measurements.		

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

FIBRES OPTIQUES –

**Partie 1-47: Méthodes de mesure et procédures d'essai –
Pertes par macrocourbures**

AVANT-PROPOS

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Cette quatrième édition annule et remplace la troisième édition publiée en 2009 dont elle constitue une révision technique.

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

- a) l'Annexe A a été renumérotée Annexe D;
- b) une nouvelle Annexe A portant sur la technique de la mesure de la puissance transmise a été introduite;
- c) l'Annexe B portant sur la technique de la fibre coupée a été introduite;

- d) l'Annexe C portant sur les exigences relatives aux caractéristiques des sources optiques pour une mesure des fibres multimodales de catégorie A1 a été introduite;
- e) l'Annexe E portant sur l'approximation des pertes par macrocourbures utilisant des plaques parallèles (deux points) a été introduite.

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

FDIS	Rapport de vote
86A/1823/FDIS	86A/1828/RVD

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

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

La présente norme doit être lue conjointement avec l'IEC 60793-1-1:2017.

Une liste de toutes les parties de la série IEC 60793, publiées sous le titre général *Fibres optiques*, peut être consultée sur site web de l'IEC.

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INTRODUCTION

Les publications de la série IEC 60793-1 concernent les méthodes de mesure et les procédures d'essai applicables aux fibres optiques.

Au sein de cette même série, plusieurs domaines différents sont regroupés comme suit, mais tous les numéros peuvent ne pas être utilisés:

Parties 1-10 à 1-19:	Généralités
Parties 1-20 à 1-29:	Méthodes de mesure et procédures d'essai pour les dimensions
Parties 1-30 à 1-39:	Méthodes de mesure et procédures d'essai pour les caractéristiques mécaniques
Parties 1-40 à 1-49:	Méthodes de mesure et procédures d'essai pour la transmission et les caractéristiques optiques
Parties 1-50 à 1-59:	Méthodes de mesure et procédures d'essai pour les caractéristiques d'environnement

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FIBRES OPTIQUES –

Partie 1-47: Méthodes de mesure et procédures d'essai – Pertes par macrocourbures

1 Domaine d'application

La présente partie de l'IEC 60793 établit des exigences uniformes pour la mesure des pertes par macrocourbures pour les fibres optiques unimodales (classe B) à 1 550 nm ou 1 625 nm, pour les fibres multimodales de catégorie A1 à 850 nm ou 1 300 nm, et les fibres multimodales des catégories A3 et A4 à 650 nm, 850 nm ou 1 300 nm, contribuant ainsi au contrôle des fibres et câbles dans des relations commerciales.

Le présent document décrit deux méthodes destinées à mesurer la sensibilité aux macrocourbures:

- Méthode A – Enroulement de fibre, se rapporte aux fibres unimodales de classe B et aux fibres multimodales de catégorie A1.
- Méthode B – Courbures d'un quart de cercle, se rapporte aux fibres multimodales de catégories A3 et A4.

Pour les deux méthodes, les pertes par macrocourbures peuvent être mesurées par des techniques générales d'affaiblissement des fibres, par exemple la technique de mesure de la puissance (voir Annexe A) ou la technique de la fibre coupée (voir Annexe B). Les méthodes A et B sont susceptibles de produire des résultats différents si elles sont appliquées à la même fibre. Ceci est dû au fait que la différence fondamentale entre les deux méthodes réside dans la façon de les déployer, comprenant à la fois le rayon de courbure et la longueur de fibre courbée. La raison de cette différence repose sur le fait que les fibres multimodales des catégories A3 et A4 sont conçues pour être installées sur de petites longueurs et avec un faible nombre de courbures par unité de longueur de fibre par rapport aux fibres unimodales et aux fibres multimodales de la catégorie A1.

Dans le présent document, le "rayon de courbure" est défini comme le rayon du support adapté de forme circulaire (par exemple, un mandrin ou une rainure de guidage sur une surface plane) sur lequel la fibre peut être courbée.

En outre, l'Annexe E (informative) a été ajoutée pour présenter une approximation des pertes par courbures pour des fibres unimodales de classe B sur une large plage de longueurs d'onde pour différentes courbures effectives.

2 Références normatives

Les documents suivants cités dans le texte 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 (toutes les parties), *Fibres optiques – Méthodes de mesure et procédures d'essai*

IEC 60793-1-1:2017, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance* (disponible en anglais seulement)

IEC 60793-2, *Fibres optiques – Partie 2: Spécifications de produits – Généralités*

IEC 60793-2-10, *Fibres optiques – Partie 2-10: Spécifications de produits – Spécification intermédiaire pour les fibres multimodales de catégorie A1*

IEC 61280-1-4, *Procédures d'essai des sous-systèmes de télécommunication à fibres optiques – Partie 1-4: Sous-systèmes généraux de télécommunication – Méthode de mesure du flux inscrit de la source lumineuse*

IEC 61280-4-1, *Procédures d'essai des sous-systèmes de télécommunication à fibres optiques – Partie 4-1: Installations câblées – Mesure de l'affaiblissement en multimodal*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions donnés dans l'IEC 60793-2, l'IEC 60793-1 (toutes les parties) et l'IEC 60793-1-1 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>

NOTE L'IEC 60793-2 donne des définitions générales sur les fibres, les normes de la série IEC 60793-1 sur les méthodes d'essai donnent des définitions des attributs spécifiés et l'IEC 60793-1-1 donne des définitions générales sur les essais.

4 Appareillage

4.1 Méthode A – Enroulement de fibre

L'appareil comprend un outil (par exemple, un mandrin ou une rainure de guidage sur une surface plane) capable de maintenir l'échantillon courbé selon un rayon indiqué dans la spécification intermédiaire de produit appropriée pour les fibres optiques ainsi qu'un appareil de mesure des pertes. Déterminer les pertes par macrocourbures à la longueur d'onde indiquée dans la spécification intermédiaire de produit appropriée par la technique de la mesure de la puissance transmise (Annexe A) ou par la technique de la fibre coupée (Annexe B), en respectant les conditions d'injection propres au type de fibre spécifique.

4.2 Méthode B – Courbures d'un quart de cercle

L'appareillage est constitué d'une ou plusieurs plaques, chacune avec une ou plusieurs "rainures de guidage" et d'un appareil pour mesurer les pertes. Les plaques doivent être conçues afin de pouvoir être empilées pendant l'essai sans qu'elles puissent toucher l'échantillon de fibre de la plaque inférieure ou supérieure, un tel contact affectant les résultats de mesure. Chaque rainure de guidage doit présenter un segment de quart de cercle (c'est-à-dire 90°) comme le montre la Figure 1. Le rayon de courbure r , c'est-à-dire le rayon du segment de quart de cercle, doit être précisé dans la spécification particulière. Il est recommandé d'utiliser des rainures de guidage dont la largeur est supérieure de 40 % par rapport au diamètre de la fibre.

Déterminer les pertes par macrocourbures à la longueur d'onde indiquée dans la spécification intermédiaire de produit appropriée par la technique de la mesure de la puissance transmise (Annexe A) ou par la technique de la fibre coupée (Annexe B), en respectant les conditions d'injection propres au type de fibre spécifique.

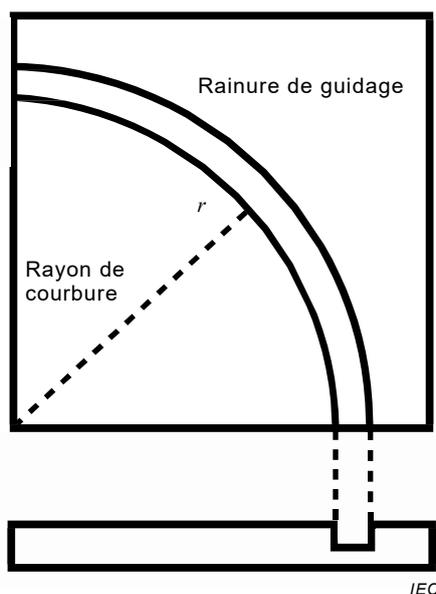


Figure 1 – Rainure de guidage d'un quart de cercle sur la plaque

4.3 Système d'entrée

4.3.1 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 être stable en position, en intensité et en longueur d'onde pendant une période de temps suffisamment longue pour effectuer toute 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 telle sorte que la raie soit étroite, par exemple inférieure à 10 nm, par rapport aux caractéristiques de l'affaiblissement spectral de la fibre. Aligner la fibre sur le cône d'injection ou connecter la fibre de manière coaxiale à une fibre d'injection.

4.3.2 Configuration de l'injection optique

4.3.2.1 Généralités

La Figure 2 représente la configuration générale de l'injection utilisée pour toutes les fibres. Appliquer la configuration appropriée pour produire une injection complète ou restreinte, en fonction du paramètre mesuré. Des informations plus détaillées sont présentées aux paragraphes 4.3.2.2 à 4.3.2.4, qui portent sur des catégories spécifiques de fibres unimodales et multimodales.

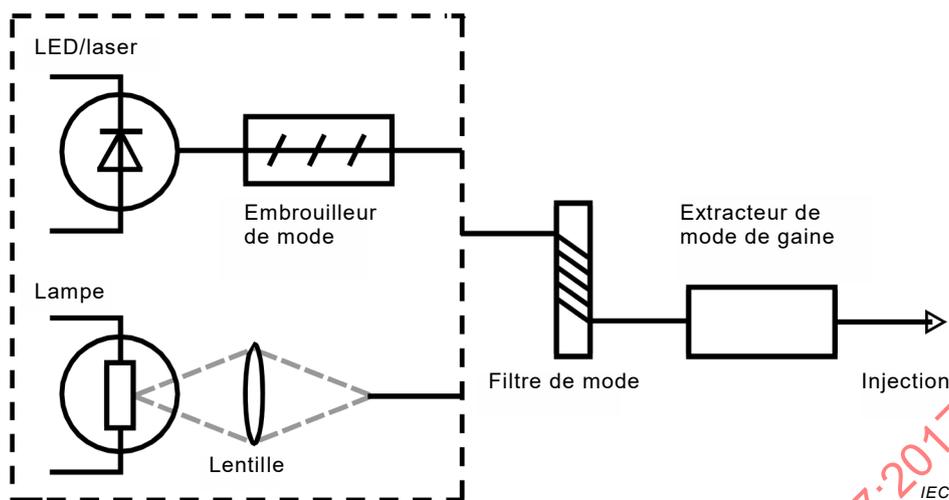


Figure 2 – Configuration générale d'injection

4.3.2.2 Configuration d'injection pour les fibres unimodales

4.3.2.2.1 Généralités

Un système de lentilles optiques ou une fibre amorce peuvent être utilisés pour exciter la fibre d'essai. La puissance couplée à la fibre doit être stable pendant toute la durée de la mesure (voir Figure A.1 ou Figure B.1).

4.3.2.2.2 Fibre amorce

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

4.3.2.2.3 Système de lentille optique

Si un système de lentille optique est utilisé, prévoir un moyen pour supporter de manière stable l'extrémité d'entrée de la fibre, par exemple un plateau à vide. Monter ce support sur un dispositif de positionnement de telle sorte que l'extrémité de la fibre puisse être positionnée de manière répétée dans le faisceau d'entrée. Un moyen de rendre le positionnement de la fibre moins sensible consiste à saturer spatialement et angulairement l'extrémité de la fibre.

4.3.2.2.4 Filtre de mode d'ordre élevé

Utiliser une méthode pour supprimer les modes de propagation d'ordre élevé dans la plage de longueurs d'onde d'intérêt.

Un exemple d'un tel filtre de mode d'ordre élevé est une boucle de rayon suffisamment petit pour décaler la longueur d'onde de coupure sous la longueur d'onde minimale d'intérêt, mais pas de taille si petite qu'elle induirait des oscillations dépendantes de la longueur d'onde.

Une autre option couramment utilisée avec les fibres unimodales insensibles aux courbures et les autres fibres unimodales présentant peu ou pas de réponse de coupure consiste à utiliser une fibre unimodale normalisée comme filtre de mode.

4.3.2.2.5 Extracteur de mode de gaine

Utiliser des techniques appropriées pour supprimer la puissance optique qui se propage dans la gaine lorsqu'elle influencerait de manière significative le signal reçu. L'extracteur de mode de gaine assure qu'aucun mode de rayonnement, se propageant dans la région de la gaine,

ne sera détectable après une courte distance le long de la fibre. L'extracteur de mode 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 réalise cette fonction.

4.3.2.3 Configuration d'injection pour les fibres multimodales A1

L'injection exigée pour mesurer les pertes par macrocourbures des fibres multimodales A1 doit être une injection à flux inscrit. L'Annexe C donne les exigences relatives aux caractéristiques de la source optique pour la mesure des fibres multimodales de catégorie A1.

Le flux inscrit émis par le cordon d'injection dépend des caractéristiques de la source de rayonnement lumineux émergeant de l'extrémité du connecteur femelle, de la connexion du cordon d'injection au connecteur femelle, de la fibre optique dans le cordon d'injection et de tout conditionnement de mode appliqué.

Il convient que le fabricant de l'appareil d'essai fournisse des spécifications relatives au cordon d'essai, compatibles avec la mise en œuvre de la source particulière utilisée. Lorsque la spécification concernant le cordon est satisfaite et qu'il est utilisé avec l'appareil d'essai, il convient de respecter les exigences relatives au flux inscrit.

4.3.2.4 Configurations d'injection pour les fibres multimodales A2 à A4

Des exemples de configurations d'injection générique pour des fibres pour liaisons de courtes distances décrits dans les Figure 3, Figure 4 et Figure 5 sont représentés ci-dessous.

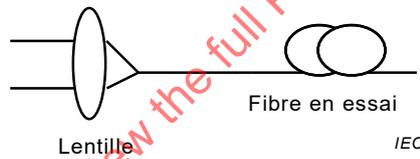


Figure 3 – Système de lentille

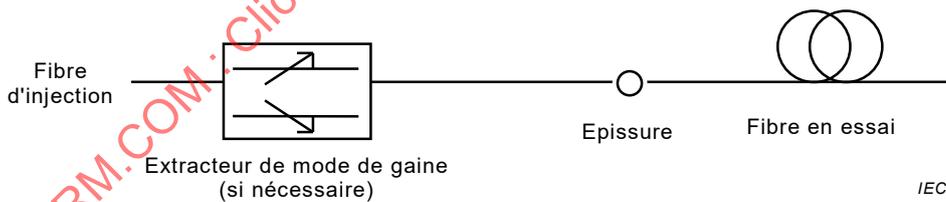


Figure 4 – Fibre d'injection

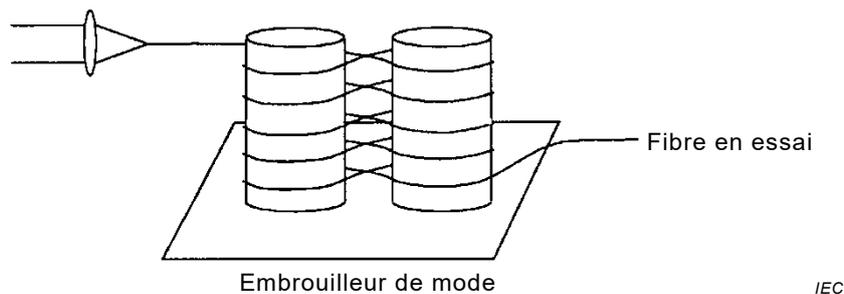


Figure 5 – Embrouilleur de mode (pour une fibre A4)

La reproductibilité des mesures d'affaiblissement des fibres à saut d'indice est critique. C'est pourquoi il est nécessaire de bien définir la configuration de l'injection. Cette configuration peut être réalisée en utilisant des composants optiques disponibles sur le marché. Elle doit être capable de fournir les tailles de points et les ouvertures numériques d'injection données au Tableau 1. En outre, la longueur d'onde de mesure doit être étalonnée à ± 10 nm.

Tableau 1 – Conditions d'injection pour des fibres A2 à A4

Attribut	Catégorie de fibre		
	A2 Cœur en verre/gaine en verre	A3 Cœur en verre/gaine en plastique	A3 Cœur en plastique/gaine en plastique
Taille du point	= taille du cœur de la fibre	= taille du cœur de la fibre	= taille du cœur de la fibre avec injection en mode complet (ou utiliser un embrouilleur de mode avec injection en mode équilibré)
Ouverture numérique	= ouverture numérique maximale de la fibre ^a	= ouverture numérique maximale de la fibre ^b	= ouverture numérique maximale de la fibre, avec injection en mode complet ^b
<p>^a Cette condition d'injection peut être produite en saturant un filtre de mode fait d'une fibre de 2 mètres identique à la fibre en essai, avec une extraction de mode de gaine appropriée et en utilisant la sortie de ce filtre de mode pour l'injecter dans la fibre en essai.</p> <p>^b Cette condition d'injection peut être produite de la même façon que celle décrite à la Note a. Toutefois, certains types de fibres A3 et A4 n'exigeront pas une extraction de mode de gaine pour le filtre de mode.</p>			

4.4 Système de sortie et détection

4.4.1 Diviseur optique

Si un diviseur optique est exigé, son rapport de division doit rester constant pendant l'essai. Le rapport de division et la stabilité de la température doivent être indiqués dans la spécification particulière. Des dispositifs disponibles dans le commerce ou fabriqués à la demande peuvent être utilisés.

4.4.2 Détecteur optique

La surface du détecteur optique doit être assez grande pour intercepter toute la puissance rayonnée dans le cône de sortie et le détecteur optique doit être suffisamment linéaire sur les puissances optiques rencontrées.

La réponse sur la surface active et la plage d'angle d'incidence à la longueur d'onde de mesure doivent être suffisamment uniformes pour assurer le mouvement du cône de sortie dans une position ou un angle par rapport au détecteur. Les limites imposées par la conception mécanique du matériel de mesure doivent être respectées et ne doivent pas affecter les résultats de manière significative.

Lorsque plusieurs détecteurs sont utilisés, comme dans le montage représenté à la Figure A.1, ils doivent provenir du même fabricant, être du même modèle et de linéarité comparable.

4.4.3 Ensemble de détection optique

Il convient que toute la puissance émise par le spécimen soit couplée à la région active du détecteur par un moyen approprié. Par exemple, un système de lentille optique, une fibre amorce terminée par une épissure en bout ou un couplage direct avec le détecteur peuvent être utilisés. Si le détecteur est déjà muni d'une fibre amorce, le diamètre du cœur et l'ouverture numérique de celle-ci 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 en effectuant la mesure. Un système typique peut inclure une photodiode en mode photovoltaïque amplifiée par un amplificateur de courant en entrée, avec détection synchrone par un amplificateur à verrouillage.

4.4.4 Traitement du signal

Il est d'usage de moduler la source de rayonnement lumineux afin d'améliorer le rapport signal/bruit au niveau du récepteur. Si une telle procédure est utilisée, 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 que ses caractéristiques soient connues.

Lorsque les pertes sont censées être faibles, d'autres courbures d'essai peuvent être utilisées à condition que des rainures distinctes soient prévues pour chaque courbure supplémentaire afin d'améliorer le rapport signal/bruit. Toutefois, l'approximation sur le diamètre de courbure et le contrôle des courbures peuvent se dégrader davantage.

5 Spécimen

5.1 Longueur des spécimens

5.1.1 Méthode A – Enroulement de fibre

La longueur de l'échantillon de fibre en essai doit être connue, comme indiqué dans la spécification particulière. En particulier, la longueur de l'échantillon en essai pour les pertes est déterminée par le montage de mesure, c'est-à-dire le rayon de courbure (R) et le nombre de tours (N); toute autre longueur de fibre n'affecte pas les résultats de mesure, à condition que le rapport signal/bruit soit optimisé.

5.1.2 Méthode B – Courbures d'un quart de cercle

La longueur du spécimen doit être déterminée conformément aux informations détaillées présentées en 6.2.

5.2 Extrémités du spécimen

Préparer une extrémité à face plane, perpendiculaire à l'axe de la fibre, aux extrémités d'entrée et de sortie de chaque spécimen en essai.

6 Procédure

6.1 Méthode A – Enroulement de fibre

6.1.1 Considérations générales

Enrouler la fibre de manière lâche sur l'outil, en évitant une torsion excessive de la fibre. Le nombre de tours, le rayon de courbure et la longueur d'onde pour lesquels les pertes doivent être mesurées sont traités ci-dessous en 6.1.1, ainsi qu'en 6.1.2 et 6.1.3.

Étant donné que le rayon de courbure réel est critique, une tolérance maximale de $\pm 0,1$ mm (pour les rayons inférieurs ou égaux à 15 mm) ou $\pm 1,0$ mm (pour de plus grands rayons) est acceptée. Une tolérance plus serrée sur des petits rayons est exigée pour une sensibilité de mesure supérieure.

Tant pour les fibres unimodales que pour les fibres multimodales, deux puissances optiques peuvent être mesurées en utilisant

- la technique de la mesure de la puissance, qui mesure l'augmentation de l'affaiblissement de la fibre due au passage de la position droite à la position courbée, ou
- la technique de la fibre coupée, qui mesure l'affaiblissement total de la fibre à l'état courbé. Afin de déterminer l'affaiblissement induit du fait des macrocourbures, il convient de corriger cette valeur pour tenir compte de l'affaiblissement intrinsèque de la fibre.

La longueur de fibre non enroulée sur le mandrin ainsi que la longueur de fibre coupée de référence doivent être exemptes de courbures qui peuvent modifier de manière significative les résultats des mesures. Il est également possible de réenrouler la fibre provenant d'un mandrin de rayon important (qui introduit des pertes par macrocourbures négligeables) sur le mandrin ayant le rayon exigé. Dans ce cas, les pertes par macrocourbures peuvent être directement déterminées en utilisant la technique de mesure de la puissance (sans correction de l'affaiblissement intrinsèque de la fibre).

Des précautions doivent être prises pour ne pas introduire de torsion sur aucune partie de fibre pendant la mesure, car ceci compromettrait le résultat.

6.1.2 Fibres unimodales

Différentes applications peuvent exiger des conditions de déploiement différentes: différents types de fibres ont été développés et présentent des performances en courbure optimisées pour chaque condition.

Deux environnements typiques sont reconnus pour des types de fibres (éventuellement) différents, pour lesquels il convient de prendre en considération différents montages de mesure lors de la caractérisation des performances de fibres.

- a) Réseaux longue distance: loin des zones urbaines, l'occupation de l'espace n'est typiquement pas un problème et les courbures imposées aux fibres peuvent être limitées à des rayons relativement grands. Il convient de soumettre à l'essai les fibres conçues pour cette application dans des conditions analogues, c'est-à-dire en enroulant les échantillons autour de mandrins de rayons relativement grands, par exemple dans la plage comprise entre 25 mm et 30 mm.

Ce montage de mesure est principalement affecté par des erreurs en relation avec un faible rapport signal/bruit et par une traction, des torsions ou des pliures indésirables sur la longueur de fibre relativement grande utilisée pour la mesure.

- b) Réseaux d'accès: les conditions de fonctionnement exigent des rayons de courbure aussi petits que possible, compatibles avec la durée de vie prévue et des pertes par courbures acceptables. Pour plus d'informations sur la durée de vie prévue, se reporter à l'UIT-T G Suppl. 59:2016. Il convient de soumettre à l'essai des fibres conçues pour cette application dans des conditions analogues, c'est-à-dire les échantillons étant courbés avec des rayons petits, par exemple dans la plage comprise entre 7,5 mm et 15 mm (voir Annexe C).

La mesure peut être affectée par différentes causes, par exemple des réflexions qui peuvent se produire au niveau de l'interface revêtement-air ou revêtement-verre, au niveau des surfaces environnantes (y compris la surface du mandrin, le cas échéant) ou au niveau des connecteurs.

L'essai peut être effectué sur des échantillons soit en réalisant un ou plusieurs tours complets (360°), à l'air libre ou autour d'un support adapté (mandrin), soit en faisant un nombre équivalent de tours partiels, par exemple demi-tours (180°) ou des quarts de tour (90°), à l'air libre ou autour de supports adaptés. La longueur en essai est différente pour les tours complets et pour les tours partiels, par exemple la longueur d'un tour complet étant deux fois la longueur d'un demi-tour ou quatre fois la longueur d'un quart de tour. Dans le présent document, le terme "enroulement" fait référence à un tour complet. Un enroulement pourrait également être constitué, par exemple, de deux demi-tours consécutifs¹ ou de quatre quarts

¹ Si le déplacement entre des demi-tours successifs est excessif, la longueur de l'échantillon disposé sur les deux demi-tours peut être plus courte qu'un enroulement. Un déplacement maximal entre deux demi-tours adjacents de 0,5 mm est, de ce fait, suggéré.

de tour consécutifs. Il convient de prendre cela en compte lors de la normalisation des résultats à la longueur de l'échantillon (nombre d'enroulements).

Les recommandations suivantes s'appliquent aux conditions d'essai dans les deux cas a) et b) indiqués ci-dessus:

Nombre de tours

- Il convient que le nombre de tours soit conforme aux valeurs indiquées dans la spécification de produit.
- Pour les fibres unimodales, l'affaiblissement augmente de façon linéaire avec le nombre de tours.
- Pour chaque rayon, le nombre de tours doit être choisi de telle manière que:
 - les pertes induites sont significativement plus élevées que la limite de détection du montage; si nécessaire, par exemple pour les fibres à faibles pertes par courbures, des essais peuvent être effectués avec davantage de tours que la spécification ne l'exige, suivis par la normalisation linéaire par rapport au nombre spécifié;
 - les pertes induites sont significativement plus faibles que le début de la région non linéaire dans le montage; pour des rayons de courbure dans la plage comprise entre 5 mm et 10 mm, ceci peut impliquer qu'il convienne de faire au maximum 5 à 10 tours.

Rayon de courbure

La valeur du rayon de courbure doit être conforme aux valeurs indiquées dans la spécification de produit².

Longueur d'onde

La longueur d'onde de mesure doit être de 1 550 nm ou de 1 625 nm, selon la spécification de produit applicable. Il convient de considérer que les pertes par courbures augmentent exponentiellement avec la longueur d'onde.

L'homogénéité des pertes par courbures en différentes positions angulaires sur la section transversale nécessite d'être vérifiée soit par plusieurs essais de positions angulaires, soit en vérifiant l'homogénéité du profil d'indice de réfraction efficace établissant les propriétés de guidage de la fibre en essai courbée.

6.1.3 Fibres multimodales (A1)

Les pertes par macrocourbures dans les fibres multimodales A1 varient avec le rayon de courbure et le nombre de tours autour d'un mandrin et sont moins sensibles à la longueur d'onde que les fibres unimodales. Toutefois, des effets d'oscillation avec la longueur d'onde liés à des groupes de modes successifs traversant la coupure et présentant une augmentation de pertes par courbures à ces longueurs d'onde peuvent se produire.

Les valeurs du rayon de courbure et le nombre de tours doivent être conformes aux valeurs indiquées dans la spécification. Lors des essais à plusieurs tours, l'affaiblissement qui se produit sur un tour spécifique dépend de l'affaiblissement des tours précédents. Les pertes ajoutées par macrocourbures incrémentielles diminuent avec chaque ajout de tour. Il convient que les pertes ajoutées par macrocourbures provoquées par plusieurs tours ne soient pas exprimées en unités "dB/tour" en divisant les pertes totales ajoutées par le nombre de tours. A la place, elles doivent être consignées en dB pour le nombre spécifié de courbures. Une extrapolation à un nombre de tours supérieur à celui spécifié donnerait lieu à une surestimation des pertes globales.

Pour les seules fibres multimodales, les caractéristiques d'injection de la source de rayonnement lumineux à la position d'injection de la fibre en essai doivent être compatibles avec l'application prévue des fibres. D'autres détails relatifs aux conditions d'injection des fibres multimodales sont donnés à l'Annexe C.

² La perte par courbure sur une fibre unimodale augmente exponentiellement lorsque la longueur d'onde augmente et lorsque le rayon diminue (voir Annexe D).

6.2 Méthode B – Courbures d'un quart de cercle

Cette méthode s'applique aux fibres multimodales des catégories A3 et A4. Il convient de positionner soigneusement la fibre soumise à l'essai dans la ou les rainures de guidage (voir Figure 1). Le début de chaque courbure contrôlée doit se situer à au moins s mètres du début de la courbure contrôlée suivante. Le début de la courbure contrôlée la plus proche du côté de l'injection doit être à au moins 1 m de l'injection. La fin de la courbure contrôlée la plus proche de l'extrémité du détecteur doit être à au moins 1 m du détecteur (voir Figure 6).

La longueur minimale du spécimen doit être déterminée selon les Equations (1) et (2).

$$L = (n - 1) \times s + 2 \quad (1)$$

$$s = \frac{3}{2} \pi \times R + 2 \times R \quad (2)$$

où

L est la longueur minimale de l'échantillon, en m;

n est le nombre de quarts de tour de courbures;

s est l'intervalle entre chaque courbure, en m;

R est le rayon de courbure lâche, en m.

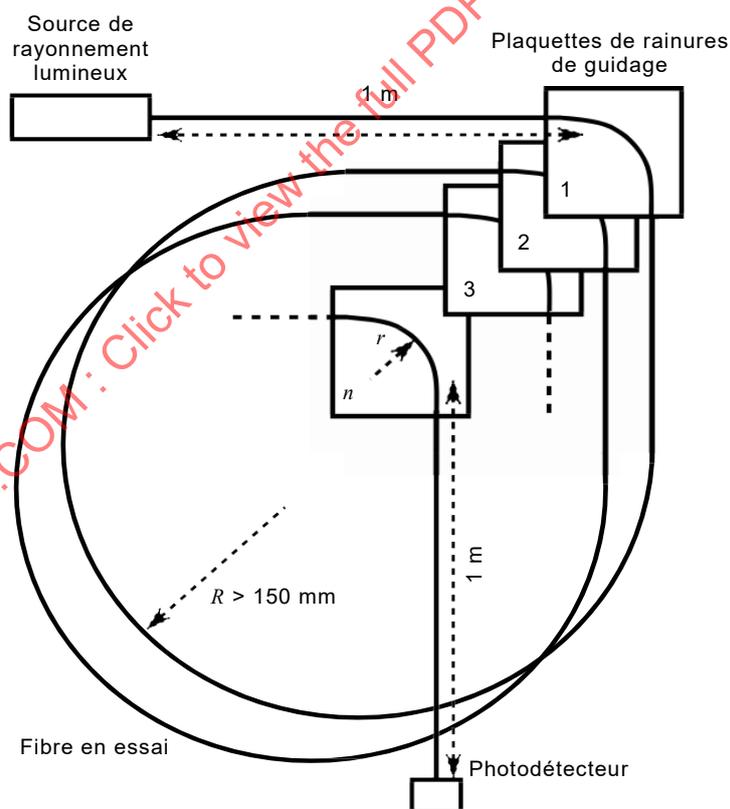


Figure 6 – Courbures multiples avec utilisation de plaques superposées

Les pertes par macrocourbures causées par des courbures multiples de rayons différents peuvent être mesurées simultanément en superposant des plaques comportant des rainures de différents rayons de courbure spécifiés (voir Figure 6).