

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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CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
2 Normative references	8
3 Terms and definitions	9
4 Apparatus.....	9
4.1 Method A – Fibre winding	9
4.2 Method B – Quarter circle bends.....	9
4.3 Input system	10
4.3.1 Optical source	10
4.3.2 Optical launch arrangement.....	10
4.4 Output system and detection.....	13
4.4.1 Optical divider	13
4.4.2 Optical detector	13
4.4.3 Optical detection assembly.....	13
4.4.4 Signal processing	13
5 Specimen	14
5.1 Specimen length	14
5.1.1 Method A – Fibre winding	14
5.1.2 Method B – Quarter circle bends.....	14
5.2 Specimen end face	14
6 Procedure.....	14
6.1 Method A – Fibre winding	14
6.1.1 General consideration.....	14
6.1.2 Single-mode fibres.....	14
6.1.3 Multimode (A1) fibres	15
6.2 Method B – Quarter circle bends.....	16
7 Calculations.....	18
8 Results	18
8.1 Information available with each measurement.....	18
8.2 Information available upon request	18
9 Specification information	18
Annex A (normative) Change in transmittance by transmitted power technique	20
A.1 Apparatus	20
A.1.1 General	20
A.2 Procedure	21
A.3 Calculations.....	21
Annex B (normative) Cut-back technique	23
B.1 General.....	23
B.2 Apparatus	23
B.2.1 General apparatus for all fibres.....	23
B.3 Procedure	23
B.4 Calculations.....	24
Annex C (normative) Requirements for the optical source characteristics for A1 multimode measurement.....	

C.1	Encircled flux (EF)	25
C.2	Limits on encircled flux	25
Annex D	(informative) Small bend radius phenomena	28
D.1	General	28
D.2	Interference between propagating and radiating modes	28
D.3	Polarization effects	30
D.4	High power damage	30
Annex E	(informative) Parallel plate (2-point) macrobend loss approximation	31
E.1	General	31
E.2	Specimen	31
E.3	Apparatus	31
E.3.1	General	31
E.3.2	Stepper motor control	32
E.3.3	Movable plate	32
E.3.4	Fixed plate	32
E.4	Procedure	33
E.5	Calculation	33
E.6	Results	33
E.7	Comparison of results with normative test	34
Bibliography		36
Figure 1	– Quarter circle guide groove in plate	10
Figure 2	– General launch arrangement	10
Figure 3	– Lens system	12
Figure 4	– Launch fibre	12
Figure 5	– Mode scrambler (for A4 fibre)	12
Figure 6	– Multiple bends using stacked plates	17
Figure A.1	– Measurement of change in optical transmittance using reference specimen	20
Figure A.2	– Measurement of change in optical transmittance using stabilized source	21
Figure B.1	– Arrangement of equipment to perform loss measurement at one specified wavelength	23
Figure B.2	– Arrangement of equipment used to obtain a loss spectrum	23
Figure C.1	– Encircled flux template example	26
Figure D.1	– Loss curves versus curve fits	29
Figure E.1	– Schematic of possible (two-point bend) apparatus	32
Figure E.2	– Example of applying an exponential fit to the spectral data of a B6_a2 fibre	34
Figure E.3	– Example of 2-point bend test data for a B6_a2 fibre	34
Table 1	– Launch conditions for A2 to A4 fibres	13
Table C.1	– Threshold tolerance	26
Table C.2	– EF requirements for 50 µm core fibre cabling at 850 nm	27
Table C.3	– EF requirements for 50 µm core fibre cabling at 1 300 nm	27
Table C.4	– EF requirements for 62,5 µm core fibre cabling at 850 nm	27
Table C.5	– EF requirements for 62,5 µm core fibre cabling at 1 300 nm	27

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).....	35
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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 singlemode 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.

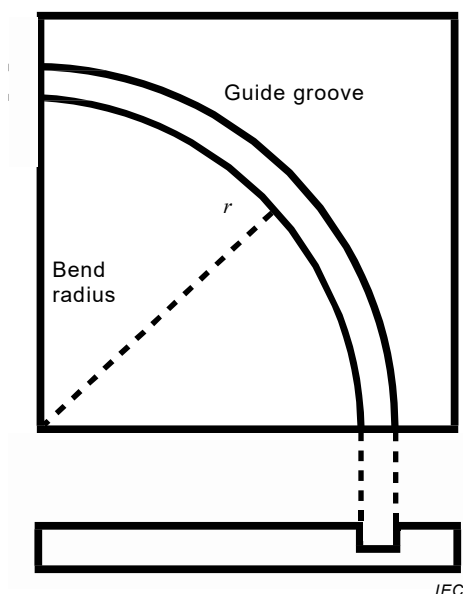


Figure 1 – Quarter circle guide groove in plate

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.

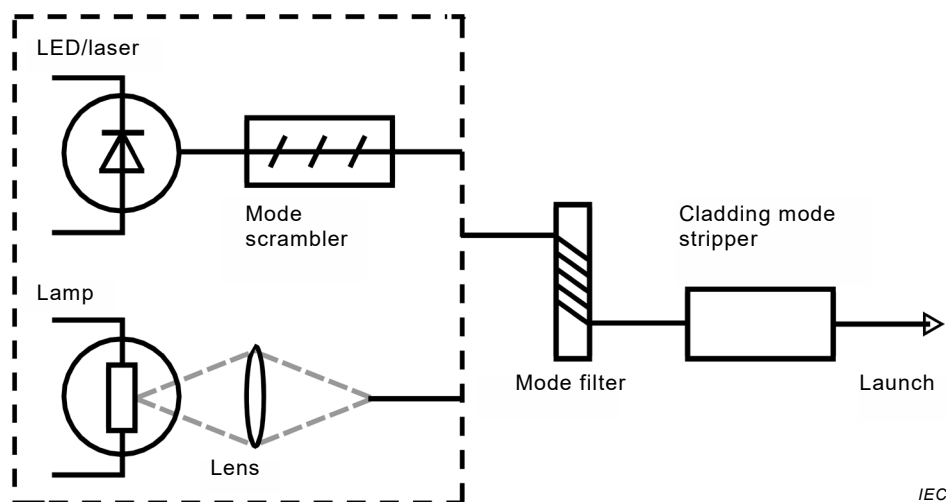


Figure 2 – General launch arrangement

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.

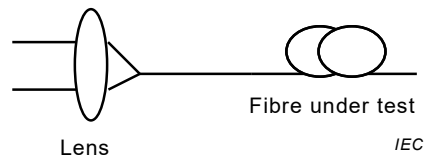


Figure 3 – Lens system

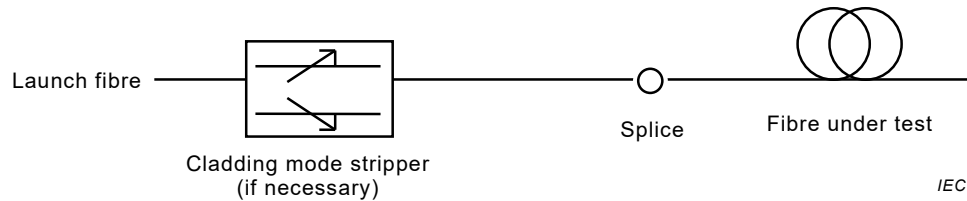


Figure 4 – Launch fibre

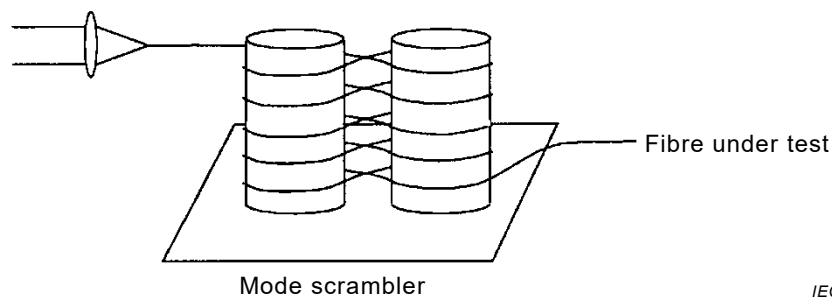


Figure 5 – Mode scrambler (for A4 fibre)

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.

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 $\pm \text{~~0,5 mm to~~ } 1,0$ 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.

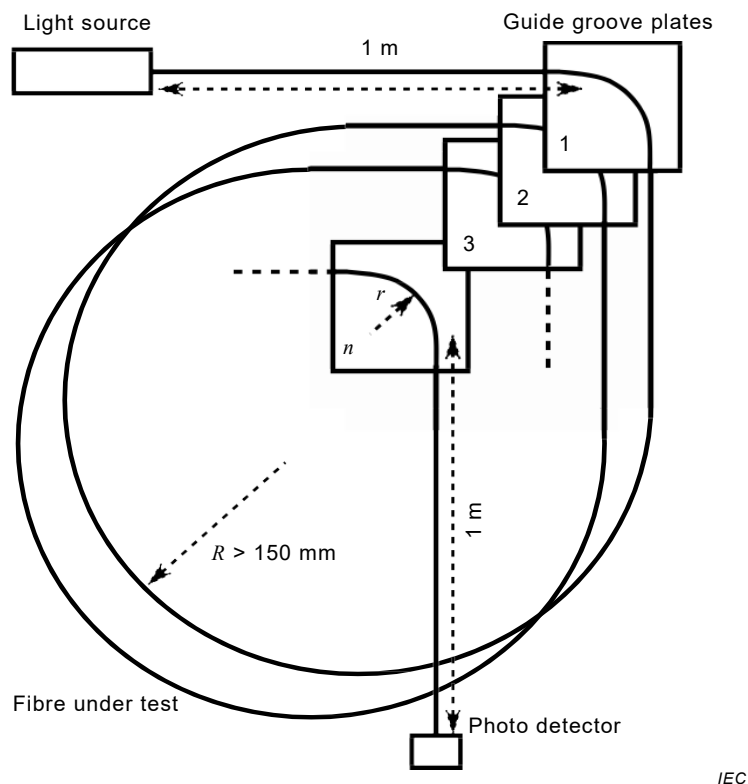


Figure 6 – Multiple bends using stacked plates

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~~ 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;

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.

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.

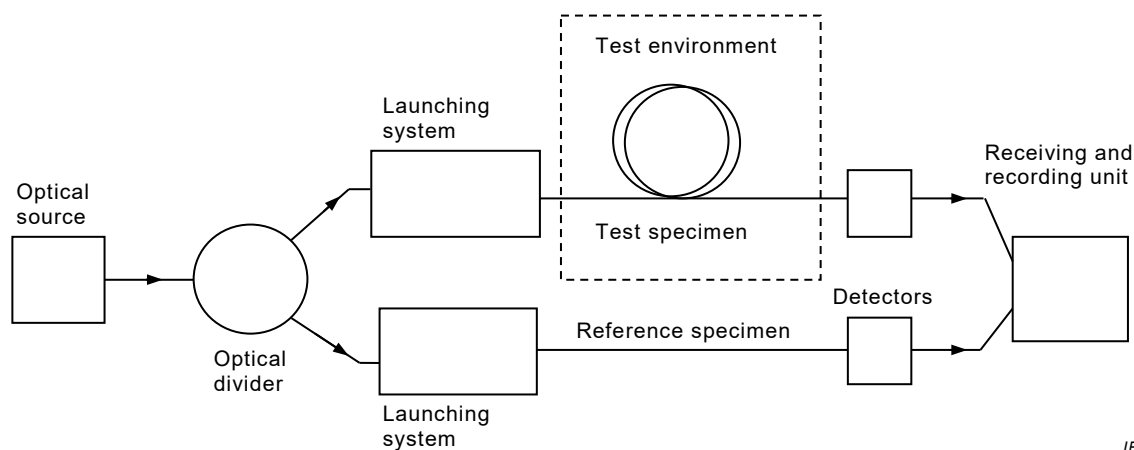


Figure A.1 – Measurement of change in optical transmittance using reference specimen

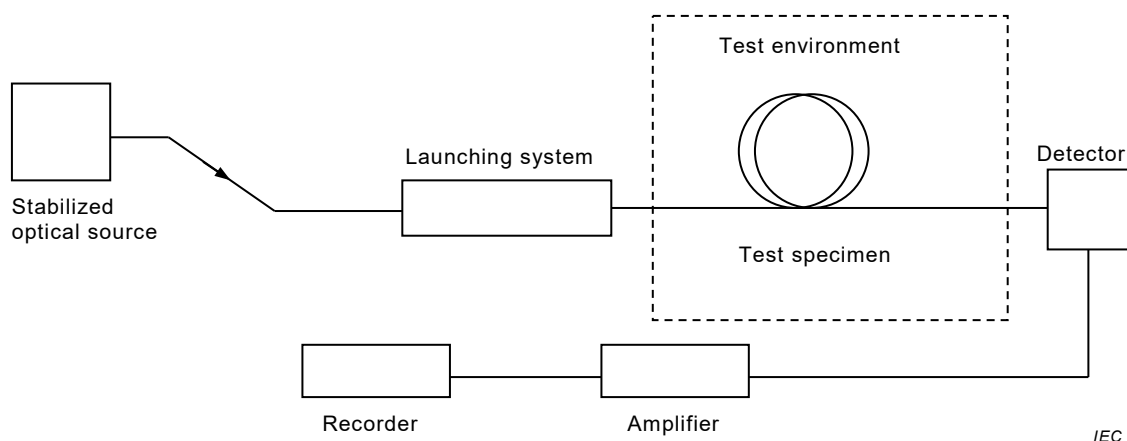


Figure A.2 – Measurement of change in optical transmittance using stabilized source

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:

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

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;

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.

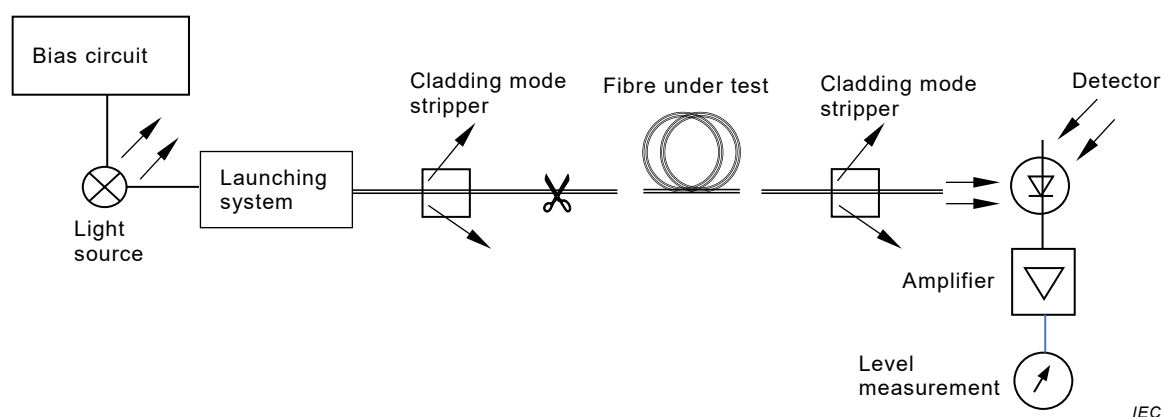


Figure B.1 – Arrangement of equipment to perform loss measurement at one specified wavelength

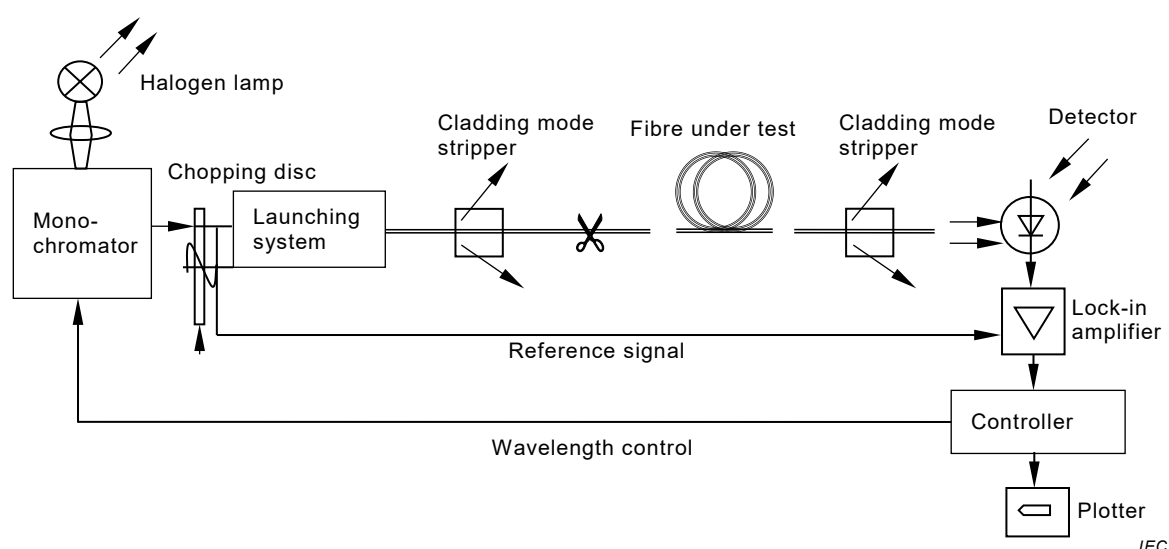


Figure B.2 – Arrangement of equipment used to obtain a loss spectrum

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.

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 ±10 % or ± 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.

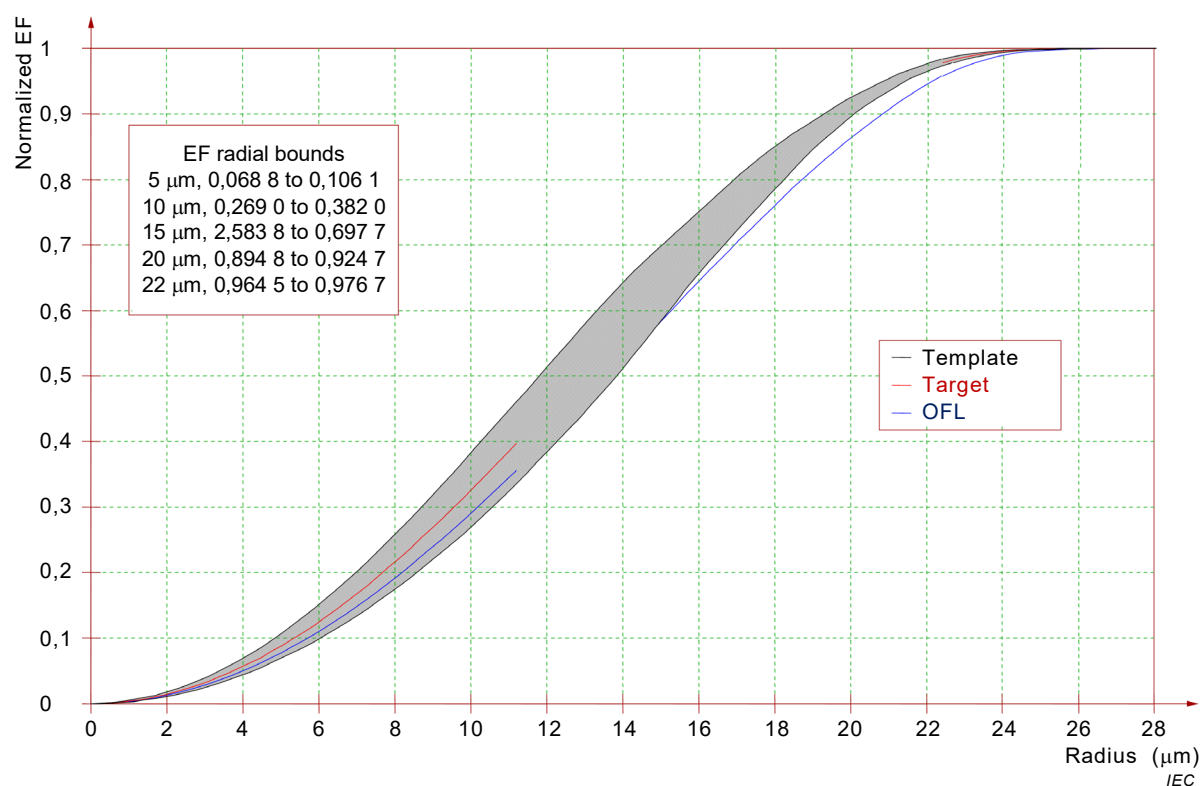
The variable X is a tolerance threshold that varies with fibre core size and wavelength according to the values in Table C.1.

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 impractical 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.

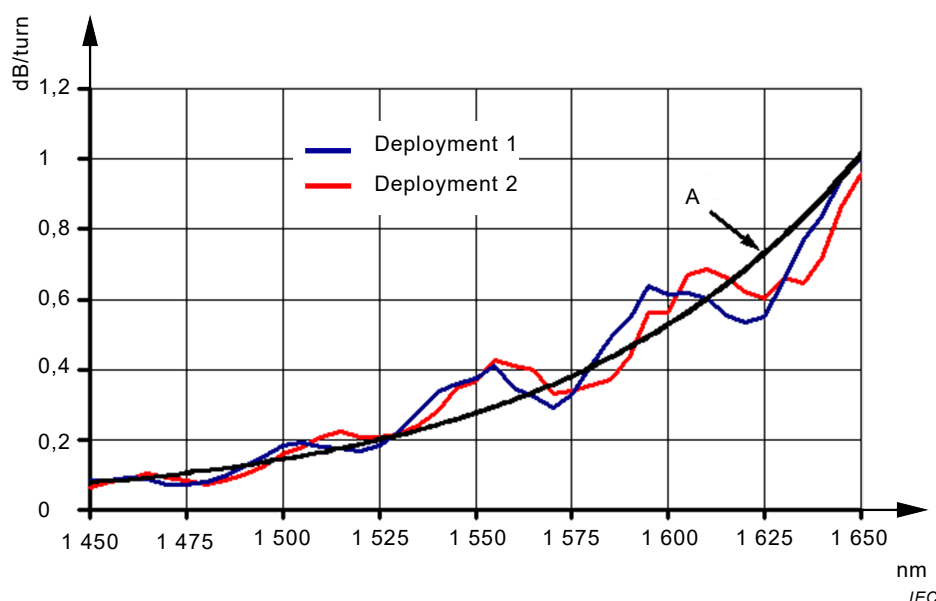


Figure D.1 – Loss curves versus curve fits

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~~

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

~~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~~

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

~~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

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

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:

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

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.

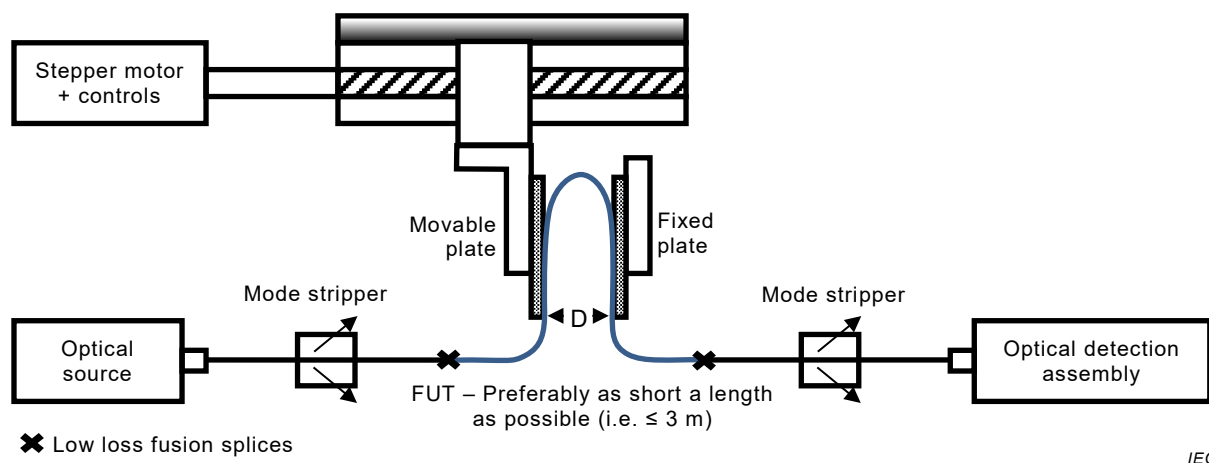
E.2 Specimen

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

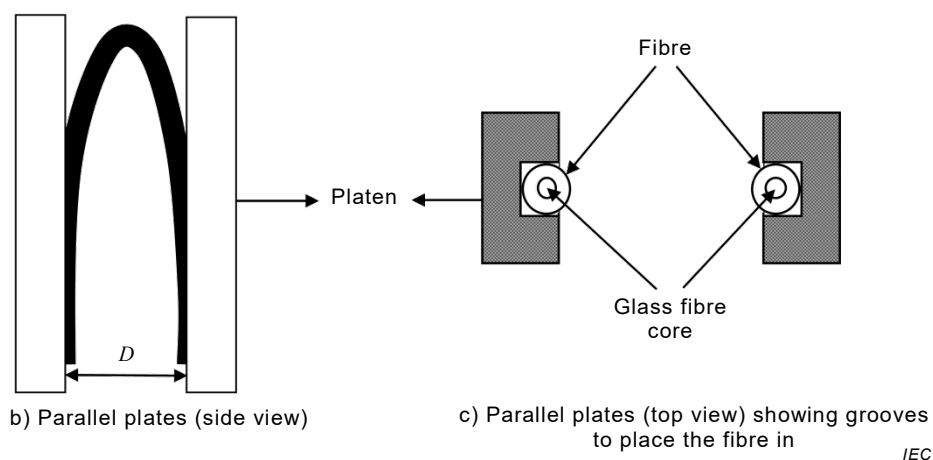


Figure E.1 – Schematic of possible (two-point bend) apparatus

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

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

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.