# IEC 60793-1-44

Edition 3.0 2023-07
COMMENTED VERSION

# INTERNATIONAL STANDARD

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## Optical fibres –
## Part 1-44: Measurement methods and test procedures – Cut-off wavelength

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IEC 60793-1-44:2023-07 CMV(en)

Full document details: IEC 60793-1-44 2023 CMV

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# OPTICAL FIBRES –

# Part 1-44: Measurement methods and test procedures – Cut-off wavelength

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**This commented version (CMV) of the official standard IEC 60793-1-44:2023 edition 3.0 allows the user to identify the changes made to the previous IEC 60793-1-44:2011 edition 2.0. Furthermore, comments from IEC SC 86A experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.**

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

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IEC 60793-1-44 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This third edition cancels and replaces the second edition published in 2011. This edition constitutes a technical revision.

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

a) used the diameter of the fibre loops to describe deployment;

b) added Annex D related to cut-off curve artifacts;

c) reorganized information and added more figures to clarify concepts.

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

| Draft | Report on voting |
|---|---|
| 86A/2314/FDIS | 86A/2327/RVD |

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

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

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

This document is to be read in conjunction with IEC 60793-1-1.

A list of all parts of the IEC 60793-1 series, published under the general title *Optical fibres – Measurement methods and test procedures*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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# OPTICAL FIBRES –

# Part 1-44: Measurement methods and test procedures – Cut-off wavelength

## 1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the cut-off wavelength of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

This document gives methods for measuring the cut-off wavelength ~~of fibre and cable~~ for uncabled or cabled single mode telecom fibre. These procedures apply to all category B and C fibre types.

~~There are two methods for measuring cable cut-off wavelength, $\lambda_{cc}$:~~

- ~~Method A: using uncabled fibre;~~
- ~~Method B: using cabled fibre.~~

~~There is only one method (Method C) for measuring fibre cut-off wavelength, $\lambda_c$.~~

~~The test method in this standard describes procedures for determining the cut-off wavelength of a sample fibre in either an uncabled condition ($\lambda_c$) or in a cable ($\lambda_{cc}$). Three default configurations are given here: any different configuration will be given in a detail specification. These procedures apply to all category B and C fibre types (see Normative references).~~

There are three methods of deployment for measuring the cut-off wavelength:

- method A: cable cut-off using uncabled fibre 22 m long sample, $\lambda_{cc}$;
- method B: cable cut-off using cabled fibre 22 m long sample, $\lambda_{cc}$;
- method C: fibre cut-off using uncabled fibre 2 m long sample, $\lambda_c$.

All methods require a reference measurement. There are two reference-scan techniques, either or both of which ~~may~~ can be used with all methods:

- bend-reference technique;
- multimode-reference technique using category A1(OM1-OM5) multimode fibre.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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## 3 Terms and definitions

No terms and definitions are listed in this document.

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

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

## 4 Background

Theoretical cut-off wavelength is the shortest wavelength at which only the fundamental mode can propagate in a single-mode fibre, as computed from the refractive index profile of the fibre.

In optical fibres, the change from multimode to single mode behaviour does not occur at an isolated wavelength, but rather smoothly over a range of wavelengths. For purposes of determining fibre performance in a telecommunications network, theoretical cut-off wavelength is less useful than the lower value actually measured when the fibre is deployed.

Measured cut-off wavelength is defined as the wavelength greater than which the ratio between the total power, including launched higher-order modes, and the fundamental mode power has decreased to less than 0,1 dB. According to this definition, the second-order ($LP_{11}$) mode undergoes 19,3 dB more attenuation than the fundamental ($LP_{01}$) mode at the cut-off wavelength. 1

Because measured cut-off wavelength depends on the length and bends of the fibre, the resulting value of cut-off wavelength depends on whether the measured fibre is configured in a deployed, cabled condition or if it is short and uncabled. Consequently, there are two overall types of cut-off wavelength:

- cable cut-off wavelength ($\lambda_{cc}$) measured in an uncabled fibre deployment condition (method A), or in a cabled condition (method B);
- fibre cut-off wavelength ($\lambda_c$) measured on a short length of uncabled, primary-coated fibre (method C).

Cable cut-off wavelength is the preferred attribute to be specified and measured.

## 5 Overview of methods

~~All of the methods shall use the transmitted-power technique, which measures the variation with wavelength of the transmitted power of a fibre under test compared to a reference transmitted-power wavelength scan. The reference scan normalizes wavelength-dependent fluctuations in the measurement equipment so that the attenuation of the $LP_{11}$ mode in the specimen can be properly characterized and the cut-off wavelength precisely determined.~~

All of the methods shall use the transmitted-power technique. A general system block diagram is depicted in Figure 1. A fibre specimen is scanned by a wavelength spectrum. The output optical power is measured and stored. This stored data is then analysed against a reference power spectrum. The reference scan normalizes any wavelength-dependent fluctuations in the measurement equipment that is not associated with the loss of the $LP_{11}$ mode. The resulting attenuation will thus properly characterize the cut-off wavelength.

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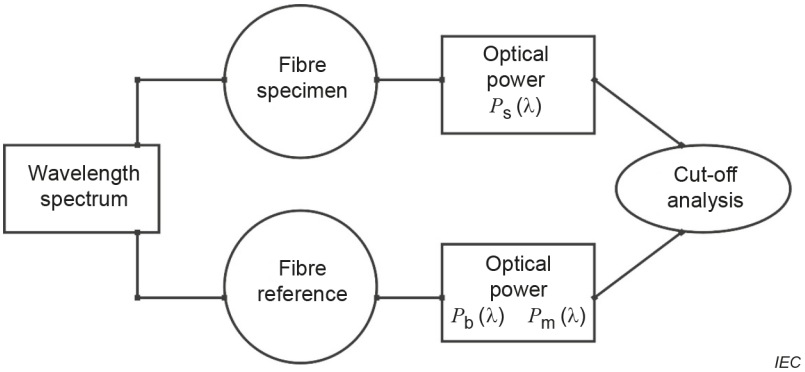


**Figure 1 – Cut-off measurement system block diagram 2**

The reference scan uses one of the following two techniques:

- ~~the specimen with an additional, smaller-radius fibre bend;~~
- ~~a (separate) category A1 multimode fibre.~~
- bend reference where a small diameter bend is added to the fibre specimen;
- multimode reference where the optical power through an A1(OM1-OM5) fibre is measured.

~~This procedure~~ Either reference technique can determine the cut-off wavelength of a fibre specimen in ~~either~~ a cabled or uncabled condition. ~~Each method has its own default configurations; the detail specification will give any different configuration required.~~

The fibre cut-off wavelength, $\lambda_c$, measured under the standard length and bend conditions described in this document, will generally exhibit a value larger than the cable cut-off wavelength, $\lambda_{cc}$. For normal installed cable spans, it is common for the measured $\lambda_c$ value to exceed the ~~system~~ long fibre's transmission wavelength. ~~Thus Cable cut-off wavelength is the more useful description of system performance and capability.~~

~~For short cables, e.g. a pigtail with a length shorter (and possibly a bending radius larger) than described in this method, the cable may introduce modal noise near the cut-off wavelength when lossy splices are present (>0,5 dB).~~

Cable cut-off wavelength is more useful in describing an installed network system performance and capability, while fibre cut-off would apply to short cables or pigtails. The two cut-off wavelengths can be mapped to each other for a specific fibre type and cut-off measurement method. The customer and the supplier shall agree to the confidence level of each mapping function established (see Clause 11 for details).

## 6 Reference test method

Method A, cable cut-off wavelength using uncabled fibre, is the reference test method (RTM). This method shall be used to settle any disputes.

~~The apparatus for each method is described in Clause 7.~~

## 7 Apparatus

### 7.1 Light source

Provide a filtered white light source, with line width not greater than 10 nm, stable in position and intensity. The light source should be capable of operating over the wavelength range 1 000 nm to 1 600 nm for most category B fibres. An operating range of 800 nm to 1 700 nm

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may be necessary for some ~~B4~~ B-655 fibres, ~~B5~~ B-656 fibres or ~~some~~ category C fibres. A scanning monochromator with a halogen bulb is one example of this kind of source.

### 7.2 Modulation

Modulate the light source to prevent ambient light affecting the results, and to aid signal recovery. A mechanical chopper with a reference output is a suitable arrangement.

### 7.3 Launch optics

Provide launch optics, such as a lens system or a multimode fibre, to overfill the test fibre over the full range of measurement wavelengths. This launch is relatively insensitive to the input end face position of the single-mode fibre and is ~~sufficient~~ able to excite the fundamental and any higher-order modes in the specimen. If using a butt splice, provide means of avoiding interference effects.

When using a multimode fibre, overfilling the reference fibre can produce an undesired ripple effect in the power-transmission spectrum. Restrict the launch sufficiently to eliminate the ripple effect. One example of restricted launch is in method A, attenuation by cut-back, of IEC 60793-1-40. Another example of restricted launch is a mandrel-wrap mode filter with sufficient (approximately 4 dB) insertion loss.

### 7.4 Support and positioning apparatus

Provide a means to stably support the input and output ends of the specimen for the duration of the test; vacuum chucks, magnetic chucks, or connectors may be used for this purpose. Support the fibre ends such that they can be repeatedly positioned in the launch and detection optics. When measuring $\lambda_{cc}$ in method B, provide a means to suitably support the cable ends. The mechanism used to hold the fibre ends allows for fibre positioning with respect to the launch and detection optics. Holding and moving of the fibre should not cause micro-bends that affect the measurement accuracy. 3

### 7.5 Deployment mandrel

#### 7.5.1 General

~~Use a means to stably support the input and output ends of the specimen for the duration of the measurement. Support the fibre ends so that they can be repeatedly and stably positioned with respect to the launch and detection optics without introducing microbends into the specimen.~~

The fibre specimen's two ends, input and output, are mechanically held in place during the measurement. The deployment and length of the specimen, together with the support apparatus, are key elements of the measurement method, and they distinguish the types of cut-off wavelength.

Additional, alternative deployments may be used if the results obtained have been demonstrated to be empirically equivalent to the results obtained using the standard deployment, to within 10 nm, or they are greater than those achieved with the standard configurations.

#### 7.5.2 Cable cut-off wavelength deployment, method A

Provide a means to make an 80 mm diameter loop at each end of the specimen and a loop of diameter ≥ 280 mm in the central portion. See Figure 2.

~~NOTE Two loops at one end can be substituted for one loop at each end.~~

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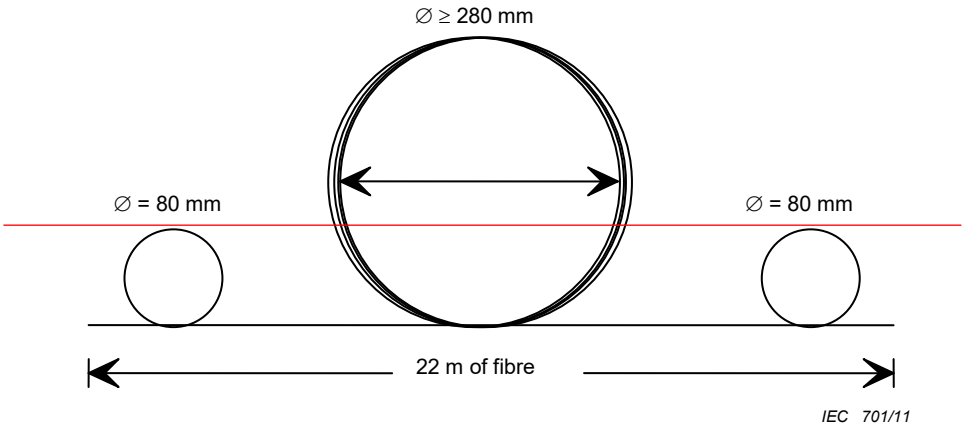


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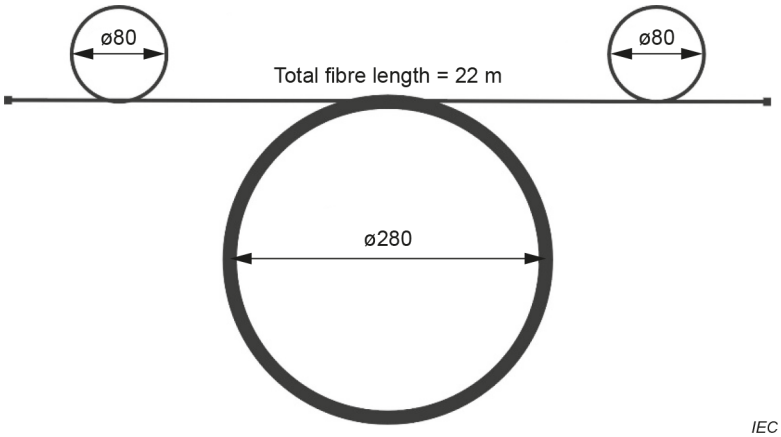
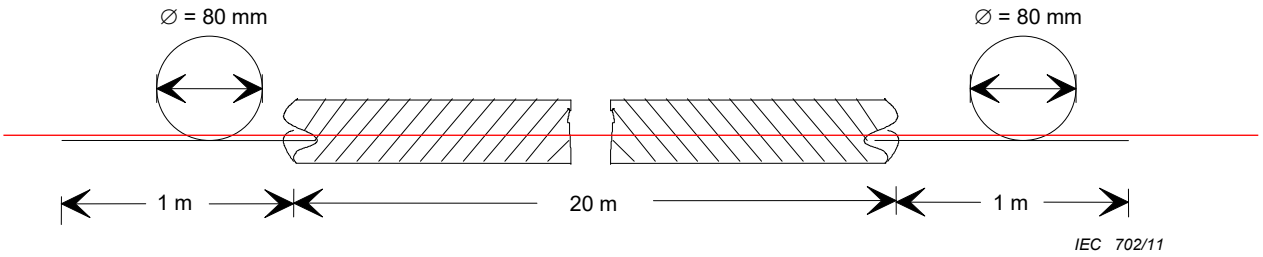



**Figure 2 – Deployment configuration for cable cut-off wavelength $\lambda_{cc}$, method A**

### 7.5.3 Cable cut-off wavelength deployment, method B

Provide a means to make an 80 mm diameter loop at each end of the specimen. See Figure 3. The cabled fibre between the two 80 mm loops has a bending diameter greater than 280 mm.

~~NOTE Two loops at one end can be substituted for one loop at each end.~~

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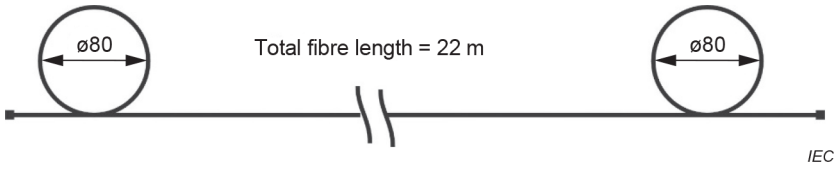
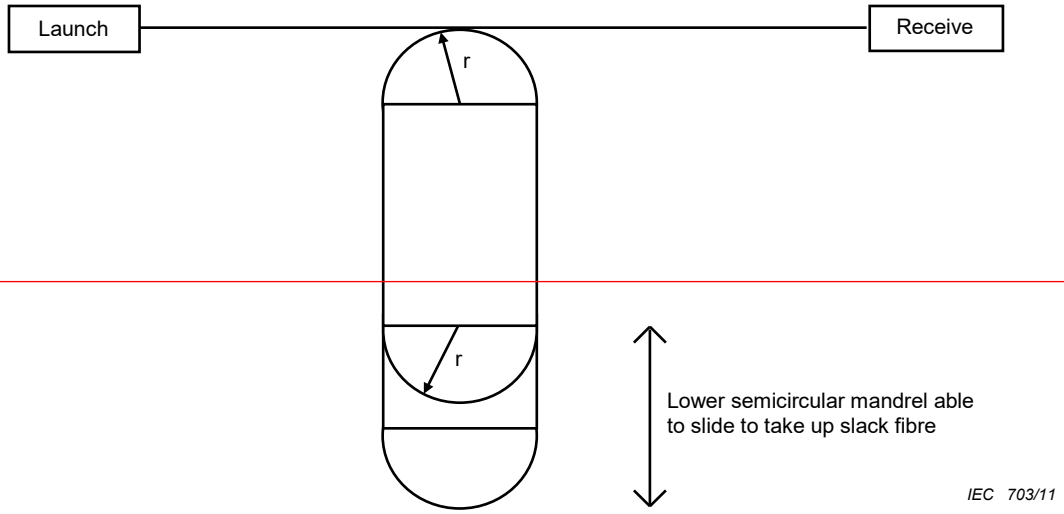



**Figure 3 – Deployment configuration for cable cut-off wavelength $\lambda_{cc}$, method B**

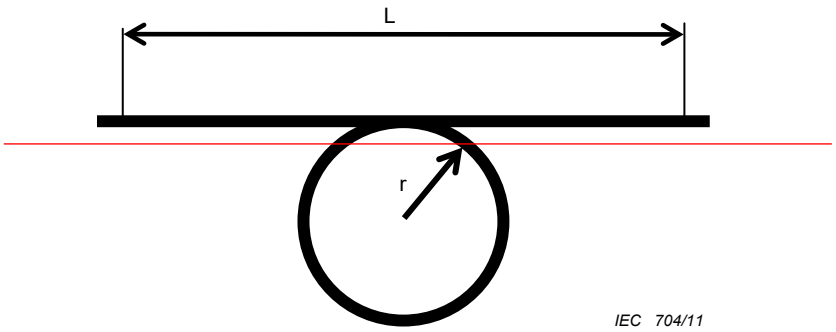
### 7.5.4 Fibre cut-off wavelength deployment, method C 4

~~Provide a circular mandrel as the initial fibre cut-off wavelength deployment. (See Figure 4a). A split, semicircular mandrel with a radius of 140 mm that is capable of sliding, hence able to take up slack fibre, is an alternative deployment . (See Figures 3 and 4b).~~

~~NOTE The introduction of a minimum bend of the cable sufficient to permit connection of the two ends of the whole specimen to the measurement setup is allowed.~~




~~**Figure 3 – Default configuration to measure $\lambda_c$**~~




~~**Key**~~

~~r = 140 mm~~

~~L = 2 m (entire fibre length)~~

~~**Figure 4a) – Initial deployment configuration for fibre cut-off wavelength measurement – circular mandrel**~~

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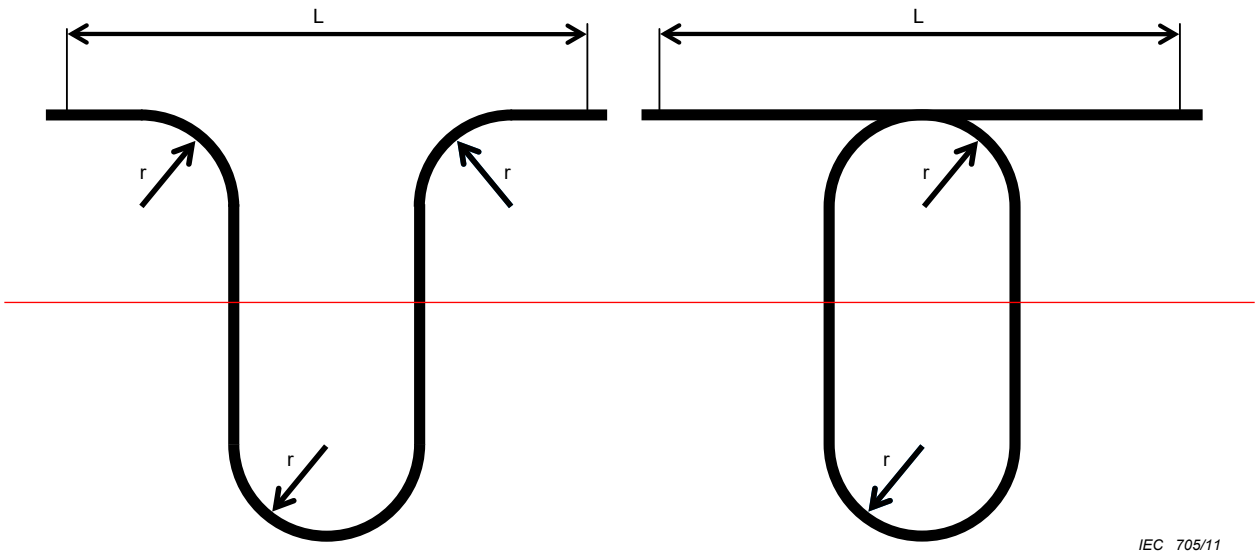


~~Key~~

~~r = 140 mm~~

~~L = 2 m (entire fibre length)~~

~~Figure 4b) – Alternative deployment configuration for fibre cut-off wavelength measurement – split mandrel~~

~~Figure 4 – Deployment configurations for fibre cut-off measurement~~

Provide means to route a fibre specimen through one complete circular loop having a diameter equal to 280 mm, see Figure 4.

Dimensions in millimetres

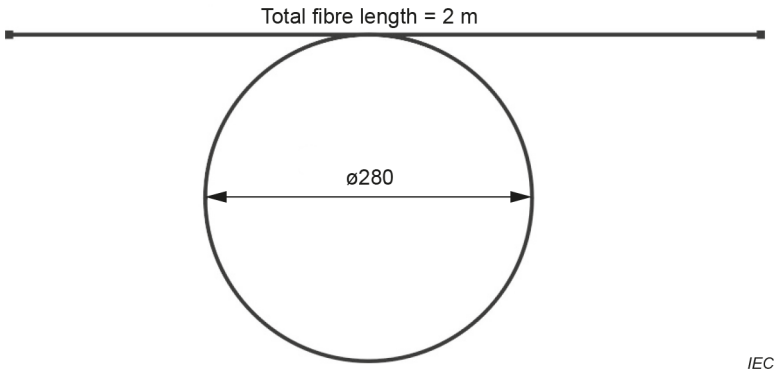


**Figure 4 – Standard deployment for fibre cut-off wavelength measurement**

### 7.6 Detection optics

Couple all power emitted from the specimen onto the active region of the detector. As examples, an optical lens system, a butt splice with a multimode fibre pigtailed to a detector, or direct coupling may be used.

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### 7.7 Detector assembly and signal detection electronics

Use a detector that is sensitive to the output radiation over the range of wavelengths to be measured and that is linear over the range of intensities encountered. A typical system might include a germanium or InGaAs photodiode, operating in the photo-voltaic mode, and a current-sensitive preamplifier, with synchronous detection by a lock-in amplifier. Generally, a computer is required to analyse the data.

### 7.8 Cladding mode stripper

Provide a means to remove cladding-mode power from the specimen. Under some circumstances, the fibre coating will perform this function; otherwise, provide methods or devices that extract cladding-mode power at the input and output ends of the specimen.

## 8 Sampling ~~and~~ specimen~~s~~

### 8.1 Specimen length

Choose the specimen length according to which parameter is being measured and, if the parameter is cable cut-off wavelength, the method to be used. See the appropriate annex: Annex A or Annex B for the cable cut-off wavelength measurement or Annex C for fibre cut-off wavelength.

### 8.2 Specimen end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each specimen. An optical fibre cleaver is often used to achieve very flat and clean end faces.

## 9 Procedure

### 9.1 Positioning of specimen in apparatus

#### 9.1.1 General requirements for all methods

Align the input and output ends of the specimen to the launch and detection optics. Do not change the launch and detection conditions during the course of the measurement.

Unless otherwise specified, when installing the specimen in the apparatus, and when using a cladding-mode stripper, ~~take care to~~ avoid imposing any additional fibre bends smaller than those specified in the configuration for the particular measurement being made.

#### 9.1.2 Deployment requirements for each method

Deploy the specimen using the information in Clause 7 and the following annexes:

- cable cut-off wavelength, method A (see Annex A);
- cable cut-off wavelength, method B (see Annex B);
- fibre cut-off wavelength, method C (see Annex C).

### 9.2 Measurement of output power

#### 9.2.1 Overview

Record the output power, $P_s(\lambda)$, along the wavelength range, in increments of 10 nm or less. The range shall be broad enough to encompass the expected cut-off wavelength ~~and, as outlined below, ultimately result in a curve similar to that in Figure 5 (using the bend-reference technique) or Figure 6 (using the multimode-reference technique).~~. The measured power is then

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normalized by the reference power producing curves similar to Figure 5, bend reference and Figure 6 multimode reference.

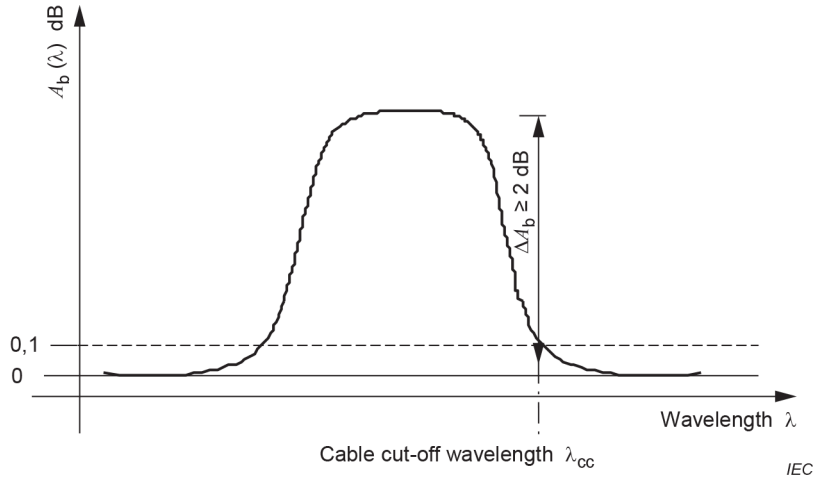
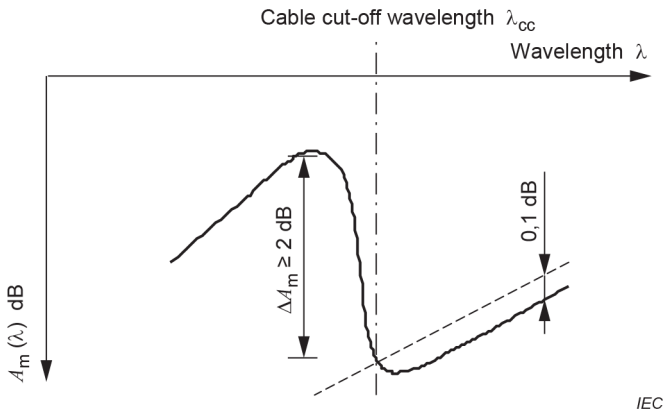



**Figure 5 – Cut-off wavelength using the bend-reference technique 5**




~~**Key**~~

~~$A_m(\lambda)$ = The spectral transmittance referenced to the multimode fibre (dB)~~

**Figure 6 – Cut-off wavelength using the multimode-reference technique**

### 9.2.2 Bend-reference technique

With input and output conditions unchanged, introduce a smaller-diameter bend between input and the output. Record the transmitted spectral power, $P_b(\lambda)$, over the same wavelength range and with the same spectral increments as in making the original measurement on the specimen.

The exact value of the smaller diameter may be determined prior to measurement; it should be small enough to attenuate the second-order mode, but not too small in order to avoid macrobending effects at higher wavelengths. ~~A radius between 10 and 30 mm is typical for most B1.1 to B5 fibres. For some B6 fibres, the radius shall be much smaller, and this measurement technique may not be adequate for these fibres. See Note to 10.1.~~ A diameter between 20 mm and 60 mm is typical for most B652 to B656 fibres.

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For some bend insensitive fibres (category B-657), the diameter may need to be smaller, and this measurement technique may not be adequate for these fibres. Curve artifacts can persist and require the use of both techniques described in Annex D. 6

### 9.2.3 Multimode-reference technique

Replace the specimen with a short (< 10 m) length of category A1(OM1-OM5) multimode fibre as a reference. Record the transmitted signal power, $P_m(\lambda)$, over the same wavelength range and with the same spectral increments as in making the original measurement on the specimen.

NOTE ~~The power using the multimode-reference technique, $P_m(\lambda)$, may be stored in a computer for use in repetitive measurements on different specimens.~~

Ripples can occur in the reference spectrum $P_m(\lambda)$. Provide a means to add mode mixing which can reduce this effect; this can be done by wrapping a multimode fibre at least 5 times around a mandrel 10 mm to 20 mm in diameter. A1(OM2-OM5) type multimode fibres are preferred for this technique.

## 10 Calculations

### 10.1 Bend-reference technique

Calculate the spectral transmittance of the specimen without the ~~smaller-radius~~ small diameter bend, referenced to the condition where the smaller-radius bend is introduced:

$$A_b(\lambda) = 10\log_{10}\frac{P_s(\lambda)}{P_b(\lambda)} \text{ in dB} \quad (1)$$

where

$A_b(\lambda)$ is the spectral transmittance referenced to the ~~smaller-radius~~ small diameter bend (dB);

$P_s(\lambda)$ is the ~~output power~~ spectral optical power through the fibre specimen;

$P_b(\lambda)$ is the ~~transmitted~~ spectral optical power through the sample with ~~the smaller-radius~~ small diameter bend ~~introduced~~.

Figure 5 shows a schematic result. The short and long wavelength edges are determined by the specimen deployed with and without the smaller-radius bend, respectively. Determine the longest wavelength at which $A_b(\lambda)$ = 0,1 dB from Figure 5. This is the cut-off wavelength, provided that $\Delta A_b$ is equal to or greater than 2 dB.

If $\Delta A_b$ < 2 dB, or if it is unobservable, broaden the wavelength scan and enlarge the single-mode launch conditions, or decrease the smaller-bend radius. Repeat these adjustments and the measurement procedure until $\Delta A_b$ > 2 dB.

~~NOTE~~ For certain implementations of bend-insensitive fibres (category ~~B6~~ B-657), $\Delta A_b$ will not reach 2 dB loss, because of the very nature of these fibres. It is recommended to use the multimode-reference technique as reference scan for these fibres. See Annex D for dealing with curve artifacts that can affect the results.

### 10.2 Multimode-reference technique

Calculate the spectral transmittance of the specimen, referenced to that of the multimode fibre:

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$$A_m(\lambda) = 10\log_{10}\frac{P_s(\lambda)}{P_m(\lambda)} \quad (2)$$

where

$A_m(\lambda)$ is the spectral transmittance referenced to the multimode fibre (dB);

$P_s(\lambda)$ is the ~~output~~ spectral optical power through the specimen;

$P_m(\lambda)$ is the ~~transmitted signal~~ spectral optical power through the multimode reference fibre.

Figure 6 shows a schematic result.

Fit a straight line to the long-wavelength portion of $A_m(\lambda)$, displacing it upward by 0,1 dB, as shown by the dashed line in Figure 6. Determine the longest wavelength at which this displaced line intersects with $A_m(\lambda)$. This is the cut-off wavelength, provided that $\Delta A_m$ is equal to or greater than 2 dB. Between measured data points, $A_m(\lambda)$ is defined by linear interpolation.

If $\Delta A_m$ < 2 dB, or if it is unobservable, broaden the wavelength scan and enlarge the single-mode launch conditions. Repeat these adjustments and the measurement procedure until $\Delta A_m$ > 2 dB, and until the long-wavelength tail is of adequate length to be fitted by a straight line.

NOTE ~~1~~ When using the multimode-reference technique, fibres with high cut-off wavelengths, when combined with reference fibres with high water peaks, can have erroneous values reported as cut-off wavelength.

~~NOTE 2~~ For certain implementations of bend-insensitive fibres (category ~~B6~~ B-657), the bend-reference technique is not the optimal technique as reference scan. For these fibres, the multimode-reference technique is recommended. See Annex D for dealing with curve artifacts that can affect the results.

~~**10.3 Curve-fitting technique for improved precision (optional)**~~

~~**10.3.1 General**~~

~~In the absence of spurious humps or excessive noise in the upper-wavelength region, accurate values for cut-off wavelength can be determined without curve fitting.~~

~~If curve fitting is considered necessary for improving precision, there are six steps. The first two steps define the $LP_{01}$ region, or upper-wavelength region. The next two steps define the transition region, where $LP_{11}$ attenuation begins to increase. The fifth step characterizes this region according to a theoretical model. The last step computes the cut-off wavelength from the characterization parameters.~~

~~This analysis is applicable for $\lambda_c$ and $\lambda_{cc}$ measured by all methods, using either the bend-reference technique or the multimode-reference technique.~~

~~The term $\alpha(\lambda)$ represents either $A_b(\lambda)$ or $A_m(\lambda)$.~~

~~**10.3.2 Step 1, define the upper-wavelength region**~~

~~**10.3.2.1 Using the bend-reference technique**~~

~~One method to identify the lower wavelength of the upper wavelength region is to find the maximum attenuation wavelength. For wavelengths greater than the maximum attenuation~~

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wavelength, the lower wavelength of the region is the wavelength at which the following function is a minimum: $\alpha(\lambda) - 8 + 8\lambda$, with $\lambda$ in µm.

The upper wavelength of the upper wavelength region is the lowest wavelength value of the upper wavelength region plus 150 nm.

#### 10.3.2.2 Using the multimode-reference technique

One method to identify the lower wavelength of the upper wavelength region is to find the maximum slope wavelength, the wavelength at which the first difference, $\alpha(\lambda) - \alpha(\lambda + 10\ \text{nm})$, is largest. For wavelengths greater than the maximum slope wavelength, the lower wavelength of the region is the wavelength at which the attenuation is a minimum.

### 10.3.3 Step 2, characterize the attenuation curve

Characterize the attenuation curve, $\alpha(\lambda)$, of the upper wavelength region as a linear equation in wavelength, $\lambda$ :

$$\alpha(\lambda) = A_u + B_u\,(\lambda \text{ in } \mu\text{m}) \qquad (3)$$

where

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

$A_u$ and $B_u$ are median attenuation values (dB).

#### a) Using the bend-reference technique

Set $B_u$ to 0 and $A_u$ to the median attenuation values in the upper wavelength region. Then define a function, $a(\lambda)$, to represent the difference between the attenuation and the line fit to the upper wavelength region:

$$a(\lambda) = \alpha(\lambda) - A_u - B_u\lambda \quad (\lambda \text{ in } \mu\text{m}) \qquad (4)$$

where

$a(\lambda)$ is the function representing the difference between attenuation and line fit (dB);

$A_u$ and $B_u$ are as defined for Equation (3).

#### b) Using the multimode-reference technique

Fit the attenuation values using a special technique to avoid the effects of positive humps:

a) Find $A_u$ and $B_u$ by simplex regression so that the sum of the absolute values of error is minimum, and such that all errors are non-negative.

b) Determine the median of the errors and add the value to $A_u$.

Then define a function, $a(\lambda)$, to represent the difference between the attenuation and the line fit to the upper wavelength region, using Equation (4).

### 10.3.4 Step 3, determine the upper wavelength of the transition region

One method to identify the lower wavelength of the upper wavelength region is by starting at the upper wavelength of the upper wavelength region, from step 1, the upper wavelength of the transition region is: 10 nm plus the maximum wavelength at which $a(\lambda)$ is greater than 0,1 dB.

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~~**10.3.5 Step 4, determine the lower wavelength of the transition region**~~

~~There are various ways to determine the lower wavelength of the transition region. Here are two examples:~~

~~a) Starting with the upper wavelength of the transition region from step 3, find the wavelength at which $a(\lambda)$ has a local maximum, and the difference between this maximum and the next local minimum (at larger $\lambda$) is maximum.~~

~~b) Find the largest wavelength, below the upper wavelength of the transition region, such that $a(\lambda)$ is greater than 2 dB and:~~

- ~~There is a local maximum for $a(\lambda)$, or~~
- ~~There is a local maximum for $a(\lambda) - a(\lambda + 10\ \text{nm})$.~~

~~**10.3.6 Step 5, characterize the transition region with the theoretical model**~~

~~The model is a linear regression of a transformation:~~

$$Y(\lambda) = 10 \log_{10}\left[\frac{10}{C}\log_{10}\left(\frac{10^{\frac{a(\lambda)}{10}} - 1}{\rho}\right)\right] \quad (5)$$

~~where~~

~~$Y(\lambda)$ is the linear regression of transformation;~~

~~$a(\lambda)$ is from equation (4);~~

$$C = 10 \log_{10}\left[\frac{\rho}{(10^{0,01} - 1)}\right] \quad (6)$$

~~and, unless otherwise specified, $\rho = 2$.~~

~~Fit the transform, $Y(\lambda)$, to the following linear model, using data from the transition region:~~

$$A_t + B_t\lambda = Y(\lambda) \quad (7)$$

~~In order to limit the effect of positive humps, the regression may be done with constraints on errors so that negative errors in the attenuation curve will not exceed the negative errors found in the characterization of the upper wavelength region. This fitting technique may be accomplished with simplex methods.~~

~~Then let $E = \min[a(\lambda)]$, for $\lambda$ in the upper wavelength region.~~

~~For the transition region, find the values of $A_t$ and $B_t$ from equation (7) so that the sum of the absolute values of error is minimized, and so that no error is less than $-v(\lambda)$, with $v(\lambda)$ derived from $w(\lambda)$ and $z(\lambda)$ and defined as:~~

$$w(\lambda) = 10^{\frac{a(\lambda) - E}{10}} \quad (8)$$

$$z(\lambda) = 10 \log_{10}\left[\frac{10}{C}\log_{10}\left(\frac{w(\lambda) - 1}{\rho}\right)\right] \quad (9)$$

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