IEC 60793-1-45

Edition 2.0 2017-11
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Optical fibres –
Part 1-45: Measurement methods and test procedures – Mode field diameter

IEC 60000:2017-01 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.180.10

ISBN 978-2-8322-5059-4

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FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60793-1-45 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

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

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

a) improvement of the description of measurement details for B6 fibre;

b) correction of Equations (1), (2),(5) and (6);

c) correction of Table E.1, Table E.2 and Table E.3.

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

CDV	Report on voting
86A/1758/CDV	86A/1802/RVC

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.

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "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- withdrawn,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 publication using a colour printer.

INTRODUCTION

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

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

- parts 1-10 to 1-19: General
- 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 1-45: Measurement methods and test procedures – Mode field diameter

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the mode field diameter (MFD) of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

2 Normative references

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

IEC 60793-1-40:2001, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-2~~:1998~~, *Optical fibres – Part 2: Product specifications – General*

3 Terms and definitions

No terms and definitions are listed in this document.

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

4 General consideration about mode field diameter

The mode field diameter measurement represents a measure of the transverse extent of the electromagnetic field intensity of the guided mode in a fibre cross section, and it is defined from the far-field intensity distribution as a ratio of integrals known as the Petermann II definition. See Equation (1).

The definitions of mode field diameter are strictly related to the measurement configurations. The mathematical equivalence of these definitions results from transform relationships between measurement results obtained by different implementations summarized in Figure 1 as follows.

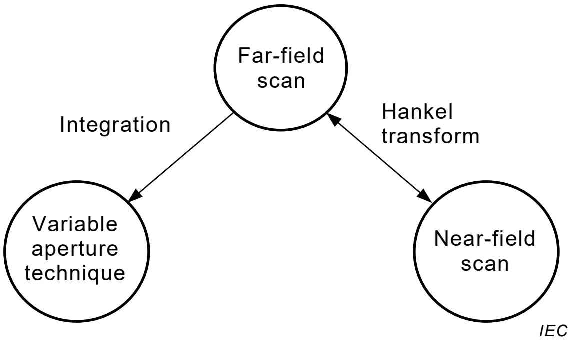


Figure 1 – Transform relationships between measurement results

Four methods are described for measuring mode field diameter:

– method A: direct far-field scan;
– method B: variable aperture in the far field;
– method C: near-field scan;
– method D: bi-directional backscatter using an optical time domain reflectometer (OTDR).

All four methods apply to all categories of type B single-mode fibre shown in IEC 60793-2 and operating near 1 310 nm or 1 550 nm. Method D is not recommended for the measurement of fibres of unknown type or design.

Information common to all four methods is contained in Clauses 1 to 11, and information pertaining to each individual method appears in annexes A, B, C and D, respectively.

5 Reference test method

Method A, direct far-field scan, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

6.1 General

The following apparatus is common to all measurement methods. Annexes A, B, C and D include layout drawings and other equipment requirements for each of the four methods, respectively.

6.2 Light source

For methods A, B and C, use a suitable coherent or non-coherent light source, such as a semiconductor laser or a sufficiently powerful filtered white light source. The source shall produce sufficient radiation at the intended wavelength(s) and be stable in intensity over a time period sufficient to perform the measurement.

A monochromator or interference filter(s) may be used, if required, for wavelength selection. The detail specification shall specify the wavelength of the source. The full width half maximum (FWHM) spectral line width of the source shall be less than or equal to 10 nm, unless otherwise specified.

See Annex D for method D.

6.3 Input optics

For method A, B, and C, an optical lens system or fibre pigtail may be employed to excite the specimen. It is recommended that the power coupled into the specimen be relatively insensitive to the position of its input end face. This can be accomplished by using a launch beam that spatially and angularly overfills the input end face.

If using a butt splice, employ index-matching material between the fibre pigtail and the specimen to avoid interference effects. The coupling shall be stable for the duration of the measurement.

See Annex D for method D.

6.4 Input positioner

Provide means of positioning the input end of the specimen to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices, three-rod splices. The position of the fibre shall remain stable over the duration of the measurement.

6.5 Cladding mode stripper

Use a device that extracts cladding modes. Under some circumstances, the fibre coating will perform this function.

6.6 High-order mode filter

Use a means to remove high-order propagating modes in the wavelength range that is greater than or equal to the cut-off wavelength of the specimen. For example, a one-turn bend with a radius of 30 mm on the fibre is generally sufficient for most B1.1 to B6 fibres. For some B6 fibres, smaller radius, multiple bends or longer specimen length can be applied to remove high-order propagating modes.

6.7 Output positioner

Provide a suitable means for aligning the fibre output end face in order to allow an accurate axial adjustment of the output end, such that, at the measurement wavelength, the scan pattern is suitably focused on the plane of the scanning detector. Such coupling may include the use of lenses, or may be a mechanical connector to a detector pigtail.

Provide means such as a side-viewing microscope or camera with a crosshair to locate the fibre at a fixed distance from the apertures or detectors. It may be sufficient to provide only longitudinal adjustment if the fibre is constrained in the lateral plane by a device such as a vacuum chuck (this depends mainly upon the size of the light detector).

6.8 Output optics

See the appropriate annex: A, B, C or D.

6.9 Detector

See the appropriate annex: A, B, C or D.

6.10 Computer

Use a computer to perform operations such as controlling the apparatus, taking intensity measurements, and processing the data to obtain the final results. For individual details, see the appropriate annex: A, B, C or D.

7 Sampling and specimens

7.1 Specimen length

For methods A, B and C, the specimen shall be a known length, typically 2 m ± 0,2 m ~~of single-mode~~ for most B1.1 to B6 fibres. For some B6 fibres, longer specimen length can be used to avoid high-order propagating modes, 22 m for example.

~~NOTE~~ For method D, OTDR, the sample ~~must~~ shall be long enough to exceed (or be positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test method IEC 60793-1-40.

7.2 Specimen end face

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

8 Procedure

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

9 Calculations

9.1 Basic equations

The basic equations for calculating mode field diameter by methods A, B and C are given below. For additional calculations, see the appropriate annex: A, B, C or D. Sample data sets for methods A, B and C are included in Annex E.

9.2 Method A – Direct far-field scan

The following equation defines the mode field diameter for method A in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter by scanning the far-field data and evaluating the Petermann II integral, which is defined from the far-field intensity distribution:

~~$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]$$~~

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]^{1/2} \quad (1)$$

where

$2W_0$ is the mode field diameter in µm;

$P_F(\theta)$ is the far-field intensity distribution;

λ is the wavelength of measurement in µm;

θ is the angle in the far-field measurement from the axis of the fibre.

NOTE 1 The integration limits are shown to be from zero to $\pi/2$, but it is understood that the integrands approach zero with increasing argument so that, in practice, the integrals can be truncated.

NOTE 2 P_F is $F^2(\theta)$ in ITU-T documents.

The far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the far-field radiation pattern of the fibre. Second, use a mathematical procedure based on the Petermann II far-field definition to calculate the mode field from far-field data, as described in Equation (1) above.

Annex E provides sample data and calculated $2W_0$ values for ~~$2W_0$ to enable one to check~~ verifying the numerical evaluation of the Petermann II Integral. The sample data are in the form of the folded power, $P_F(\theta)$, as a function of the angle, θ.

9.3 Method B – Variable aperture in the far field

The following equations define the mode field diameter for method B in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter, $2W_0$, as follows:

~~$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty a(x)\frac{x}{\left(x^2+D^2\right)^2}\mathrm{d}x\right]^{1/2}$$~~

$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty a(x)\frac{x}{\left(x^2+D^2\right)^2}dx\right]^{-1/2} \quad (2)$$

where

$2W_0$ is the mode field diameter, in µm;

λ is the wavelength of measurement, in µm;

D is the distance between the aperture and the fibre, in mm;

$a(x)$ is the complementary aperture transmission function, calculated as

$$a(x) = 1 - \frac{P(x)}{P(\max)} \quad (3)$$

where

$P(x)$ is the power measured through an aperture of radius, x, or half angle, θ;

$P(\max)$ is the maximum power, assuming an infinite aperture;

x is the aperture radius, calculated as

$$x = D\tan(\theta) \quad (4)$$

~~where D is the distance between the aperture and the fibre, in mm.~~

~~The mathematical equivalence of equations (1) and (2) is valid in the approximation of small angles, θ. Under this approximation, equation (2) can be derived from equation (1) by integration.~~

Another equivalent expression of Equation (2) is

~~$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty a(\theta)\sin 2\theta\,\mathrm{d}\theta\right]^{1/2}$$~~

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty a(\theta)\sin 2\theta\,\mathrm{d}\theta\right]^{-1/2} \quad (5)$$

~~where~~

~~$2W_0$ is the MFD, in µm;~~

~~$a(\theta)$ is the complementary aperture function, calculated as~~

~~$$a(\theta) = 1 - \frac{P(\theta)}{P(\max)} \quad (6)$$~~

where

$P(\theta)$ is the power through the largest aperture;

$P(\max)$ is the maximum power, assuming an infinite aperture.

The variable aperture far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the two-dimensional far-field pattern as the power passing through a series of transmitting apertures of various size. Second, use a mathematical procedure to calculate the mode field diameter from the far-field data.

The mathematical basis for the calculation of mode field diameter is based on the Petermann II far-field definition from Equation (1). The mathematical equivalence of equations (1) and (3) is valid in the approximation of small angles, θ. Derive Equation (5) from Equation (1) by integration. Equation (2) and Equation (5) can be derived from Equation (1) by integration.

9.4 Method C – Near-field scan

The following equation defines the mode field diameter for method C in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter from the measured near-field intensity distribution, using the following integral:

$$2W_0 = 2\left[2\frac{\int_0^\infty r\,f^2(r)\mathrm{d}r}{\int_0^\infty \left(\frac{\mathrm{d}f(r)}{\mathrm{d}r}\right)^2 \mathrm{d}r}\right] \qquad 2W_0 = 2\left(2\frac{\int_0^\infty r\,f^2(r)dr}{\int_0^\infty r\left(\frac{\mathrm{d}f(r)}{\mathrm{d}r}\right)^2 dr}\right)^{1/2} \tag{6}$$

where

$2W_0$ is the mode field diameter, in µm;

r is the radial coordinate, in µm;

$f^2(r)$ is the near-field intensity distribution.

NOTE The upper integration limits are shown to infinity, but it is understood that since the integrands approach zero with increasing argument, in practice the integrals can be truncated. A smoothing algorithm can be used for the calculation of the derivative.

The near-field scan method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the radial near-field pattern. Second, use a mathematical procedure to calculate the mode field diameter from the near-field data.

The mathematical basis for the calculation of the mode field diameter is based on the Petermann II definition from Equation (1). The mathematical equivalence of equations (1) and (5) is valid in the approximation of small angles, θ. Under this approximation, The near field, $f(r)$, and the far field, $F(\theta)$, form a Hankel pair. By means of the Hankel transformation it is possible to pass from Equation (1) to equation (7), and reverse. The near field, $f(r)$, and the far field, $F(\theta)$, form a Hankel transform pair. By Hankel transforming and using $P_F = F^2(\theta)$, it is possible to derive Equation (6) from Equation (1), and vice versa.

10 Results

10.1 Information to be provided available with each measurement

Report the following information with each measurement:

– date and title of measurement;

– identification of specimen;
– optical source wavelength;
– mode field diameter(s), in micrometres.

10.2 Information available upon request

The following information shall be available upon request:

– measurement method used: A, B, C or D;
– type of optical source used and its spectral width (FWHM);
– description of equipment;
– description of high-order modes filter;
– details of computation technique;
– date of latest calibration of measurement equipment.

11 Specification information

The detail specification shall specify the following information:

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

Annex A
(normative)

Requirements specific to method A – Mode field diameter by direct far-field scan

A.1 Apparatus

A.1.1 General

Annex A describes apparatus in addition to the requirements set down in Clause 6.

Figure A.1 illustrates a typical set-up for measurement by direct far-field scan.

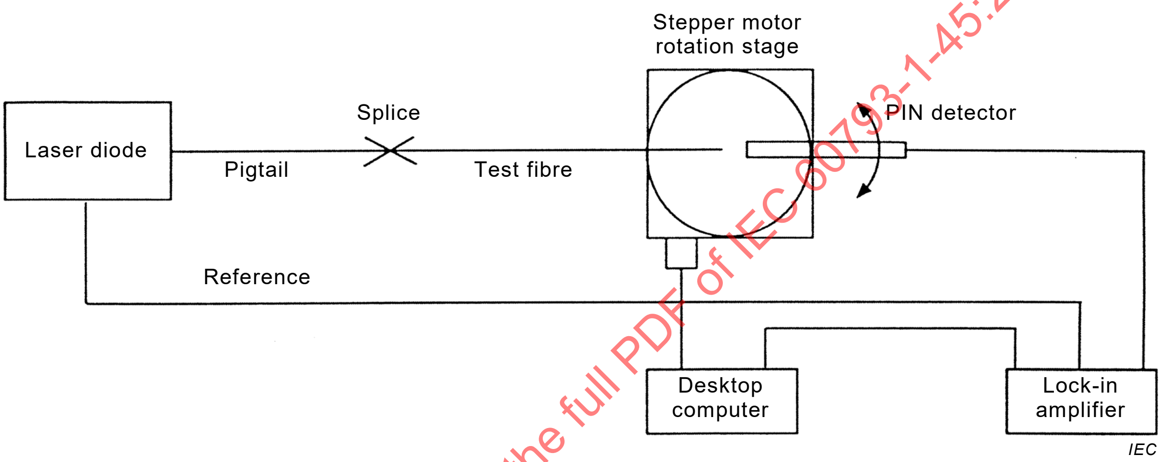


Figure A.1 – Far-field measurement set

A.1.2 Scanning detector assembly – Signal detection electronics

Use a mechanism to scan the far-field intensity distribution. Use a scanning device capable of 0,5° steps or finer to scan the detector. Use a means of aligning the fibre axis with respect to the rotation plane of the detector, and of aligning the fibre end-face with the centre of rotation of the scan. A typical system might include a PIN photodiode, operating in a photovoltaic mode, amplified by a current-input preamplifier, with synchronous detection by a lock-in amplifier. The detector should be at least 10 mm from the fibre end, and the detector's active area should not subtend an angle too large in the far field. To ensure this, place the detector at a distance from the fibre end greater than $2wb/\lambda$, where $2w$ is the expected mode field diameter of the specimen and b is the diameter of the active area of the detector.

For very accurate measurements, the minimum dynamic range of the measurement should be 50 dB. This corresponds to a maximum scan half-angle of 20° and 25°, or greater, for category B1 and B2 fibres, respectively. Reducing the dynamic range (or maximum scan half-angle) requirements may introduce errors. For example, restricting those values to 30 dB and 12,5° for category B1 fibres, and to 40 dB and 20° for category B2 fibres, may result in a relative error, in the determination of the mode field diameter, that is greater than 1 %.

A.1.3 Computer

A typical system should also include a computer to process the far-field data.

A.2 Procedure

Align the fibre in the system, prepared as described in Clause 6, with its output end aligned on the detector assembly for maximum power.

Scan the detector in 0,5° steps, equally spaced, and record the detector power.

Calculate a value of the Petermann II integral from the recorded data, and use it to compute the fibre mode field diameter as described in Equation (1), and in Clause A.3.

A.3 Calculations

A.3.1 Determine folded power curve

The folded power curve for $0 \leq \theta_i = \theta_{max}$ is

$$P_F(\theta_i) = \frac{P(\theta_i) + P(\theta_{-i})}{2} \tag{A.1}$$

where

$P_F(\theta_i)$ is the folded power curve;

$P(\theta_{-i})$ is the measured power as a function of the angular position, θ_i (radians), indexed by i.

A.3.2 Compute the top (T) and bottom (B) integrals of Equation (1)

Use an appropriate numerical integration technique to compute the integrals of Equation (1). The following is an example using the rectangular method. Any other integration method shall be at least as accurate as this one.

$$T = \sum_{0}^{n} P_F(\theta_i)\sin(\theta_i)\cos(\theta_i)d\theta \tag{A.2}$$

$$B = \sum_{0}^{n} P_F(\theta_i)\sin^3(\theta_i)\cos(\theta_i)d\theta \tag{A.3}$$

where

P_F is the folded power curve;

θ_i is the angular position, indexed by i (radians);

$d\theta = \theta_1 - \theta_0$.

A.3.3 Complete the calculation

$$\text{MFD} = 2W_0 = \left(\frac{\lambda\sqrt{2}}{\pi}\right)\sqrt{\frac{T}{B}} \tag{A.4}$$

where

$2W_0$ is the mode field diameter, in µm;

T is from Equation (A.2);

B is from Equation (A.3).

A.4 Sample data

See Table E.1 for a sample data set as calculated in Clause A.3.

Annex B
(normative)

Requirements specific to method B – Mode field diameter by variable aperture in the far field

B.1 Apparatus

B.1.1 General

Annex B describes apparatus in addition to the requirements in Clause 6.

Figure B.1 illustrates a typical set-up for the measurement by variable aperture in the far field.

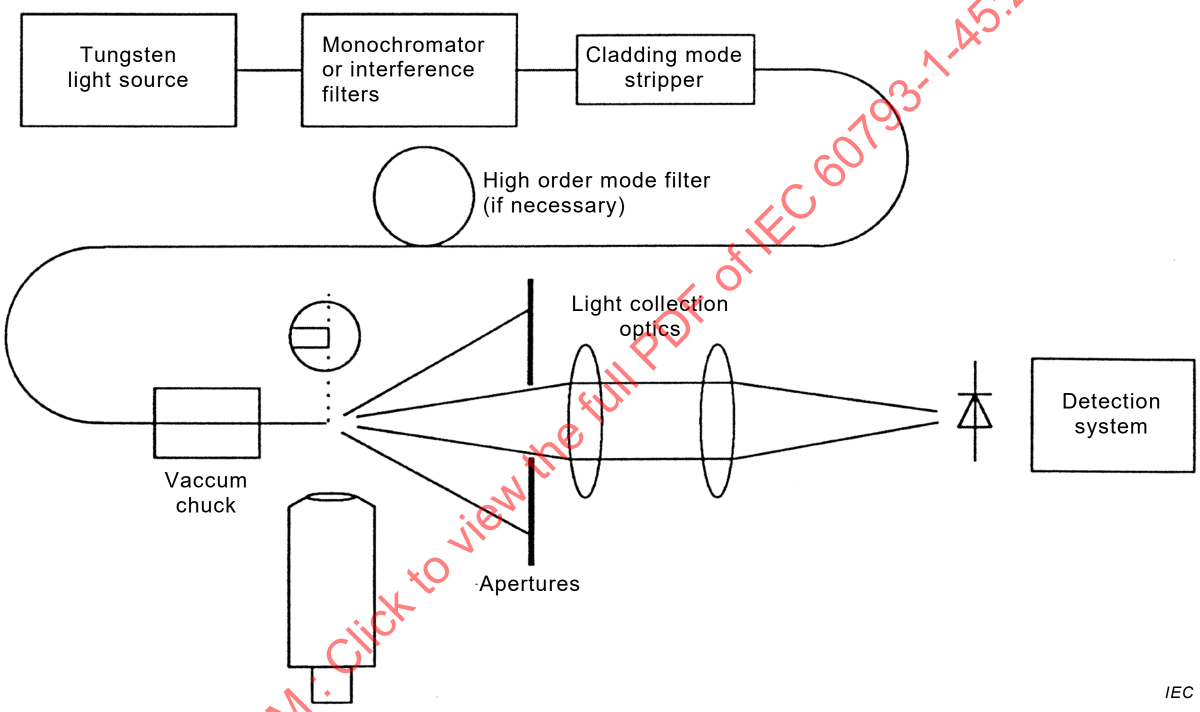


Figure B.1 – Variable aperture by far-field measurement set

B.1.2 Output variable aperture assembly

B.1.2.1 Principle

Place a device consisting of round, transmitting apertures of various sizes (such as an aperture wheel) at a distance of at least 100 W_0^2/λ from the specimen, and use it to vary the power detached from the fibre output far field pattern. Typically, the apertures are located 20 mm to 50 mm away from the fibre end.

Use a means of centring the apertures with respect to the pattern in order to decrease the sensitivity to fibre end angle. Use a sufficient number and size of apertures such that the measurement results are not unduly affected by the inclusion of any additional aperture. In addition, take care to ensure that the largest apertures are of sufficient size to avoid truncation of the collected pattern.

NOTE 1 Optical alignment is critical.

NOTE 2 The number and size of the apertures are critical to the accuracy of this method. The optimum can vary depending on the design of the fibres being tested. Verification of a particular selection can be completed by comparison with method A, direct far-field.

B.1.2.2 Equipment requirements for category B1 and B6 fibre

The accuracy of the mode field diameter measurement given by this procedure depends on the maximum numerical aperture of the measurement set. For category B1 and B6 fibre, the error is typically 1 % or less for a measurement set with a maximum numerical aperture of 0,25. If less error is desired, or if the specimen has a mode field diameter less than 8,2 µm, use either of two approaches:

a) use a measurement system with a maximum numerical aperture of 0,35 or greater; or

b) determine a mapping function that relates the measurement of category B1 and B6 fibre on limited aperture measurement set to that of a set with 0,35 or greater numerical aperture.

B.1.2.3 Equipment requirements for category B2, ~~B3,~~ B4 and B5 fibres

The maximum numerical aperture of the measurement set shall be equal to or greater than 0,40 for fibres with mode field diameters equal to or greater than 6 µm.

B.1.3 Output optics system

Use an optical system, such as a pair of lenses, mirrors, or other suitable arrangement, to collect all the light transmitted through the aperture, and to couple it to the detector.

B.1.4 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~~ can include a germanium or GaInAs photodiode, operating in the photovoltaic mode, and a current-sensitive preamplifier, with synchronous detection by a lock-in amplifier. Generally, a computer is required to analyze the data.

B.2 Procedure

a) Place the specimen, prepared as described in Clause 6, in the input and output alignment devices, and adjust it for the correct distance to the aperture assembly.

a) Set the aperture assembly to a small aperture, and adjust the far field to an aperture lateral alignment for maximum detected power.

b) Measure the detected power for each of the apertures.

c) Repeat B.2.3 for each specified measurement wavelength.

d) Calculate the mode field diameter per Equation (2) and Clause B.3.

B.3 Calculations

B.3.1 Determine complementary aperture function

Determine the complementary aperture function for each aperture, from 1 to n:

$$a(\theta_i) = 1 - \frac{P(\theta_i)}{P(\theta_n)} \qquad \text{(B.1)}$$

where

$a(\theta_i)$ is the complementary function for each aperture, indexed with i , from 1 to n;

$P(\theta_i)$ is the measured power as a function of the angular position, θ_i, indexed by i .

B.3.2 Complete the integration

Use an appropriate numerical integration technique to compute the integrals of Equation (5). The following is an example. Any other integration method shall be at least as accurate as this example.

$$T = \sum_{1}^{n} a(\theta_i)\sin(2\theta_i)(\theta_i - \theta_{i-1}) \tag{B.2}$$

where

T is the top integral of Equation (1);

$a(\theta_i)$ is the complementary aperture function from Equation (B.1).

NOTE $\theta_0 = 0$

B.3.3 Complete the calculation

$$\text{MFD} = 2W_0 = \left(\frac{\lambda}{\pi}\right)\sqrt{\frac{2}{T}} \tag{B.3}$$

where

$2W_0$ is the mode field diameter in micrometres (µm);

T is from Equation (B.2).

B.4 Sample data ~~set~~

See Table E.2 for a sample data set as calculated in Clause B.3.

Annex C
(normative)

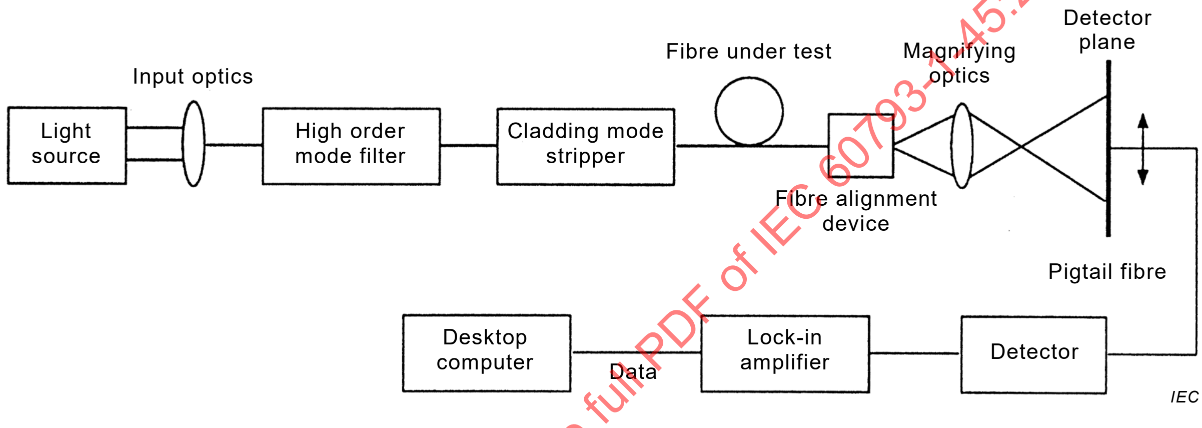
Requirements specific to method C – Mode field diameter by near-field scan

C.1 Apparatus

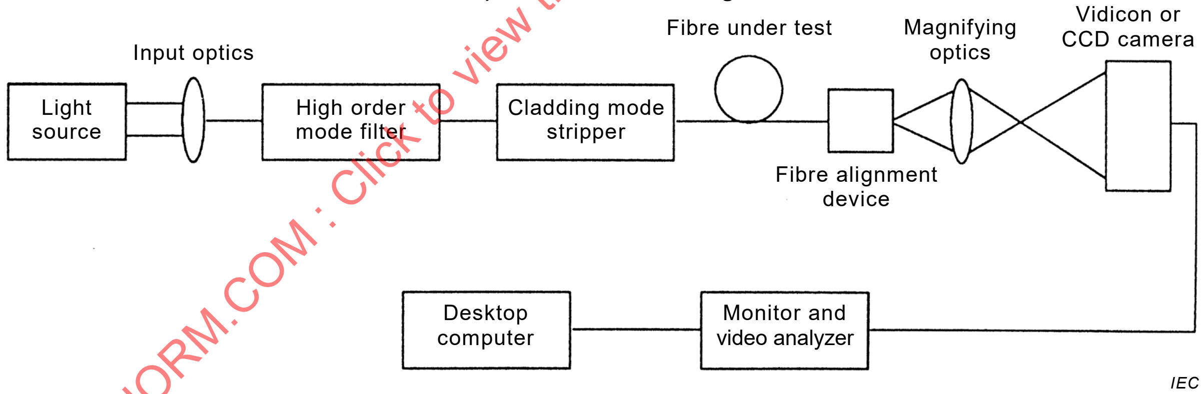
C.1.1 General

Annex C describes apparatus in addition to the requirements in Clause 6.

Figure C.1 illustrates a typical set-up for the measurement by near-field scan.



a) Mechanical scanning



b) Electronic scanning

Figure C.1 – Near-field measurement set-ups

C.1.2 Magnifying output optics

Use a suitable optical system (for example a microscopic objective) to magnify the output end of the specimen, focusing it onto the plane of the scanning detector. These optics shall not restrict the numerical aperture of the formed image and shall have a numerical aperture greater than the maximum NA of the fibre output radiation and ~~not less~~ larger than 0,45 for B2 and B3 fibres, and ~~not less~~ larger than 0,35 for B1 fibres.

C.1.3 Scanning detector

Use a suitable scanning detector to measure the point-to-point intensity of the transmitted near field pattern. The detector shall be linear over the range of intensities encountered.

Use a scanning system (mechanical or electronic) that permits a suitable resolution of the near-field image (typically 100 points or more along a range of the near-field pattern, which is about three times the nominal mode field diameter reported to the fibre surface).

For example, any of the following techniques can be used:

a) a fixed photo detector in which the field is scanned by a scanning pigtail fibre;

b) a scanning vidicon, charge-coupled devices (CCD) or other pattern/intensity recognition devices.

Accurately calibrate such devices in position.

C.1.4 Detection electronics

In order to increase the signal level, use a suitable electronic system. Choose the bandwidth of such an electronic system according to type of technique used.

When scanning the output end of the fibre with a mechanical or optical system, it is customary to modulate the optical source. If adopting such a procedure, link the amplifier (for example lock-in amplifier) to the source modulation frequency. When performing the scanning electronically, use a suitable video analyzing system and a system for automatic scanning of the near-field image, data acquisition, and processing.

C.2 Procedure

a) Place the specimen, prepared as described in Clause 6, in the input and output alignment devices, and adjust it for correct distance to the magnifying optics in such a way as to be focused onto the plane of the scanning detector. The criterion of maximizing the contrast of the image can be used for a proper focus.

b) Either scan the magnified near-field pattern by moving the scanning fibre and recording the detected intensity as a function of position, or process the near-field pattern by means of a video analyzer, according to whether the scanning is mechanical or electronic, respectively.

c) Calculate the value of the mode field diameter from the near-field intensity pattern, $f^2(r)$, expressed on the fibre output face, taking into account the magnification and the actual radial coordinate, r, according to Clause C.3.

d) Periodically measure the magnification of the magnifying optics in conjunction with the scanning system. Perform the initial calibration using a suitable calibrated grating, and then periodically check it by scanning the image of a fibre end face whose dimensions are known with suitable accuracy.

C.3 Calculations

C.3.1 Calculate the centroid

For a given cross section of the near-field test pattern that is of maximum extent, calculate the centroid position as follows:

$$r_c = \frac{\sum r_i f^2(r_i)}{\sum f^2(r_i)} \quad \text{(C.1)}$$

where

r_c is the centroid position;

r_i are the position values;

$f^2(r_i)$ are the intensity values.

C.3.2 Fold the intensity profile

Re-index the position and intensity data around the position centroid from Equation (C.1) so that positions above have index values greater than zero, and positions below have index values less than zero. The maximum index is given as n. The folded index profile is

$$f_f^2(r_i) = \left[\frac{f^2(r_i) + f^2(r_{-i})}{2} \right] \tag{C.2}$$

where

$f_f^2(r_i)$ is the folded intensity value;

$f^2(r_i)$ are the intensity values.

C.3.3 Compute the integrals

Use an appropriate numerical integration technique to compute the integrals of Equation (6). The following is an example. Any other integration method shall be at least as accurate.

Compute the top and bottom integrals of Equation (6) as follows:

$$T = \sum_0^n r_i f_f^2(r_i) dr \tag{C.3}$$

where

T is the top integral of Equation (~~3~~ 6);

r_i are the position values;

$f_f^2(r_i)$ are the folded intensity profiles.

$$\sout{B = \sum_0^n r_i \left[\frac{df_f(r_i)}{dr} \right] dr} \quad B = \sum_0^n r_i \left[\frac{df_f(r_i)}{dr} \right]^2 dr \tag{C.4}$$

where

B is the bottom integral of Equation (~~3~~ 6);

$df_f(r_i)$ $= f_f(r_i) - f_f(r_{i-1})$ for $i > 0$, or 0 for $i = 0$;

dr $= (r_1 - r_0)$.

~~NOTE~~ The data may be fitted to a curve for the computation of the derivative.

C.3.4 Complete the calculation

$$MFD = 2W_0 = 2\sqrt{\frac{2T}{B}} \tag{C.5}$$

where

$2W_0$ is the mode field diameter in μm;

T is from Equation (C.3);

B is from Equation (C.4).

C.4 Sample data

See Table E.1 for a sample data set as calculated in Clause C.3.

Annex D
(normative)

Requirements specific to method D – Mode field diameter by optical time domain reflectometer (OTDR)

D.1 General

This method describes the calculation of mode field diameter at the fibre ends using the results of bi-directional backscatter measurements from an optical time domain reflectometer (OTDR).

The measurement is made by comparison to a reference pigtail fibre with a known value of mode field diameter at the pigtail fibre ends. This reference fibre should be of a similar single-mode design as the fibre that is being characterized, for example, matched cladding B1 type fibre. An empirical mapping can sometimes be used for characterization of a fibre of one design with a reference fibre of another design. This mapping is specific to the design pair.

The measurement is limited to mode field diameter at the reference-sample joint because OTDRs are non-linear. This attribute is often specified by instrument manufacturers. Although typical specification values are sufficient for attenuation coefficient measurements, they are not sufficiently stringent to allow accurate characterization of mode field diameter over the entire fibre length. Bi-directional backscatter traces are required to characterize mode field diameter.

This method is most often used in manufacturing, where the fibre design is well known. The latter methods shall be used to resolve disputes in value. Periodic validation of the results of this method is recommended.

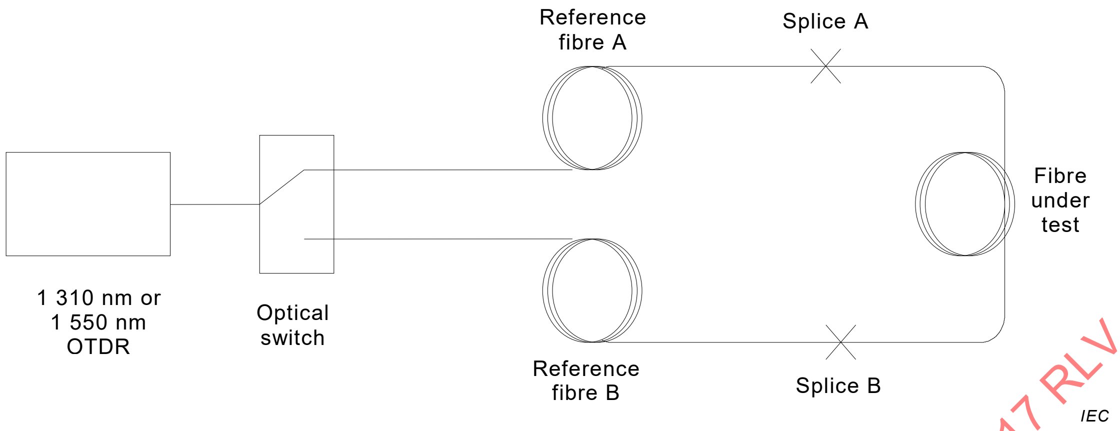
D.2 Apparatus

D.2.1 OTDR

The equipment is described in method C – Backscattering of IEC 60793-1-40. The actual centre wavelengths of the OTDR should be known to within 2 nm for best results. An error of 2,5 nm will cause about a 0,025 μm error in the mode field diameter when wavelengths in the 1 310 nm and 1 550 nm region are used.

D.2.2 Optional auxiliary switches

Various optical switching schemes can be used to make this method more efficient. Figure D.1 illustrates an example in which an OTDR with lasers at two wavelengths is employed to carry out bi-directional backscattering measurements. The two reference fibres allow characterization of both ends of the fibre under test.



~~NOTE~~ The splices can be butt joints and ~~must~~ shall be stable for the duration of the measurement.

Figure D.1 – Optical switch arrangement

D.2.3 Optional computer

A computer, used for evaluating the loss across the splices, is recommended.

D.2.4 Test sample

The sample is a type B single-mode fibre, wound on a reel or in a cable, long enough to exceed (or positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test of IEC 60793-1-40.

D.2.5 Reference sample

Use a single-mode fibre which has been measured for mode field diameter at one or more wavelengths. Two reference fibres, one for each end of the specimen, may be used.

The reference fibre is typically of the same design as the fibre under test and is of a length sufficient to avoid the OTDR dead-zone. If the reference fibre is not of the same design as the fibre under test, a mapping of the values generated by this method and the values generated by a primary method shall be completed.

D.3 Procedure

D.3.1 Orientation and notation

This method describes the characterization of position A of Figure D.1. The notation of Clause D.3 can be inverted for characterization of position B. The backscatter loss across position A is measured by launching light ~~of~~ from one or more wavelengths into both reference fibre A and reference fibre B.

For this procedure, the following symbols are used:

λ_j is a particular wavelength;

RFA is reference fibre A;

RFB is reference fibre B;

$L_A(\lambda_j)$ is the loss across splice A when launching λ_j through RFA;

$L_B(\lambda_j)$ is the loss across splice A when launching λ_j through RFB;

$W_A(\lambda_j)$ is the measured mode field diameter at λ_j at the end of RFA;

$W_S(\lambda_j)$ is the mode field diameter at λ_j derived from this method for the specimen.

Figure D.2 and Figure D.3 show these loss values on two backscatter traces.

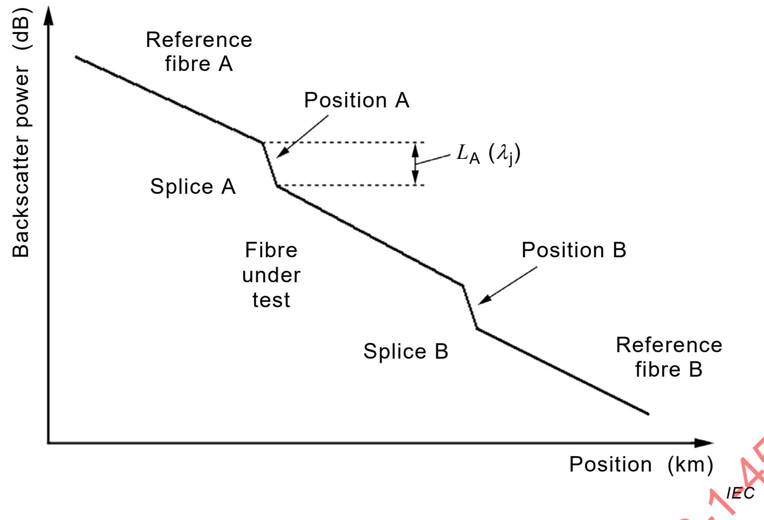


Figure D.2 – View from reference fibre A

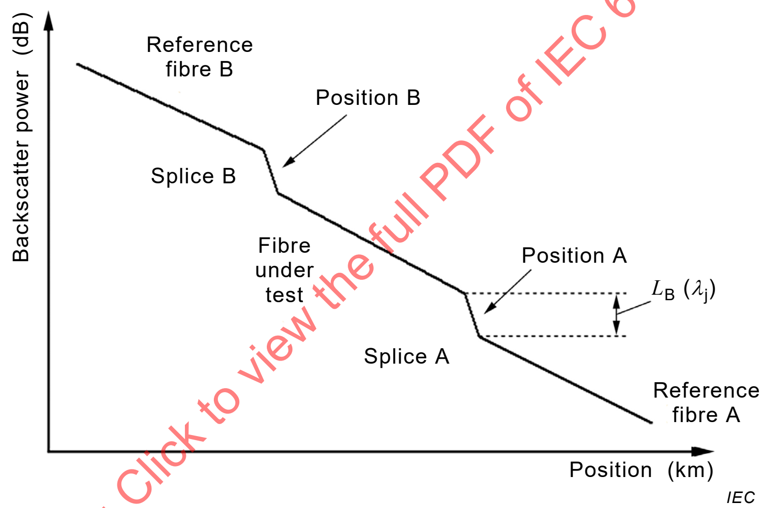


Figure D.3 – View from reference fibre B

The loss across splice A is measured using C.3.6 of IEC 60793-1-40:2001 when launching light at λ_j from RFA. The result is recorded as $L_A(\lambda_j)$. The loss across splice A is measured using C.3.6 of IEC 60793-1-40:2001 when launching light at λ_j from RFB. The result is recorded as $L_B(\lambda_j)$.

D.4 Calculations

D.4.1 Reference fibre mode field diameter

The mode field diameter of reference fibre A should be measured at each desired wavelength.

D.4.2 Computation of the specimen mode field diameter

For each desired wavelength, λ_j, the difference in loss between RFA and RFB views is computed as follows:

$$\Delta L(\lambda_j) = L_A(\lambda_j) - L_B(\lambda_j) \quad \text{(D.1)}$$

The mode field diameter of the specimen at λ_j is computed as follows:

$$W_S(\lambda_j) = W_A(\lambda_j) 10^{[g_j \Delta L(\lambda_j) + f_j]/20} \quad \text{(D.2)}$$

The parameters g_j and f_j allow improvements in the result. For a given product design, g_j and f_j values that optimize accuracy may be determined experimentally by validation, see details in D.4.3. Alternatively, g_j and f_j may be set to values of 1 and 0, respectively.

D.4.3 Validation

Figure D.4 illustrates a validation plot.

A sample of the population of the fibre design is measured with both a primary method and this method. The sample should cover a broad range of mode field diameter and cut-off values.

The values of this method are plotted against the values from the primary method to verify that an essentially linear relationship is present. The slope of the line should be close to unity and the intercept should be close to zero. The best test for non-unit slopes is to correlate the paired differences with the paired totals. If the correlation is not significant, the slope is not significantly different than 1. Bias, or non-zero intercept, is addressed below.

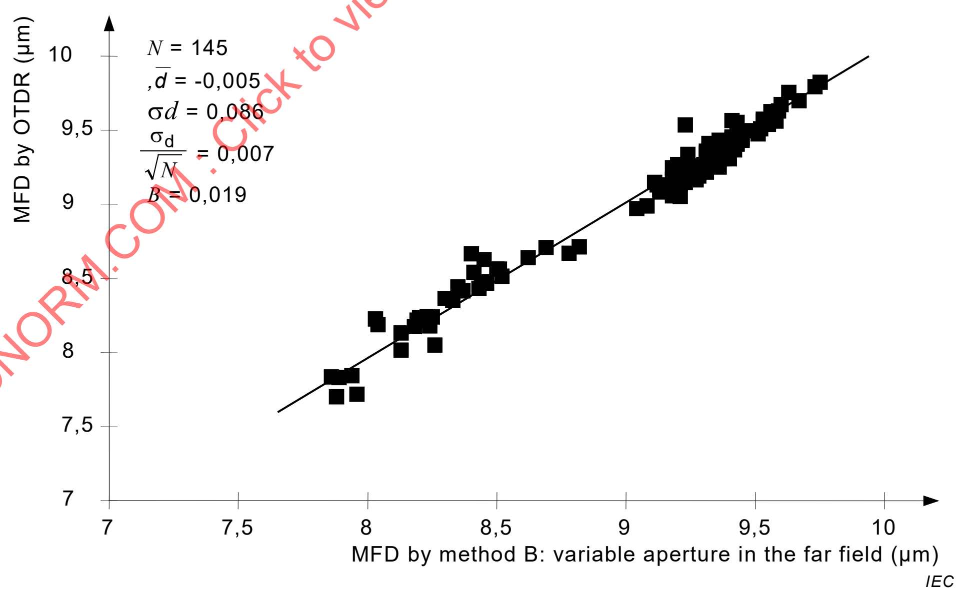


Figure D.4 – Validation example – Comparison of methods

The paired difference, d_i, between the values of this method and the primary methods is computed for each specimen, indexed with i, from 1 to N. A histogram is formed of these paired differences and the average, $\bar{d}$, and standard deviation, σd, of these differences are computed. The empirical accuracy is represented as follows:

$$B = \left|\bar{d}\right| + 2\frac{\sigma d}{\sqrt{N}} \quad (D.3)$$

~~NOTE~~ If B is too large, i.e. larger than expected between two instruments using other methods from this document, refinement of the equations or of the procedure is recommended. A typical maximum value of B is 0,1 µm.

Annex E
(informative)

Sample data sets and calculated values

E.1 General

Tables E.1 to E.3 represent sample data and calculated values obtained from Annexes A, B and C, respectively.

E.2 Method A – Mode field diameter by direct far-field scan

Table E.1 – Sample data, method A – Mode field diameter by direct far-field scan

Angle °	Folded power	Angle °	Folded power
0,000	1,000 00	9,405	0,048 47
0,495	0,986 26	9,900	0,039 11
0,990	0,944 69	10,395	0,031 55
1,485	0,881 28	10,890	0,025 58
1,980	0,802 91	11,385	0,020 59
2,475	0,713 44	11,880	0,016 59
2,970	0,621 16	12,375	0,013 35
3,465	0,533 03	12,870	0,010 77
3,960	0,452 02	13,365	0,008 65
4,455	0,378 06	13,860	0,006 97
4,950	0,313 73	14,355	0,005 59
5,445	0,258 48	14,850	0,004 47
5,940	0,211 16	15,345	0,003 56
6,435	0,171 70	15,840	0,002 83
6,930	0,139 50	16,335	0,002 24
7,425	0,113 30	16,830	0,001 79
7,920	0,091 99	17,325	0,001 45
8,415	0,074 47	17,820	0,001 13
8,910	0,060 09	18,315	0,000 87
Wavelength: 1 550 nm. Calculated mode field diameter: 6,73 μm.			

E.3 Method B – Mode field diameter by variable aperture in the far field

Details of the calculation method may cause differences in computed value on the order of 0,01 µm.

Table E.2 – Sample data set, method B – Mode field diameter by variable aperture in the far field

θi °	Power	θi °	Power
1,273	0,085 72	10,367	0,708 23
2,201	0,208 64	11,172	0,714 50
2,930	0,312 50	11,944	0,719 71
3,820	0,423 22	13,216	0,725 10
4,631	0,509 08	14,879	0,729 71
5,403	0,567 77	16,671	0,733 06
6,271	0,613 60	18,275	0,734 74
7,107	0,646 90	20,042	0,735 82
7,776	0,667 85	21,788	0,735 84
8,663	0,686 43	23,478	0,736 16
9,558	0,699 63	-	-
Wavelength: ~~1 300~~ 1 550 nm. Calculated mode field diameter: ~~8,163~~ 8,13 µm.			

E.4 Method C – Mode field diameter by near-field scan

A sample data set and the calculation of mode field diameter appears in Table E.3.

Table E.3 – Sample data set, method C – Mode field diameter by near-field scan

r µm	$f^2(r)/I(0)$	r µm	$f^2(r)/I(0)$
0,000	1,000 00	10,817	0,001 97
1,082	0,890 27	11,899	0,000 88
2,163	0,635 61	12,981	0,000 36
3,245	0,350 31	14,063	0,000 15
4,327	0,166 87	15,144	0,000 06
5,409	0,078 26	16,226	0,000 02
6,490	0,037 35	17,308	0,000 00
7,572	0,017 52	18,389	0,000 00
8,654	0,008 72	19,471	0,000 00
9,736	0,004 33	20,553	0,000 00
Wavelength: ~~1 300~~ 1 550 nm. Calculated mode field diameter: ~~10,76~~ 10,48 µm.			

IEC 60793-1-45

Edition 2.0 2017-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical fibres –
Part 1-45: Measurement methods and test procedures – Mode field diameter

Fibres optiques –
Partie 1-45: Méthodes de mesure et procédures d'essai – Diamètre du champ de mode

IEC 60793-1-45:2017-11(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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OPTICAL FIBRES –
Part 1-45: Measurement methods and test procedures –
Mode field diameter

FOREWORD

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International Standard IEC 60793-1-45 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

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

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

a) improvement of the description of measurement details for B6 fibre;
b) correction of Equations (1), (2),(5) and (6);
c) correction of Table E.1, Table E.2 and Table E.3.

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

CDV	Report on voting
86A/1758/CDV	86A/1802/RVC

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.

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "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.

OPTICAL FIBRES –

Part 1-45: Measurement methods and test procedures – Mode field diameter

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the mode field diameter (MFD) of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

2 Normative references

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

IEC 60793-1-40:2001, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

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

3 Terms and definitions

No terms and definitions are listed in this document.

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

4 General consideration about mode field diameter

The mode field diameter measurement represents a measure of the transverse extent of the electromagnetic field intensity of the guided mode in a fibre cross section, and it is defined from the far-field intensity distribution as a ratio of integrals known as the Petermann II definition. See Equation (1).

The definitions of mode field diameter are strictly related to the measurement configurations. The mathematical equivalence of these definitions results from transform relationships between measurement results obtained by different implementations summarized in Figure 1 as follows.

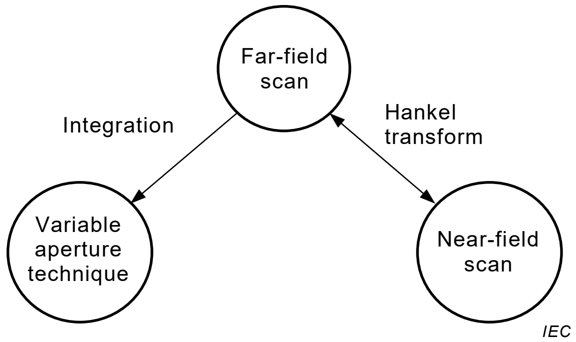


Figure 1 – Transform relationships between measurement results

Four methods are described for measuring mode field diameter:

– method A: direct far-field scan;
– method B: variable aperture in the far field;
– method C: near-field scan;
– method D: bi-directional backscatter using an optical time domain reflectometer (OTDR).

All four methods apply to all categories of type B single-mode fibre shown in IEC 60793-2 and operating near 1 310 nm or 1 550 nm. Method D is not recommended for the measurement of fibres of unknown type or design.

Information common to all four methods is contained in Clauses 1 to 11, and information pertaining to each individual method appears in annexes A, B, C and D, respectively.

5 Reference test method

Method A, direct far-field scan, is the reference test method (RTM), which shall be the one used to settle disputes.

6 Apparatus

6.1 General

The following apparatus is common to all measurement methods. Annexes A, B, C and D include layout drawings and other equipment requirements for each of the four methods, respectively.

6.2 Light source

For methods A, B and C, use a suitable coherent or non-coherent light source, such as a semiconductor laser or a sufficiently powerful filtered white light source. The source shall produce sufficient radiation at the intended wavelength(s) and be stable in intensity over a time period sufficient to perform the measurement.

A monochromator or interference filter(s) may be used, if required, for wavelength selection. The detail specification shall specify the wavelength of the source. The full width half maximum (FWHM) spectral line width of the source shall be less than or equal to 10 nm, unless otherwise specified.

See Annex D for method D.

6.3 Input optics

For method A, B, and C, an optical lens system or fibre pigtail may be employed to excite the specimen. It is recommended that the power coupled into the specimen be relatively insensitive to the position of its input end face. This can be accomplished by using a launch beam that spatially and angularly overfills the input end face.

If using a butt splice, employ index-matching material between the fibre pigtail and the specimen to avoid interference effects. The coupling shall be stable for the duration of the measurement.

See Annex D for method D.

6.4 Input positioner

Provide means of positioning the input end of the specimen to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices, three-rod splices. The position of the fibre shall remain stable over the duration of the measurement.

6.5 Cladding mode stripper

Use a device that extracts cladding modes. Under some circumstances, the fibre coating will perform this function.

6.6 High-order mode filter

Use a means to remove high-order propagating modes in the wavelength range that is greater than or equal to the cut-off wavelength of the specimen. For example, a one-turn bend with a radius of 30 mm on the fibre is generally sufficient for most B1.1 to B6 fibres. For some B6 fibres, smaller radius, multiple bends or longer specimen length can be applied to remove high-order propagating modes.

6.7 Output positioner

Provide a suitable means for aligning the fibre output end face in order to allow an accurate axial adjustment of the output end, such that, at the measurement wavelength, the scan pattern is suitably focused on the plane of the scanning detector. Such coupling may include the use of lenses, or may be a mechanical connector to a detector pigtail.

Provide means such as a side-viewing microscope or camera with a crosshair to locate the fibre at a fixed distance from the apertures or detectors. It may be sufficient to provide only longitudinal adjustment if the fibre is constrained in the lateral plane by a device such as a vacuum chuck (this depends mainly upon the size of the light detector).

6.8 Output optics

See the appropriate annex: A, B, C or D.

6.9 Detector

See the appropriate annex: A, B, C or D.

6.10 Computer

Use a computer to perform operations such as controlling the apparatus, taking intensity measurements, and processing the data to obtain the final results. For individual details, see the appropriate annex: A, B, C or D.

7 Sampling and specimens

7.1 Specimen length

For methods A, B and C, the specimen shall be a known length, typically 2 m ± 0,2 m for most B1.1 to B6 fibres. For some B6 fibres, longer specimen length can be used to avoid high-order propagating modes, 22 m for example.

For method D, OTDR, the sample shall be long enough to exceed (or be positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test method IEC 60793-1-40.

7.2 Specimen end face

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

8 Procedure

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

9 Calculations

9.1 Basic equations

The basic equations for calculating mode field diameter by methods A, B and C are given below. For additional calculations, see the appropriate annex: A, B, C or D. Sample data sets for methods A, B and C are included in Annex E.

9.2 Method A – Direct far-field scan

The following equation defines the mode field diameter for method A in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter by scanning the far-field data and evaluating the Petermann II integral, which is defined from the far-field intensity distribution:

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]^{1/2} \quad (1)$$

where

$2W_0$ is the mode field diameter in μm;

$P_F(\theta)$ is the far-field intensity distribution;

λ is the wavelength of measurement in μm;

θ is the angle in the far-field measurement from the axis of the fibre.

NOTE 1 The integration limits are shown to be from zero to π/2, but it is understood that the integrands approach zero with increasing argument so that, in practice, the integrals can be truncated.

NOTE 2 P_F is $F^2(\theta)$ in ITU-T documents.

The far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the far-field radiation pattern of the fibre. Second, use a mathematical procedure based on the Petermann II far-field definition to calculate the mode field from far-field data, as described in Equation (1) above.

Annex E provides sample data and calculated $2W_0$ values for verifying the numerical evaluation of the Petermann II Integral. The sample data are in the form of the folded power, $P_F(\theta)$, as a function of the angle, θ.

9.3 Method B – Variable aperture in the far field

The following equations define the mode field diameter for method B in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter, $2W_0$, as follows:

$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty a(x)\frac{x}{\left(x^2+D^2\right)^2}dx\right]^{-1/2} \quad (2)$$

where

$2W_0$ is the mode field diameter, in μm;

λ is the wavelength of measurement, in μm;

D is the distance between the aperture and the fibre, in mm;

$a(x)$ is the complementary aperture transmission function, calculated as

$$a(x) = 1 - \frac{P(x)}{P(\text{max})} \quad (3)$$

where

$P(x)$ is the power measured through an aperture of radius, x, or half angle, θ;

$P(\text{max})$ is the maximum power, assuming an infinite aperture;

x is the aperture radius, calculated as

$$x = D\tan(\theta) \quad (4)$$

Another equivalent expression of Equation (2) is

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty a(\theta)\sin 2\theta \, d\theta\right]^{-1/2} \quad (5)$$

The variable aperture far-field method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the two-dimensional far-field pattern as the power passing through a series of transmitting apertures of various size. Second, use a mathematical procedure to calculate the mode field diameter from the far-field data.

The mathematical basis for the calculation of mode field diameter is based on the Petermann II far-field definition from Equation (1). Equation (2) and Equation (5) can be derived from Equation (1) by integration.

9.4 Method C – Near-field scan

The following equation defines the mode field diameter for method C in terms of the electromagnetic field emitted from the end of the specimen.

Calculate the mode field diameter from the measured near-field intensity distribution, using the following integral:

$$2W_0 = 2\left(2\frac{\int_0^\infty \mathrm{r}\, f^2(r)dr}{\int_0^\infty \mathrm{r}\left(\frac{\mathrm{df(r)}}{\mathrm{dr}}\right)^2 dr}\right)^{1/2} \quad (6)$$

where

$2W_0$ is the mode field diameter, in µm;

r is the radial coordinate, in µm;

$f^2(r)$ is the near-field intensity distribution.

NOTE The upper integration limits are shown to infinity, but it is understood that since the integrands approach zero with increasing argument, in practice the integrals can be truncated. A smoothing algorithm can be used for the calculation of the derivative.

The near-field scan method for obtaining the mode field diameter of a single-mode fibre is a two-step procedure. First, measure the radial near-field pattern. Second, use a mathematical procedure to calculate the mode field diameter from the near-field data.

The mathematical basis for the calculation of the mode field diameter is based on the Petermann II definition from Equation (1). The near field, $f(r)$, and the far field, $F(\theta)$, form a Hankel transform pair. By Hankel transforming and using $P_F = F^2(\theta)$, it is possible to derive Equation (6) from Equation (1), and vice versa.

10 Results

10.1 Information available with each measurement

Report the following information with each measurement:

– date and title of measurement;
– identification of specimen;
– optical source wavelength;
– mode field diameter(s), in micrometres.

10.2 Information available upon request

The following information shall be available upon request:

– measurement method used: A, B, C or D;
– type of optical source used and its spectral width (FWHM);
– description of equipment;
– description of high-order modes filter;
– details of computation technique;
– date of latest calibration of measurement equipment.

11 Specification information

The detail specification shall specify the following information:

– type of fibre to be measured;

– failure or acceptance criteria;
– information to be reported;
– any deviations to the procedure that apply.

Annex A
(normative)

Requirements specific to method A – Mode field diameter by direct far-field scan

A.1 Apparatus

A.1.1 General

Annex A describes apparatus in addition to the requirements set down in Clause 6.

Figure A.1 illustrates a typical set-up for measurement by direct far-field scan.

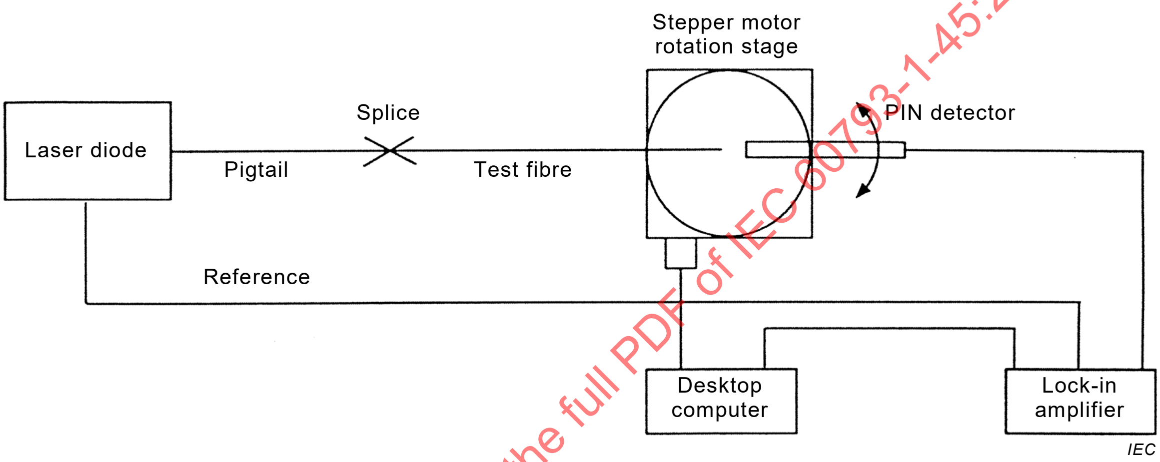


Figure A.1 – Far-field measurement set

A.1.2 Scanning detector assembly – Signal detection electronics

Use a mechanism to scan the far-field intensity distribution. Use a scanning device capable of 0,5° steps or finer to scan the detector. Use a means of aligning the fibre axis with respect to the rotation plane of the detector, and of aligning the fibre end-face with the centre of rotation of the scan. A typical system might include a PIN photodiode, operating in a photovoltaic mode, amplified by a current-input preamplifier, with synchronous detection by a lock-in amplifier. The detector should be at least 10 mm from the fibre end, and the detector's active area should not subtend an angle too large in the far field. To ensure this, place the detector at a distance from the fibre end greater than $2wb/\lambda$, where $2w$ is the expected mode field diameter of the specimen and b is the diameter of the active area of the detector.

For very accurate measurements, the minimum dynamic range of the measurement should be 50 dB. This corresponds to a maximum scan half-angle of 20° and 25°, or greater, for category B1 and B2 fibres, respectively. Reducing the dynamic range (or maximum scan half-angle) requirements may introduce errors. For example, restricting those values to 30 dB and 12,5° for category B1 fibres, and to 40 dB and 20° for category B2 fibres, may result in a relative error, in the determination of the mode field diameter, that is greater than 1 %.

A.1.3 Computer

A typical system should also include a computer to process the far-field data.

A.2 Procedure

Align the fibre in the system, prepared as described in Clause 6, with its output end aligned on the detector assembly for maximum power.

Scan the detector in 0,5° steps, equally spaced, and record the detector power.

Calculate a value of the Petermann II integral from the recorded data, and use it to compute the fibre mode field diameter as described in Equation (1), and in Clause A.3.

A.3 Calculations

A.3.1 Determine folded power curve

The folded power curve for $0 \leq \theta_i = \theta_{max}$ is

$$P_F(\theta_i) = \frac{P(\theta_i) + P(\theta_{-i})}{2} \quad \text{(A.1)}$$

where

$P_F(\theta_i)$ is the folded power curve;

$P(\theta_{-i})$ is the measured power as a function of the angular position, θ_i (radians), indexed by i.

A.3.2 Compute the top (T) and bottom (B) integrals of Equation (1)

Use an appropriate numerical integration technique to compute the integrals of Equation (1). The following is an example using the rectangular method. Any other integration method shall be at least as accurate as this one.

$$T = \sum_{0}^{n} P_F(\theta_i)\sin(\theta_i)\cos(\theta_i)d\theta \quad \text{(A.2)}$$

$$B = \sum_{0}^{n} P_F(\theta_i)\sin^3(\theta_i)\cos(\theta_i)d\theta \quad \text{(A.3)}$$

where

P_F is the folded power curve;

θ_i is the angular position, indexed by i (radians);

$d\theta = \theta_1 - \theta_0$.

A.3.3 Complete the calculation

$$\text{MFD} = 2W_0 = \left(\frac{\lambda\sqrt{2}}{\pi}\right)\sqrt{\frac{T}{B}} \quad \text{(A.4)}$$

where

$2W_0$ is the mode field diameter, in µm;

T is from Equation (A.2);

B is from Equation (A.3).

A.4 Sample data

See Table E.1 for a sample data set as calculated in Clause A.3.

Annex B
(normative)

Requirements specific to method B – Mode field diameter by variable aperture in the far field

B.1 Apparatus

B.1.1 General

Annex B describes apparatus in addition to the requirements in Clause 6.

Figure B.1 illustrates a typical set-up for the measurement by variable aperture in the far field.

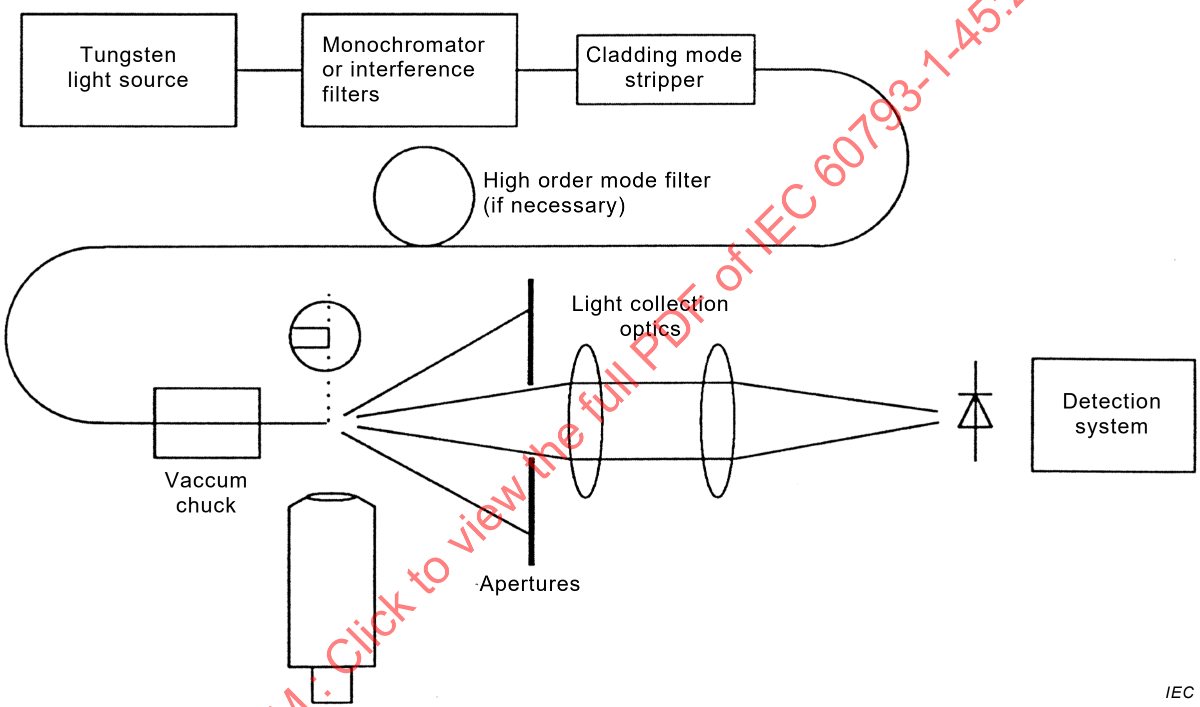


Figure B.1 – Variable aperture by far-field measurement set

B.1.2 Output variable aperture assembly

B.1.2.1 Principle

Place a device consisting of round, transmitting apertures of various sizes (such as an aperture wheel) at a distance of at least 100 W_0^2/λ from the specimen, and use it to vary the power detached from the fibre output far field pattern. Typically, the apertures are located 20 mm to 50 mm away from the fibre end.

Use a means of centring the apertures with respect to the pattern in order to decrease the sensitivity to fibre end angle. Use a sufficient number and size of apertures such that the measurement results are not unduly affected by the inclusion of any additional aperture. In addition, take care to ensure that the largest apertures are of sufficient size to avoid truncation of the collected pattern.

NOTE 1 Optical alignment is critical.

NOTE 2 The number and size of the apertures are critical to the accuracy of this method. The optimum can vary depending on the design of the fibres being tested. Verification of a particular selection can be completed by comparison with method A, direct far-field.

B.1.2.2 Equipment requirements for category B1 and B6 fibre

The accuracy of the mode field diameter measurement given by this procedure depends on the maximum numerical aperture of the measurement set. For category B1 and B6 fibre, the error is typically 1 % or less for a measurement set with a maximum numerical aperture of 0,25. If less error is desired, or if the specimen has a mode field diameter less than 8,2 µm, use either of two approaches:

a) use a measurement system with a maximum numerical aperture of 0,35 or greater; or
b) determine a mapping function that relates the measurement of category B1 and B6 fibre on limited aperture measurement set to that of a set with 0,35 or greater numerical aperture.

B.1.2.3 Equipment requirements for category B2, B4, and B5 fibres

The maximum numerical aperture of the measurement set shall be equal to or greater than 0,40 for fibres with mode field diameters equal to or greater than 6 µm.

B.1.3 Output optics system

Use an optical system, such as a pair of lenses, mirrors, or other suitable arrangement, to collect all the light transmitted through the aperture, and to couple it to the detector.

B.1.4 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 can include a germanium or GaInAs photodiode, operating in the photovoltaic mode, and a current-sensitive preamplifier, with synchronous detection by a lock-in amplifier. Generally, a computer is required to analyze the data.

B.2 Procedure

a) Place the specimen, prepared as described in Clause 6, in the input and output alignment devices, and adjust it for the correct distance to the aperture assembly.
b) Set the aperture assembly to a small aperture, and adjust the far field to an aperture lateral alignment for maximum detected power.
c) Measure the detected power for each of the apertures.
d) Repeat B.2.3 for each specified measurement wavelength.
e) Calculate the mode field diameter per Equation (2) and Clause B.3.

B.3 Calculations

B.3.1 Determine complementary aperture function

Determine the complementary aperture function for each aperture, from 1 to n:

$$a(\theta_i) = 1 - \frac{P(\theta_i)}{P(\theta_n)} \tag{B.1}$$

where

$a(\theta_i)$ is the complementary function for each aperture, indexed with i , from 1 to n;

$P(\theta_i)$ is the measured power as a function of the angular position, θ_i, indexed by i .

B.3.2 Complete the integration

Use an appropriate numerical integration technique to compute the integrals of Equation (5). The following is an example. Any other integration method shall be at least as accurate as this example.

$$T = \sum_{1}^{n} a(\theta_i)\sin(2\theta_i)(\theta_i - \theta_{i-1}) \tag{B.2}$$

where

T is the top integral of Equation (1);

$a(\theta_i)$ is the complementary aperture function from Equation (B.1).

NOTE $\theta_0 = 0$

B.3.3 Complete the calculation

$$\text{MFD} = 2W_0 = \left(\frac{\lambda}{\pi}\right)\sqrt{\frac{2}{T}} \tag{B.3}$$

where

$2W_0$ is the mode field diameter in micrometres (µm);

T is from Equation (B.2).

B.4 Sample data

See Table E.2 for a sample data set as calculated in Clause B.3.

Annex C
(normative)

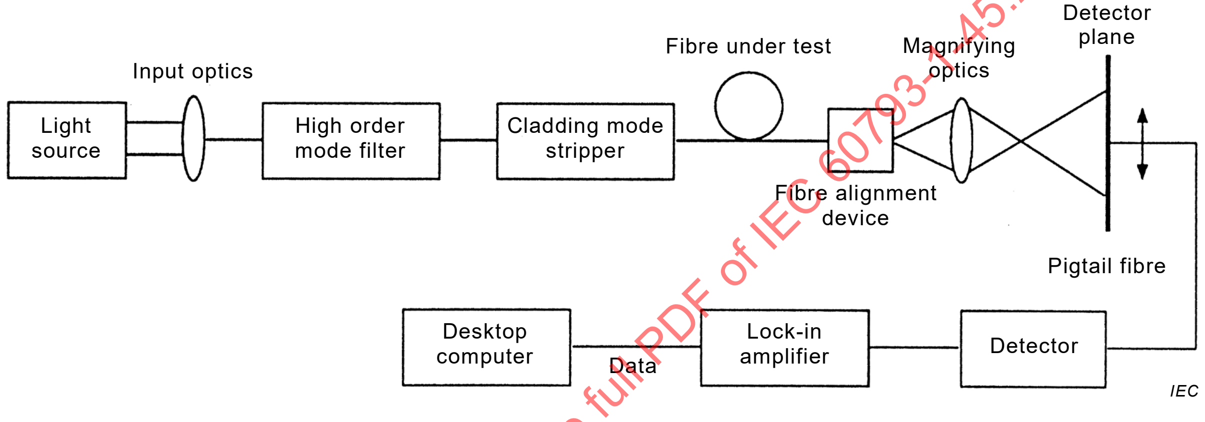
Requirements specific to method C – Mode field diameter by near-field scan

C.1 Apparatus

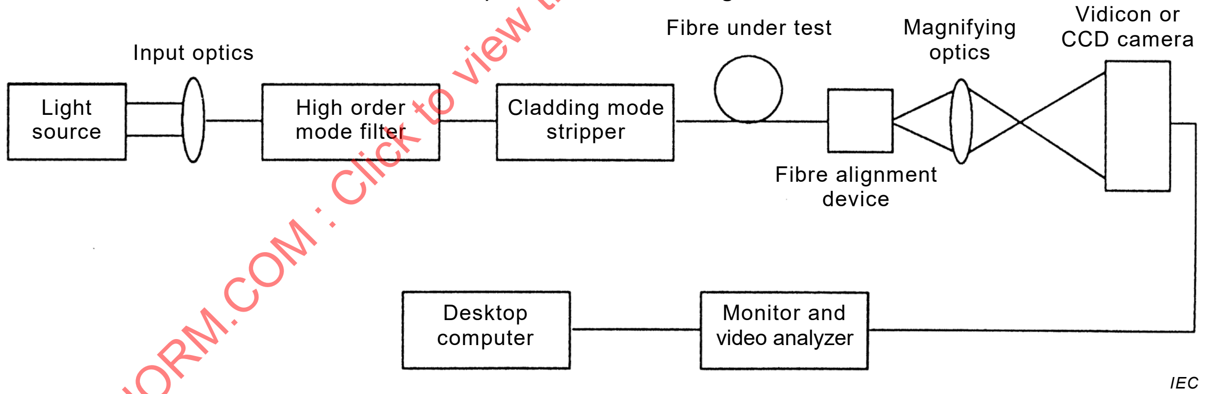
C.1.1 General

Annex C describes apparatus in addition to the requirements in Clause 6.

Figure C.1 illustrates a typical set-up for the measurement by near-field scan.



a) Mechanical scanning



b) Electronic scanning

Figure C.1 – Near-field measurement set-ups

C.1.2 Magnifying output optics

Use a suitable optical system (for example a microscopic objective) to magnify the output end of the specimen, focusing it onto the plane of the scanning detector. These optics shall not restrict the numerical aperture of the formed image and shall have a numerical aperture greater than the maximum NA of the fibre output radiation and larger than 0,45 for B2 and B3 fibres, and larger than 0,35 for B1 fibres.

C.1.3 Scanning detector

Use a suitable scanning detector to measure the point-to-point intensity of the transmitted near field pattern. The detector shall be linear over the range of intensities encountered.

Use a scanning system (mechanical or electronic) that permits a suitable resolution of the near-field image (typically 100 points or more along a range of the near-field pattern, which is about three times the nominal mode field diameter reported to the fibre surface).

For example, any of the following techniques can be used:

a) a fixed photo detector in which the field is scanned by a scanning pigtail fibre;
b) a scanning vidicon, charge-coupled devices (CCD) or other pattern/intensity recognition devices.

Accurately calibrate such devices in position.

C.1.4 Detection electronics

In order to increase the signal level, use a suitable electronic system. Choose the bandwidth of such an electronic system according to type of technique used.

When scanning the output end of the fibre with a mechanical or optical system, it is customary to modulate the optical source. If adopting such a procedure, link the amplifier (for example lock-in amplifier) to the source modulation frequency. When performing the scanning electronically, use a suitable video analyzing system and a system for automatic scanning of the near-field image, data acquisition, and processing.

C.2 Procedure

a) Place the specimen, prepared as described in Clause 6, in the input and output alignment devices, and adjust it for correct distance to the magnifying optics in such a way as to be focused onto the plane of the scanning detector. The criterion of maximizing the contrast of the image can be used for a proper focus.
b) Either scan the magnified near-field pattern by moving the scanning fibre and recording the detected intensity as a function of position, or process the near-field pattern by means of a video analyzer, according to whether the scanning is mechanical or electronic, respectively.
c) Calculate the value of the mode field diameter from the near-field intensity pattern, $f^2(r)$, expressed on the fibre output face, taking into account the magnification and the actual radial coordinate, r, according to Clause C.3.
d) Periodically measure the magnification of the magnifying optics in conjunction with the scanning system. Perform the initial calibration using a suitable calibrated grating, and then periodically check it by scanning the image of a fibre end face whose dimensions are known with suitable accuracy.

C.3 Calculations

C.3.1 Calculate the centroid

For a given cross section of the near-field test pattern that is of maximum extent, calculate the centroid position as follows:

$$r_c = \frac{\sum r_i f^2(r_i)}{\sum f^2(r_i)} \qquad \text{(C.1)}$$

where

r_c is the centroid position;

r_i are the position values;

$f^2(r_i)$ are the intensity values.

C.3.2 Fold the intensity profile

Re-index the position and intensity data around the position centroid from Equation (C.1) so that positions above have index values greater than zero, and positions below have index values less than zero. The maximum index is given as n. The folded index profile is

$$f_f^2(r_i) = \left[\frac{f^2(r_i) + f^2(r_{-i})}{2}\right] \quad \text{(C.2)}$$

where

$f_f^2\ (r_i)$ is the folded intensity value;

$f^2\ (r_i)$ are the intensity values.

C.3.3 Compute the integrals

Use an appropriate numerical integration technique to compute the integrals of Equation (6). The following is an example. Any other integration method shall be at least as accurate.

Compute the top and bottom integrals of Equation (6) as follows:

$$T = \sum_0^n r_i f_f^2(r_i) dr \quad \text{(C.3)}$$

where

T is the top integral of Equation (6);

r_i are the position values;

$f_f^2\ (r_i)$ are the folded intensity profiles.

$$B = \sum_0^n r_i \left[\frac{df_f(r_i)}{dr}\right]^2 dr \quad \text{(C.4)}$$

where

B is the bottom integral of Equation (6);

$df_f(r_i)$ $= f_f(r_i) - f_f(r_{i-1})$ for $i > 0$, or 0 for $i = 0$;

dr $= (r_1 - r_0)$.

The data may be fitted to a curve for the computation of the derivative.

C.3.4 Complete the calculation

$$\text{MFD} = 2W_0 = 2\sqrt{\frac{2T}{B}} \quad \text{(C.5)}$$

where

$2W_0$ is the mode field diameter in μm;

T is from Equation (C.3);

B is from Equation (C.4).

C.4 Sample data

See Table E.1 for a sample data set as calculated in Clause C.3.

Annex D
(normative)

Requirements specific to method D – Mode field diameter by optical time domain reflectometer (OTDR)

D.1 General

This method describes the calculation of mode field diameter at the fibre ends using the results of bi-directional backscatter measurements from an optical time domain reflectometer (OTDR).

The measurement is made by comparison to a reference pigtail fibre with a known value of mode field diameter at the pigtail fibre ends. This reference fibre should be of a similar single-mode design as the fibre that is being characterized, for example, matched cladding B1 type fibre. An empirical mapping can sometimes be used for characterization of a fibre of one design with a reference fibre of another design. This mapping is specific to the design pair.

The measurement is limited to mode field diameter at the reference-sample joint because OTDRs are non-linear. This attribute is often specified by instrument manufacturers. Although typical specification values are sufficient for attenuation coefficient measurements, they are not sufficiently stringent to allow accurate characterization of mode field diameter over the entire fibre length. Bi-directional backscatter traces are required to characterize mode field diameter.

This method is most often used in manufacturing, where the fibre design is well known. The latter methods shall be used to resolve disputes in value. Periodic validation of the results of this method is recommended.

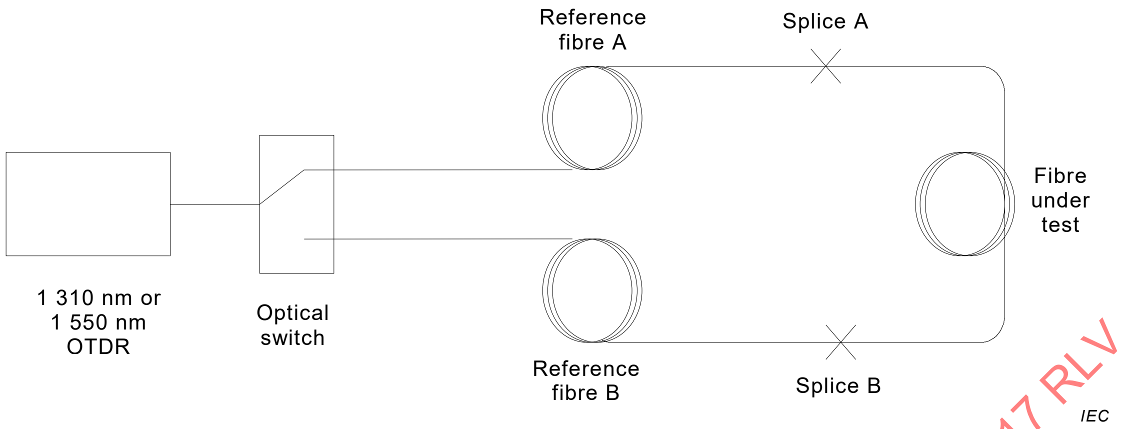
D.2 Apparatus

D.2.1 OTDR

The equipment is described in method C – Backscattering of IEC 60793-1-40. The actual centre wavelengths of the OTDR should be known to within 2 nm for best results. An error of 2,5 nm will cause about a 0,025 µm error in the mode field diameter when wavelengths in the 1 310 nm and 1 550 nm region are used.

D.2.2 Optional auxiliary switches

Various optical switching schemes can be used to make this method more efficient. Figure D.1 illustrates an example in which an OTDR with lasers at two wavelengths is employed to carry out bi-directional backscattering measurements. The two reference fibres allow characterization of both ends of the fibre under test.



The splices can be butt joints and shall be stable for the duration of the measurement.

Figure D.1 – Optical switch arrangement

D.2.3 Optional computer

A computer, used for evaluating the loss across the splices, is recommended.

D.2.4 Test sample

The sample is a type B single-mode fibre, wound on a reel or in a cable, long enough to exceed (or positioned beyond) the dead zone of the OTDR, with both ends accessible, as described in the backscatter test of IEC 60793-1-40.

D.2.5 Reference sample

Use a single-mode fibre which has been measured for mode field diameter at one or more wavelengths. Two reference fibres, one for each end of the specimen, may be used.

The reference fibre is typically of the same design as the fibre under test and is of a length sufficient to avoid the OTDR dead-zone. If the reference fibre is not of the same design as the fibre under test, a mapping of the values generated by this method and the values generated by a primary method shall be completed.

D.3 Procedure

D.3.1 Orientation and notation

This method describes the characterization of position A of Figure D.1. The notation of Clause D.3 can be inverted for characterization of position B. The backscatter loss across position A is measured by launching light from one or more wavelengths into both reference fibre A and reference fibre B.

For this procedure, the following symbols are used:

λ_j	is a particular wavelength;
RFA	is reference fibre A;
RFB	is reference fibre B;
$L_A(\lambda_j)$	is the loss across splice A when launching λ_j through RFA;
$L_B(\lambda_j)$	is the loss across splice A when launching λ_j through RFB;
$W_A(\lambda_j)$	is the measured mode field diameter at λ_j at the end of RFA;
$W_S(\lambda_j)$	is the mode field diameter at λ_j derived from this method for the specimen.

Figure D.2 and Figure D.3 show these loss values on two backscatter traces.

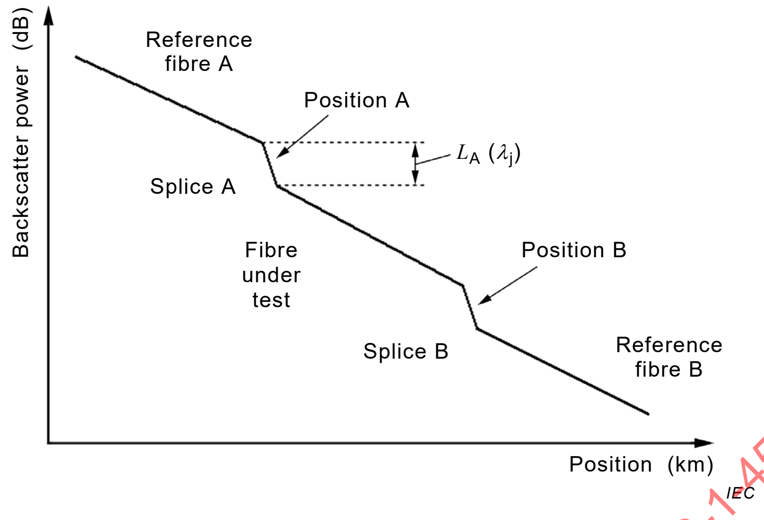


Figure D.2 – View from reference fibre A

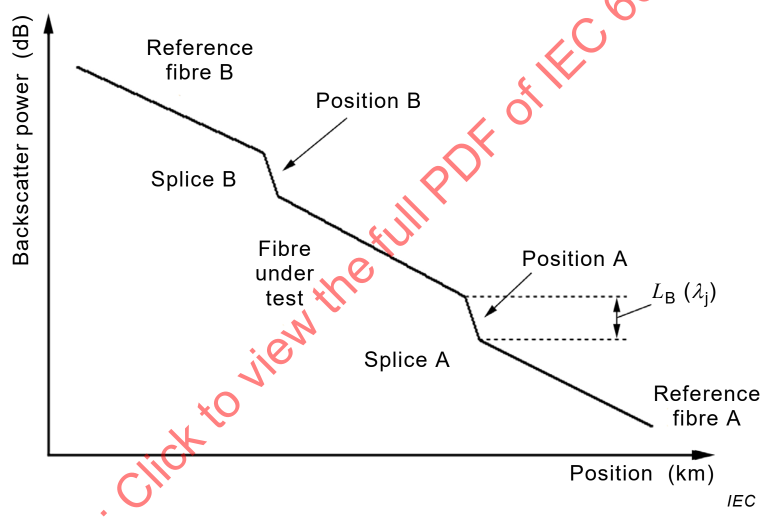


Figure D.3 – View from reference fibre B

The loss across splice A is measured using C.3.6 of IEC 60793-1-40:2001 when launching light at λ_j from RFA. The result is recorded as $L_A(\lambda_j)$. The loss across splice A is measured using C.3.6 of IEC 60793-1-40:2001 when launching light at λ_j from RFB. The result is recorded as $L_B(\lambda_j)$.

D.4 Calculations

D.4.1 Reference fibre mode field diameter

The mode field diameter of reference fibre A should be measured at each desired wavelength.

D.4.2 Computation of the specimen mode field diameter

For each desired wavelength, λ_j, the difference in loss between RFA and RFB views is computed as follows:

$$\Delta L(\lambda_j) = L_{\text{A}}(\lambda_j) - L_{\text{B}}(\lambda_j) \qquad \text{(D.1)}$$

The mode field diameter of the specimen at λ_j is computed as follows:

$$W_{\text{S}}(\lambda_j) = W_{\text{A}}(\lambda_j) 10^{\left[g_j \Delta L(\lambda_j) + f_j\right]/20} \qquad \text{(D.2)}$$

The parameters g_j and f_j allow improvements in the result. For a given product design, g_j and f_j values that optimize accuracy may be determined experimentally by validation, see details in D.4.3. Alternatively, g_j and f_j may be set to values of 1 and 0, respectively.

D.4.3 Validation

Figure D.4 illustrates a validation plot.

A sample of the population of the fibre design is measured with both a primary method and this method. The sample should cover a broad range of mode field diameter and cut-off values.

The values of this method are plotted against the values from the primary method to verify that an essentially linear relationship is present. The slope of the line should be close to unity and the intercept should be close to zero. The best test for non-unit slopes is to correlate the paired differences with the paired totals. If the correlation is not significant, the slope is not significantly different than 1. Bias, or non-zero intercept, is addressed below.

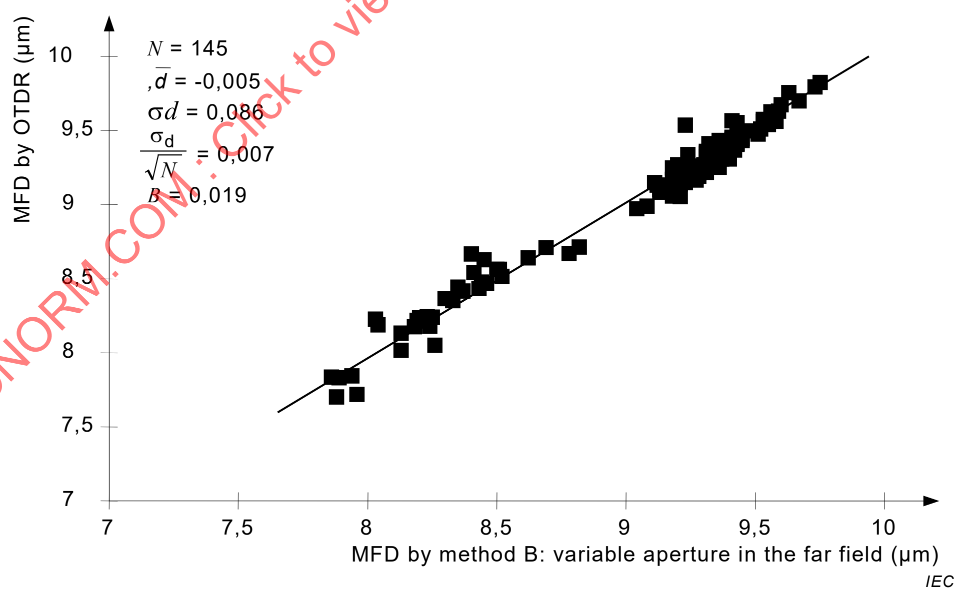


Figure D.4 – Validation example – Comparison of methods

The paired difference, d_i, between the values of this method and the primary methods is computed for each specimen, indexed with i, from 1 to N. A histogram is formed of these paired differences and the average, $\bar{d}$, and standard deviation, σd, of these differences are computed. The empirical accuracy is represented as follows:

$$B = \left|\bar{d}\right| + 2\frac{\sigma d}{\sqrt{N}} \tag{D.3}$$

If B is too large, i.e. larger than expected between two instruments using other methods from this document, refinement of the equations or of the procedure is recommended. A typical maximum value of B is 0,1 µm.

Annex E
(informative)

Sample data sets and calculated values

E.1 General

Tables E.1 to E.3 represent sample data and calculated values obtained from Annexes A, B and C, respectively.

E.2 Method A – Mode field diameter by direct far-field scan

Table E.1 – Sample data, method A – Mode field diameter by direct far-field scan

Angle °	Folded power	Angle °	Folded power
0,000	1,000 00	9,405	0,048 47
0,495	0,986 26	9,900	0,039 11
0,990	0,944 69	10,395	0,031 55
1,485	0,881 28	10,890	0,025 58
1,980	0,802 91	11,385	0,020 59
2,475	0,713 44	11,880	0,016 59
2,970	0,621 16	12,375	0,013 35
3,465	0,533 03	12,870	0,010 77
3,960	0,452 02	13,365	0,008 65
4,455	0,378 06	13,860	0,006 97
4,950	0,313 73	14,355	0,005 59
5,445	0,258 48	14,850	0,004 47
5,940	0,211 16	15,345	0,003 56
6,435	0,171 70	15,840	0,002 83
6,930	0,139 50	16,335	0,002 24
7,425	0,113 30	16,830	0,001 79
7,920	0,091 99	17,325	0,001 45
8,415	0,074 47	17,820	0,001 13
8,910	0,060 09	18,315	0,000 87
Wavelength: 1 550 nm. Calculated mode field diameter: 6,73 µm.			

E.3 Method B – Mode field diameter by variable aperture in the far field

Details of the calculation method may cause differences in computed value on the order of 0,01 µm.

Table E.2 – Sample data set, method B – Mode field diameter by variable aperture in the far field

θi °	Power	θi °	Power
1,273	0,085 72	10,367	0,708 23
2,201	0,208 64	11,172	0,714 50
2,930	0,312 50	11,944	0,719 71
3,820	0,423 22	13,216	0,725 10
4,631	0,509 08	14,879	0,729 71
5,403	0,567 77	16,671	0,733 06
6,271	0,613 60	18,275	0,734 74
7,107	0,646 90	20,042	0,735 82
7,776	0,667 85	21,788	0,735 84
8,663	0,686 43	23,478	0,736 16
9,558	0,699 63	-	-
Wavelength: 1 550 nm. Calculated mode field diameter: 8,13 µm.			

E.4 Method C – Mode field diameter by near-field scan

A sample data set and the calculation of mode field diameter appears in Table E.3.

Table E.3 – Sample data set, method C – Mode field diameter by near-field scan

r µm	$f^2(r)/I(0)$	r µm	$f^2(r)/I(0)$
0,000	1,000 00	10,817	0,001 97
1,082	0,890 27	11,899	0,000 88
2,163	0,635 61	12,981	0,000 36
3,245	0,350 31	14,063	0,000 15
4,327	0,166 87	15,144	0,000 06
5,409	0,078 26	16,226	0,000 02
6,490	0,037 35	17,308	0,000 00
7,572	0,017 52	18,389	0,000 00
8,654	0,008 72	19,471	0,000 00
9,736	0,004 33	20,553	0,000 00
Wavelength: 1 550 nm. Calculated mode field diameter: 10,48 µm.			

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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FIBRES OPTIQUES –

Partie 1-45: Méthodes de mesure et procédures d'essai – Diamètre du champ de mode

AVANT-PROPOS

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La Norme internationale IEC 60793-1-45 a été établie par le sous-comité 86A: Fibres et câbles, du comité d'études 86 de l'IEC: Fibres optiques.

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

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

a) amélioration de la description des détails relatifs à la mesure de la fibre de catégorie B6;
b) correction des Équations (1), (2), (5) et (6);
c) correction du Tableau E.1, Tableau E.2 et Tableau E.3.

Le texte de la présente Norme internationale est issu des documents suivants:

CDV	Rapport de vote
86A/1758/CDV	86A/1802/RVC

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

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2.

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

Le comité a décidé que le contenu de cette publication ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives à la publication recherchée. A cette date, la publication sera

- reconduite,
- supprimée,
- remplacée par une édition révisée, ou
- amendée.

FIBRES OPTIQUES –

Partie 1-45: Méthodes de mesure et procédures d'essai – Diamètre du champ de mode

1 Domaine d'application

La présente partie de l'IEC 60793 établit des exigences uniformes pour mesurer le diamètre du champ de mode (DCM) d'une fibre optique unimodale, contribuant ainsi au contrôle des fibres et câbles à des fins commerciales.

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 60793-1-40:2001, *Fibres optiques – Partie 1-40: Méthodes de mesure et procédures d'essai – Affaiblissement*

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

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

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

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

4 Considérations générales concernant le diamètre du champ de mode

La mesure du diamètre du champ de mode représente une mesure de l'étendue transversale de l'intensité du champ électromagnétique du mode guidé dans la section droite d'une fibre, et il est défini à partir de la distribution de l'intensité du champ lointain comme un rapport d'intégrales, connu comme étant la définition de Petermann II. Voir l'Équation (1).

Les définitions du diamètre du champ de mode sont strictement liées aux configurations de mesure. L'équivalence mathématique de ces définitions résulte des relations de transformées entre les résultats de mesure obtenus par différents outils résumés à la Figure 1 ci-dessous.

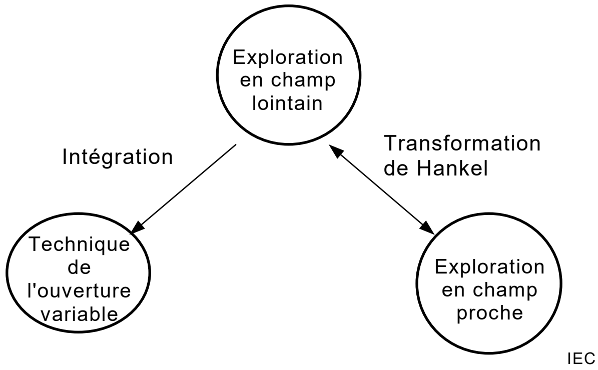

Figure 1 – Relations de transformées entre les résultats de mesure

Quatre méthodes de mesure du diamètre du champ de mode sont décrites:

– méthode A: exploration directe en champ lointain;
– méthode B: ouverture variable en champ lointain;
– méthode C: exploration en champ proche;
– méthode D: rétrodiffusion bidirectionnelle utilisant un réflectomètre optique fonctionnant dans le domaine temporel (RODT).

Ces quatre méthodes s'appliquent à toutes les catégories de fibres unimodales de type B de l'IEC 60793-2 opérant au voisinage de 1 310 nm ou de 1 550 nm. La méthode D n'est pas recommandée pour la mesure des fibres de type ou de modèle inconnus.

L'information commune aux quatre méthodes est contenue dans les Articles 1 à 11, et l'information concernant individuellement chaque méthode se trouve respectivement aux Annexes A, B, C et D.

5 Méthode d'essai de référence

La méthode A, exploration directe en champ lointain, est la méthode d'essai de référence (MTR), qui doit être utilisée pour résoudre les contestations.

6 Appareillage

6.1 Généralités

L'appareillage suivant est commun à toutes les méthodes de mesure. Les Annexes A, B, C et D contiennent respectivement les dessins et les exigences des autres équipements pour chacune des quatre méthodes.

6.2 Source lumineuse

Pour les méthodes A, B et C, utiliser une source appropriée de lumière cohérente ou incohérente, telle qu'un laser à semiconducteur ou une source de lumière blanche filtrée suffisamment puissante. La source doit produire une radiation suffisante à la longueur d'onde voulue et doit être stable en intensité pendant une durée suffisante pour permettre d'effectuer la mesure.

Si cela est exigé, un monochromateur ou un ou des filtres interférentiels peuvent être utilisés pour la sélection des longueurs d'onde. La longueur d'onde de la source doit être indiquée dans la spécification particulière. La largeur spectrale à mi-hauteur (LMH) de la source doit être inférieure ou égale à 10 nm, sauf spécification contraire.

Voir l'Annexe D pour la méthode D.

6.3 Système optique d'entrée

Pour les méthodes A, B et C, l'utilisation d'un système de lentilles optiques ou d'une fibre amorce pour exciter la fibre à l'essai est admise. Il est recommandé que la puissance couplée dans la fibre à l'essai soit relativement insensible à la position de la face d'entrée de la fibre à l'essai. Cela peut être réalisé en utilisant un faisceau d'injection permettant une saturation à la fois spatiale et angulaire de la face d'entrée.

Si une épissure en bout est utilisée, employer un matériau d'adaptation d'indice entre la fibre amorce et la fibre à l'essai pour éviter les phénomènes d'interférence. Le couplage doit rester stable pendant toute la durée de l'essai.

Voir l'Annexe D pour la méthode D.

6.4 Dispositif de positionnement d'entrée

Prévoir un dispositif pour le positionnement de l'extrémité d'entrée de l'échantillon à l'essai par rapport à la source lumineuse. Des exemples comprennent l'utilisation de plateaux de micropositionneur x-y-z, ou des dispositifs de couplage mécanique tels que des connecteurs, des épissures sous vide, des épissures à trois piges. La position de la fibre doit rester stable pendant toute la durée de la mesure.

6.5 Extracteur de modes de gaine

Utiliser un dispositif d'extraction de modes de gaine. Dans certains cas, c'est le revêtement de la fibre qui assure cette fonction.

6.6 Filtre des modes d'ordre supérieur

Utiliser un moyen pour éliminer la propagation des modes d'ordre supérieur dans la plage des longueurs d'ondes supérieures ou égales à la longueur d'onde de coupure de la fibre à l'essai. Par exemple, une boucle d'un seul tour d'un rayon de 30 mm sur la fibre à l'essai suffit généralement pour la plupart des fibres de type B1.1 à B6. Pour certaines fibres de type B6, un rayon plus petit, des boucles plus nombreuses ou une longueur d'échantillon plus importante peuvent être appliqués afin d'éviter la propagation des modes d'ordre supérieur.

6.7 Dispositif de positionnement de sortie

Prévoir un dispositif approprié pour l'alignement de la face d'extrémité de sortie de la fibre de façon à permettre un ajustement axial précis de l'extrémité de sortie, tel que, à la longueur d'onde de mesure, le balayage soit focalisé convenablement sur le plan du détecteur de balayage. Un tel couplage peut comprendre l'utilisation de lentilles ou peut être un connecteur mécanique à une fibre amorce du détecteur.

Prévoir un moyen tel qu'un microscope à vision latérale ou un appareil photographique muni d'un réticule pour localiser la fibre à une distance fixe par rapport aux ouvertures ou au détecteur. Un réglage longitudinal seul peut s'avérer suffisant si la fibre est maintenue dans le plan latéral par un dispositif tel qu'un mandrin à succion (cela dépend essentiellement de la taille du détecteur de lumière).

6.8 Dispositif optique de sortie

Voir l'annexe appropriée: A, B, C ou D.

6.9 Détecteur

Voir l'annexe appropriée: A, B, C ou D.

6.10 Calculateur

Utiliser un calculateur pour effectuer les opérations telles que le contrôle de l'appareillage, l'exécution des mesures d'intensité et le traitement des données pour obtenir les résultats finals. Pour les détails des opérations, voir l'annexe appropriée: A, B, C ou D.

7 Échantillonnage et échantillons à l'essai

7.1 Longueur de l'échantillon à l'essai

Pour les méthodes A, B et C, la longueur de l'échantillon à l'essai doit être une longueur connue, généralement de 2 m ± 0,2 m, de la plupart des fibres de type B1.1 à B6. Pour certaines fibres de type B6, une longueur d'échantillon plus importante peut être appliquée afin d'éviter la propagation des modes d'ordre supérieur, par exemple de 22 m.

Pour la méthode D, RODT, l'échantillon doit être suffisamment long pour dépasser (ou être placé au-delà de) la zone morte du RODT, avec les deux extrémités accessibles, comme décrit dans la méthode d'essai de rétrodiffusion de l'IEC 60793-1-40.

7.2 Surface d'extrémité de l'échantillon à l'essai

Préparer une surface plane, perpendiculaire à l'axe de la fibre, à l'extrémité d'entrée et à l'extrémité de sortie de l'échantillon à l'essai.

8 Mode opératoire

Voir respectivement les Annexes A, B, C et D pour les méthodes A, B, C et D.

9 Calculs

9.1 Équations de base

Les équations de base pour le calcul du diamètre du champ de mode pour chacune des méthodes A, B, et C sont indiquées ci-après. Pour des calculs supplémentaires, voir l'annexe appropriée: A, B, C ou D. Des ensembles de données sur échantillons pour les méthodes A, B et C figurent à l'Annexe E.

9.2 Méthode A – Exploration directe en champ lointain

L'équation suivante définit le diamètre du champ de mode pour la méthode A en termes de champ électromagnétique émis à partir de l'extrémité de l'échantillon à l'essai.

Calculer le diamètre du champ de mode à partir des données de l'exploration en champ lointain et de l'évaluation de l'intégrale de Petermann II, qui est définie à partir de la distribution de l'intensité en champ lointain:

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\frac{\int_0^{\pi/2} P_F(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} P_F(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]^{1/2} \quad (1)$$

où

$2W_0$ est le diamètre du champ de mode en µm;

$P_F(\theta)$ est la distribution de l'intensité en champ lointain;

λ est la longueur d'onde de mesure, en µm;

θ est l'angle dans la mesure en champ lointain à partir de l'axe de la fibre.

NOTE 1 Les limites d'intégration vont de zéro à $\pi/2$; il est cependant entendu que les intégrandes tendent vers zéro lorsque la variable d'intégration augmente, de sorte qu'en pratique, les intégrales peuvent être tronquées.

NOTE 2 P_F est $F^2(\theta)$ dans les publications de l'UIT-T.

La méthode du champ lointain pour déterminer le diamètre du champ de mode d'une fibre unimodale est un mode opératoire en deux étapes. La première étape consiste à mesurer le diagramme de rayonnement de la fibre en champ lointain. La seconde étape est un mode opératoire mathématique fondé sur la définition de Petermann II du champ lointain pour calculer le champ de mode à partir des données en champ lointain, comme décrit dans l'Équation (1) ci-dessus.

L'Annexe E fournit des données sur échantillon et des valeurs calculées pour les valeurs de $2W_0$ afin de pouvoir vérifier l'évaluation numérique de l'intégrale de Petermann II. Les données sur échantillon sont sous la forme de la puissance symétrisée par moyennes des écarts, $P_F(\theta)$, fonction de l'angle, θ.

9.3 Méthode B – Ouverture variable en champ lointain

Les équations suivantes définissent le diamètre du champ de mode pour la méthode B en termes de champ électromagnétique émis à partir de l'extrémité de l'échantillon à l'essai.

Calculer comme suit le diamètre du champ de mode $2W_0$:

$$2W_0 = \left(\frac{\lambda}{\pi D}\right)\left[\int_0^\infty \mathrm{a}(x)\frac{x}{\left(x^2+D^2\right)^2}dx\right]^{-1/2} \tag{2}$$

où

$2W_0$ est le diamètre du champ de mode en µm;

λ est la longueur d'onde de mesure, en µm;

D est la distance entre l'ouverture et la fibre, en mm;

$a(x)$ est la fonction de transmission de l'ouverture complémentaire, calculée comme

$$a(x) = 1 - \frac{P(x)}{P(\max)} \tag{3}$$

où

$P(x)$ est la puissance mesurée à travers une ouverture de rayon, x, ou de demi-angle, θ;

$P(\max)$ est la puissance maximale, supposant une ouverture infinie;

x est le rayon d'ouverture, calculé comme

$$x = D\tan(\theta) \tag{4}$$

Une autre expression équivalente de l'Équation (2) est

$$2W_0 = \frac{\lambda\sqrt{2}}{\pi}\left[\int_0^\infty \mathrm{a}(\theta)\sin 2\theta \,\mathrm{d}\theta\right]^{-1/2} \tag{5}$$

La méthode de l'ouverture variable en champ lointain pour calculer le diamètre du champ de mode d'une fibre unimodale est un mode opératoire en deux étapes. La première étape consiste à mesurer la répartition bidimensionnelle en champ lointain comme la puissance passant à travers des ouvertures de différentes tailles. La seconde étape est un mode opératoire mathématique qui consiste à calculer le diamètre du champ de mode à partir des données en champ lointain.

La base mathématique pour le calcul du diamètre du champ de mode est fondée sur la définition de Petermann II du champ lointain à partir de l'Équation (1). L'Équation (2) et l'Équation (5) peuvent être tirées de l'Équation (1) par intégration.

9.4 Méthode C – Exploration en champ proche

L'équation suivante définit le diamètre du champ de mode pour la méthode C en termes de champ électromagnétique émis à partir de l'extrémité de l'échantillon à l'essai.

Calculer le diamètre du champ de mode à partir de la répartition de l'intensité en champ proche mesurée, au moyen de l'intégrale suivante:

$$2W_0 = 2\left(2\frac{\int_0^\infty \mathrm{r}\, f^2(r)dr}{\int_0^\infty \mathrm{r}\left(\frac{\mathrm{df(r)}}{\mathrm{dr}}\right)^2 dr}\right)^{1/2} \tag{6}$$

où

$2W_0$ est le diamètre du champ de mode en µm;

r est la coordonnée radiale, en µm;

$f^2(r)$ est la répartition de l'intensité en champ proche.

NOTE La limite d'intégration supérieure va jusqu'à l'infini; il est cependant entendu que, les intégrandes tendant vers zéro lorsque la variable d'intégration augmente, en pratique les intégrales peuvent être tronquées. Un algorithme de lissage peut être utilisé pour le calcul de la dérivée.

La méthode du champ proche pour déterminer le diamètre du champ de mode d'une fibre unimodale est un mode opératoire en deux étapes. La première étape consiste à mesurer le diagramme de rayonnement de la fibre en champ proche. La seconde étape utilise un mode opératoire mathématique pour calculer le diamètre du champ de mode à partir des données en champ proche.

La base mathématique du calcul du diamètre du champ de mode se fonde sur la définition de Petermann II à partir de l'Équation (1). Le champ proche, $f(r)$, et le champ lointain, $F(\theta)$, forment une paire de transformées de Hankel. Par la transformation de Hankel et l'utilisation de $P_F = F^2(\theta)$, il est possible de tirer l'Équation (6) de l'Équation (1), et inversement.

10 Résultats

10.1 Informations disponibles pour chaque mesure

Relever les informations suivantes pour chaque mesure:

– date et titre de l'essai;
– identification de l'échantillon à l'essai;
– longueur d'onde de la source optique;
– diamètre(s) du champ de mode, en micromètres.