IEC 60793-1-45

Edition 3.0 2024-04

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 60793-1-45:2024-04(en-fr)

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FOREWORD

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

This third edition cancels and replaces the second edition published in 2017. This edition constitutes a technical revision.

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

a) Modification of the minimum distance between the fibre end and the detector for the direct far field scan (Annex A).
b) Generalization of the requirement for the minimum dynamic range for all fibre types (Annex A).

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

Draft	Report on voting
86A/2300/CDV	86A/2366/RVC

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

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

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

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

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

- reconfirmed,
- withdrawn, or
- revised.

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

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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

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

3.2 Abbreviated terms

The abbreviated terms are given in Table 1.

Table 1 – Abbreviated terms

Abbreviated term	Full term
CCD	charge-coupled devices
FWHM	full width half maximum
MFD	mode field diameter
OTDR	optical time domain reflectometer
RTM	reference test method

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 Formula (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.

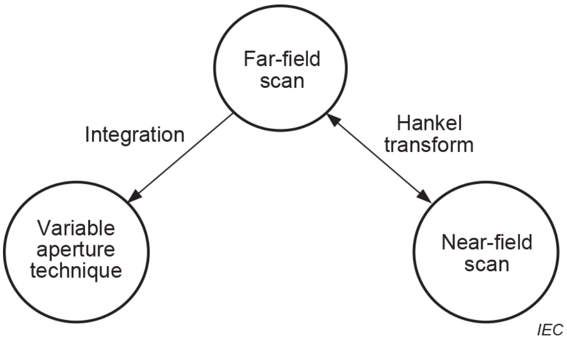

Figure 1 – Transform relationships between measurement results

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 Clause 1 to Clause 11, and information pertaining to each individual method appears in Annex A, Annex B, Annex C, and Annex 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. Annex A, Annex B, Annex C, and Annex D include layout drawings and other equipment requirements for each of the four methods, respectively.

6.2 Light source

For method A, method B and method C, use a suitable coherent or non-coherent light source, such as a semiconductor laser or a powerful filtered white light source.

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

The source power level shall be chosen so it is not impacting the repeatability of the mode diameter measurement.

The source power shall be stable for the complete duration of the measurement.

See Annex D for method D.

6.3 Input optics

For method A, method B, and method C, an optical lens system or fibre pigtail may be employed to excite the sample. It is recommended that the power coupled into the sample 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 sample 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 sample to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices,or 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 sample. For example, a one-turn bend with a radius of 30 mm on the fibre is generally sufficient for most B-652, B-653, B-654, B-655, B-656 and B-657 fibres. For some B-657 fibres, smaller radius, multiple bends, or longer sample 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 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 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 can 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: Annex A, Annex B, Annex C or Annex D.

6.9 Detector

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

7 Sampling and samples

7.1 Sample length

For method A, method B and method C, the sample shall be a known length, typically 2 m ± 0,2 m for most B-652, B-653, B-654, B-655, B-656 and B-657 fibres. For some B-657 fibres, longer sample 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 in IEC 60793-1-40.

7.2 Sample end face

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

8 Procedure

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

9 Calculations

9.1 Basic formulae

The basic formulae for calculating mode field diameter are Formula (1) for method A, Formula (2) for method B and Formula (6) for method C. For additional calculations, see the appropriate annex: Annex A, Annex B, Annex C or Annex D. Sample data sets for method A, method B and method C are included in Annex E.

9.2 Method A – Direct far-field scan

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

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 $\pi/2$, 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 Formula (1).

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

Formula (2) defines the mode field diameter for method B in terms of the electromagnetic field emitted from the end of the sample.

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

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

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

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

Another equivalent expression of Formula (2) is

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

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 Formula (1). Formula (2) and Formula (5) can be derived from Formula (1) by integration.

9.4 Method C – Near-field scan

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

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

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

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.