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**Optical fibres –
Part 1-41: Measurement methods and test procedures – Bandwidth**

**Fibres optiques –
Partie 1-41: Méthodes de mesure et procédures d'essai – Largeur de bande**

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OPTICAL FIBRES –

Part 1-41: Measurement methods and test procedures – Bandwidth

FOREWORD

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IEC 60793-1-41 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2010. This edition constitutes a technical revision.

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

- a) the addition of a direct reference for method A and method B.

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

Draft	Report on voting
86A/2302/CDV	86A/2365/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 of the IEC 60793 series, published under the general title *Optical fibres – Measurement methods and test procedures*, can be found on the IEC website.

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

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OPTICAL FIBRES –

Part 1-41: Measurement methods and test procedures – Bandwidth

1 Scope

This part of IEC 60793 describes three methods for determining and measuring the modal bandwidth of multimode optical fibres (see IEC 60793-2-10, IEC 60793-2-30, and the IEC 60793-2-40 series). The baseband frequency response is directly measured in the frequency domain by determining the fibre response to a sinusoidally modulated light source. The baseband response can also be measured by observing the broadening of a narrow pulse of light. The calculated response is determined using differential mode delay (DMD) data. The three methods are:

- Method A – Time domain (pulse distortion) measurement
- Method B – Frequency-domain measurement
- Method C – Overfilled launch modal bandwidth calculated from differential mode delay (OMBc)

Method A and method B can be performed using one of two launches: an overfilled launch (OFL) condition or a restricted mode launch (RML) condition. Method C is only defined for A1-OM3 to A1-OM5 multimode fibres and uses a weighted summation of DMD launch responses with the weights corresponding to an overfilled launch condition. The relevant test method and launch condition is chosen according to the type of fibre.

NOTE 1 These test methods are commonly used in production and research facilities and are not easily accomplished in the field.

NOTE 2 OFL has been used for the modal bandwidth value for LED-based applications for many years. However, no single launch condition is representative of the laser (e.g. VCSEL) sources that are used for gigabit and higher rate transmission. This fact drove the development of IEC 60793-1-49 for determining the effective modal bandwidth of laser optimized 50 μm fibres. See IEC 60793-2-10 and IEC 61280-4-1 for more information.

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 60793-1-20, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture*

IEC 60793-1-49, *Optical fibres – Part 1-49: Measurement methods and test procedures – Differential mode delay*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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>

3.1.1

bandwidth (–3 dB)

value numerically equal to the lowest modulation frequency at which the magnitude of the baseband transfer function of an optical fibre decreases to a specified fraction, generally to one half (–3 dB), of the zero frequency value

Note 1 to entry: The bandwidth is denoted in this document as $f_{3\text{ dB}}$.

Note 2 to entry: It is known that there can be various calculations, sometimes called markdowns, to avoid reporting extremely high values associated with "plateaus". For example, the 1,5 dB frequency, multiplied by $\sqrt{2}$ is one treatment used in IEC 60793-1-49. If such a calculation is used it should clearly be reported.

3.1.2

transfer function

discrete function of complex numbers, dependent on frequency, representing the frequency-domain response of the fibre under test

Note 1 to entry: Method A determines the frequency response by processing time domain data through Fourier transforms. Method B can only measure the transfer function if an instrument which measures phase as well as amplitude is used. Method C is similar to method A as it uses Fourier transforms in a similar manner. The transfer function is denoted in this document as $H(f)$.

3.1.3

power spectrum

discrete function of real numbers, dependent on frequency, representing the amplitude of the frequency-domain response of the fibre under test

Note 1 to entry: Method A and method C determine the power spectrum from the transfer function. Method B determines the transfer function by taking the ratio of the amplitude measured through the fibre under test and the reference. The power spectrum is denoted in this document as $|H(f)|$.

3.1.4

impulse response

discrete function of real numbers, dependent on time, representing the time-domain response of the fibre under test to a perfect impulse stimulus

Note 1 to entry: The impulse response is derived, in all methods, through the inverse Fourier transform of the transfer function.

Note 2 to entry: The impulse response is denoted in this document as $h(t)$.

3.2 Abbreviated terms

The abbreviated terms are given in Table 1.

Table 1 – Abbreviated terms

Abbreviated term	Full term
CW	continuous wave
DMD	differential mode delay
FWHM	full width half maximum
NIDL	normalized intermodal dispersion limit
OFL	overfilled launch
OMBc	overfilled modal bandwidth
RML	restricted mode launch
SSFL	system stability frequency limit

4 Apparatus

4.1 Radiation source

4.1.1 Method A – Time domain (pulse distortion) measurement

Use a radiation source such as an injection laser diode that produces short duration, narrow spectral width pulses for the purposes of the measurement. The pulse distortion measurement method requires the capability to switch the energy of the light sources electrically or optically. Some light sources shall be electrically triggered to produce a pulse; in this case a means shall be provided to produce triggering pulses. An electrical function generator or equivalent can be used for this purpose. Its output should be used to both induce pulsing in the light source and to trigger the recording system. Other light sources can self-trigger; in this case, means shall be provided to synchronize the recording system with the pulses coming from the light source. This can be accomplished in some cases electrically; in other cases, optoelectronic means can be employed.

4.1.2 Method B – Frequency domain measurement

Use a radiation source such as a continuous wave (CW) injection laser diode for the purposes of the measurement. The frequency domain measurement method requires the capability to modulate the energy of the light sources electrically or optically. Connect the modulation output of the tracking generator or network analyzer through any required driving amplifiers to the modulator.

4.1.3 Method C – Overfilled launch modal bandwidth calculated from differential mode delay (OMBc)

Use a radiation source as described in IEC 60793-1-49.

4.1.4 For method A and method B

Annex A: Use a radiation source with a centre wavelength that is known and within ± 10 nm of the nominal specified wavelength. For injection laser diodes, laser emission coupled into the fibre shall exceed spontaneous emission by a minimum of 15 dB (optical).

Annex B: Use a source with sufficiently narrow linewidth to assure the measured bandwidth is at least 90 % of the intermodal bandwidth. This is accomplished by calculating the normalized intermodal dispersion limit, NIDL (refer to Annex A). For A4 fibre, the linewidth of any laser diode is narrow enough to neglect its contribution to bandwidth measurement.

Annex C: For A1 and A3 fibres, calculate the NIDL (see Annex A) for each wavelength's measurement from the optical source spectral width for that wavelength as follows:

$$\text{NIDL} = \frac{\text{IDF}}{\Delta\lambda} \text{ in GHz}\cdot\text{km} \quad (1)$$

where

$\Delta\lambda$ is the source Full Width Half Maximum (FWHM) spectral width in nm;

IDF is the Intramodal Dispersion Factor (GHz·km·nm) from Annex A according to the wavelength of the source

NIDL is not defined for wavelengths from 1 200 nm to 1 400 nm. The source spectral width for these wavelengths shall be ≤ 10 nm, FWHM.

NOTE The acceptability of a NIDL value depends upon the specific user's test requirements. For example, a 0,5 GHz·km NIDL would be satisfactory for checking that fibres had minimum bandwidths ≥ 500 MHz·km, but would not be satisfactory for checking that fibres had minimum bandwidths > 500 MHz·km.

When the NIDL is found too low, a source with smaller spectral width is required.

Annex D: The radiation source shall be spectrally stable throughout the duration of a single pulse and over the time during which the measurement is made.

4.2 Launch system

4.2.1 Overfilled launch (OFL)

4.2.1.1 OFL condition for A1 fibre

Use a mode scrambler between the light source and the test sample to produce a controlled launch irrespective of the radiation properties of the light source. The output of the mode scrambler shall be coupled to the input end of the test sample in accordance with Annex D. The fibre position shall be stable for the complete duration of the measurement. A viewing system can be used to aid fibre alignment where optical imaging is used.

The OFL prescription in Annex D, based on the allowed variance of light intensity on the input of the fibre under test, can result in large ($> 25\%$) variations in the measured results for high bandwidth ($> 1\,500$ MHz·km) A1-OM3, A1-OM4 and A1-OM5 fibres. Subtle differences in the launches of conforming equipment are a cause of these differences. Method C is introduced as a means of obtaining an improvement.

Provide means to remove cladding light from the test sample. Often the fibre coating is sufficient to perform this function. Otherwise, it will be necessary to use cladding mode strippers near both ends of the test sample. The fibres may be retained on the cladding mode strippers with small weights, but care shall be taken to avoid microbending at these sites.

NOTE Bandwidth measurements obtained by the overfilled launch (OFL) support the use of category A1 multimode fibres, especially in LED applications at 850 nm and 1 300 nm. Some laser applications can also be supported with this launch but could result in reduced link lengths (at 850 nm) or restrictions on the laser sources (at 1 300 nm).

4.2.1.2 OFL condition for A3 and A4 fibres

OFL is obtained with geometrical optic launch in which the maximum theoretical numerical aperture of the fibre is exceeded by the launching cone and in which the diameter of the launched spot is in the order of the core diameter of the fibre. The light source shall be able to excite both low-order and high-order modes in the fibre equally.

NOTE A mode scrambler excites most modes. Mode excitation is very sensitive to the source and mode scrambler alignment and the interaction with any intermediary optics such as connectors or optical imaging systems. A light source with large NA and core diameter will only excite meridional modes or $LP_{0,m}$ modes.

4.2.2 Restricted mode launch (RML)

4.2.2.1 RML condition for A1-OM1 fibre

The RML for bandwidth is created by filtering the overfilled launch (as defined by Annex D) with a RML fibre. The OFL is defined by Annex D and it needs to be only large enough to overfill the RML fibre both angularly and spatially. The RML fibre has a core diameter of $23,5 \mu\text{m} \pm 0,1 \mu\text{m}$, and a numerical aperture of $0,208 \pm 0,01$. The fibre shall have a graded-index profile with an alpha of approximately 2 and an OFL bandwidth greater than $700 \text{ MHz}\cdot\text{km}$ at 850 nm and 1 300 nm. For convenience, the clad diameter should be 125 μm . The RML fibre should be at least 1,5 m in length to eliminate leaky modes; and it should be <5 m in length to avoid transient loss effects. The launch exiting the RML fibre is then coupled into the fibre under test.

Provide means to remove cladding light from the test sample. Often the fibre coating is sufficient to perform this function. Otherwise, it will be necessary to use cladding mode strippers near both ends of the test sample. The fibres may be retained on the cladding mode strippers with small weights, but care shall be taken to avoid microbending at these sites.

To achieve the highest accuracy, tight tolerances are required on the geometry and profile of the RML fibre. To achieve the highest measurement reproducibility, tight alignment tolerances are required in the connection between the launch RML fibre and the fibre under test to ensure the RML fibre is centred to the fibre under test.

NOTE Bandwidth measurements obtained by a restricted mode launch (RML) are used to support 1 Gigabit Ethernet laser launch applications. The present launch is especially proven for 850 nm sources transported over type A1-OM1 fibres.

4.2.2.2 RML condition for A3 fibre

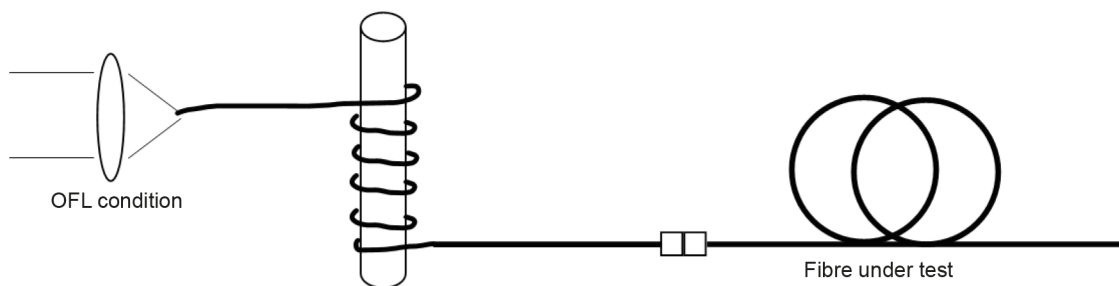
RML condition for A3 fibre is created with geometrical optic launch which corresponds to launch $\text{NA} = 0,3$.

Spot size shall be larger or equal to the size of core.

4.2.2.3 RML condition for A4 fibre

The RML for A4 fibre shall correspond to $\text{NA} = 0,3$. It can be created by filtering the overfilled launch with a mandrel wrapped mode filter, shown in Figure 1. The mode filter shall be made with the fibre of the same category as the fibre under test. To avoid redundant loss, the length of fibre should be 1 m. The diameter of the mandrel shall be 20 times as large as that of the fibre cladding and the number of coils shall be 5. Unwound parts of fibre should be set straight.

Do not apply any excessive stress in winding fibre on to the mandrel. The wound fibre may be fixed to the mandrel with an adhesive.



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Figure 1 – Mandrel wrapped mode filter

4.2.3 Differential mode delay (DMD) launch

The DMD launch shall comply with the launch requirements of IEC 60793-1-49.

4.3 Detection system

The output optical detection apparatus shall be capable of coupling all guided modes from the test sample to the detector active area such that the detection sensitivity is not significantly mode dependent.

A device shall be available to position the specimen output end with sufficient stability and reproducibility to meet the conditions of 4.6.

An optical detector shall be used that is suitable for use at the test wavelength, linear in amplitude response, spatially uniform to within 10 %, and sufficiently large to detect all emitted power. An optical attenuator may be used to control the optical intensity on the detector. It shall be mode independent as well.

The detection electronics as well as any signal preamplifier shall be linear in amplitude response (nonlinearities less than 5 %) over the range of encountered signals.

The detection system for method C shall comply with the requirements of IEC 60793-1-49.

4.4 Recording system

For the time domain (pulse distortion) measurement (method A), use an oscilloscope suitably connected to a recording device, such as a digital processor, to store the received pulse amplitude as a function of time. For temporal measurements, data taken from the oscilloscope display shall be considered secondary to those derived from the recorded signal.

For the frequency domain measurement (method B), use a tracking generator-electrical spectrum analyzer combination, scalar network analyzer, vector network analyzer or an equivalent instrument to detect, display and record the amplitude of the RF modulation signal derived from the optical detector. This shall be done in such a manner as to reduce harmonic distortion to less than 5 %.

The recording system for method C shall comply with the requirements of IEC 60793-1-49.

4.5 Computational equipment

For the time domain (pulse distortion) method (method A) and overfilled launch bandwidth calculated from differential mode delay (method C) or if impulse response is required from method B, computational equipment capable of performing Fourier transforms on the detected optical pulse waveforms as recorded by the waveform recording system shall be used. This equipment may implement any of the several fast Fourier transforms or other suitable algorithms, and is useful for other signal conditioning functions, waveform averaging and storage as well.

4.6 Overall system performance

NOTE 4.6 provides a means of verifying system stability for the duration of a measurement or the system calibration period, depending on the method used (A, B or C, see 6.1, 6.2 and IEC 60793-1-49, respectively).

The measurement system stability is tested by comparing system input pulse Fourier transforms (method B) or input frequency responses (method A) over a time interval. As shown in Annex B, a bandwidth measurement normalizes the fibre output pulse transform by the system calibration transform. If a reference sample is substituted for the fibre sample, the resultant response, $H(f)$, represents a comparison of the system to itself over the time interval. This normalized system amplitude stability is used to determine the system stability frequency limit (SSFL).

The SSFL is the lowest frequency at which the system amplitude stability deviates from unity by 5 %. The value of the time interval used for the SSFL determination depends on the method used for the measurement. If method A-1 or B-1 is employed, SSFL shall be determined based on one re-measurement at a time interval similar to that used for an actual fibre measurement. If method A-2 or B-2 is employed, it shall be determined over substantially the same time interval as that which is used for periodic system calibration (see 6.1.3). In this latter case, the time interval can influence the SSFL.

To determine the SSFL, attenuate the optical signal reaching the detector by an amount equal to or greater than the attenuation of the test sample plus 3 dB. This can require the introduction of an attenuator into the optical path, if an attenuator, such as the one used for signal normalization and scaling, is not already present. Also, normal deviations in the position and amplitude of the pulse or frequency response on the display device shall be present during the determination of the SSFL.

5 Sampling and specimens

5.1 Test sample

The test sample shall be a known length of optical fibre or optical fibre cable.

5.2 Reference sample

The reference sample shall be a short length of fibre of the same type as the test sample or cut from the test sample. Except A4 fibre, the reference length shall be less than 1 % of the test sample length or less than 10 m, whichever is shorter.

For A4 fibre, the reference length shall be 1 m to 2 m. In case of RML, the output of the mode filter is the reference.

5.3 End face preparation

Prepare smooth, flat end faces, perpendicular to the fibre axis.

5.4 Test sample packaging

For A1 fibres, the deployment (spool type, wind tension, and other winding characteristics) can affect the results by significant values. It is normal to conduct most quality control measurements with the fibre deployed on spools in a manner that is suitable for shipment. The reference deployment, however, is one in which the fibre is stress-free and in which microbending is minimized. Mapping functions can be used to report the expected value that would be obtained from a reference deployment measurement based on measurements of the fibre as deployed on a shipping spool. The mapping function shall be developed from measurements of a set of fibres that have been deployed both ways and which represent the full range of bandwidth values of interest.

For A4 fibre, test sample shall be wound into coils with diameter of at least 300 mm, free from any stress. It shall be certain that the test sample is free from both macro- and microbending and that the energy distribution at the output of the launching system is substantially constant.

5.5 Test sample positioning

Position the input end of the test sample such that it is aligned to the output end of the launch system to create launching conditions in accordance with 4.2.

Position the output end of the test sample such that it is aligned to the optical detector.