IEC 60793-1-41

Edition 3.0 2010-08

INTERNATIONAL STANDARD

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colour inside

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

IEC 60793-1-41:2010

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

FOREWORD

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

This third edition cancels and replaces the second edition published in 2003. This edition constitutes a technical revision.

The main change with respect to the previous edition is the addition of a third method for determining modal bandwidth based on DMD data and to improve measurement procedures for A4 fibres.

This standard should be read in conjunction with IEC 60793-1-1 and IEC 60793-1-2, which cover generic specifications.

The text of this standard is based on the following documents:

FDIS	Report on voting
86A/1294/CDV	86A/1329/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60793-1-4x 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 publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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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 60793-30 series and IEC 60793-40 series). The baseband frequency response is directly measured in the frequency domain by determining the fibre response to a sinusoidaly 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)

Methods A and 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 A1a.2 (and A1a.3 in preparation) multimode fibre 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 should be 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 60793-2-10:2004 or later and IEC 61280-4-1:2003 or later for more information.

2 Normative references

The following referenced documents are indispensable for the application 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 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

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

IEC 60793-1-49:2006, Optical fibres – Part 1-49: *Measurement methods and test procedures – Differential mode delay*

3 Terms and definitions

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

3.1
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, of the zero frequency value. The bandwidth is denoted in this document as $f_{3\ \mathrm{dB}}$.

NOTE 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.

3.2
transfer function
discrete function of complex numbers, dependent on frequency, representing the frequency-domain response of the fibre under test

NOTE 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 $H(f)$.

3.3
power spectrum

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

NOTE Methods A and 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 $|H(f)|$.

3.4
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. The impulse response is derived, in all methods, through the inverse Fourier transform of the transfer function. The impulse response is denoted in this document as $h(t)$.

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 may self-trigger; in this case, means shall be provided to synchronize the recording system with the pulses coming from the light source. This may be accomplished in some cases electrically; in other cases optoelectronic means may 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 methods A and B

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 shallexceed spontaneous emission by a minimum of 15 dB (optical).

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.

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:

$$\mathrm{NIDL} = \frac{\mathrm{IDF}}{\Delta\lambda}, \text{ in GHz·km}$$

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 less than or equal to 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 greater than some value less than 500 MHz·km, but would not be satisfactory for checking that fibres had minimum bandwidths greater than 500 MHz·km. If the NIDL is too low, a source with smaller spectral width is required.

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 may 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) A1a 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 may 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 more or less all modes. Mode excitation is very sensitive to the source/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 A1b 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 µm ± 0,1 µm, and a numerical aperture of 0,208 ± 0,01. The fibre shall have a graded-index profile with an alpha of approximately 2 and an OFL bandwidth greater than 700 MHz·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 less than 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.

NOTE 1 In order to achieve the highest accuracy, tight tolerances are required on the geometry and profile of the RML fibre. In order 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 2 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 A1b 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 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 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. In order to avoid redundant loss, the length of fibre should be 1 m. The diameter of the mandrel should be 20 times as large as that of the fibre cladding and the number of coils may be 5.

NOTE 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. Unwound parts of fibre should be set straight.

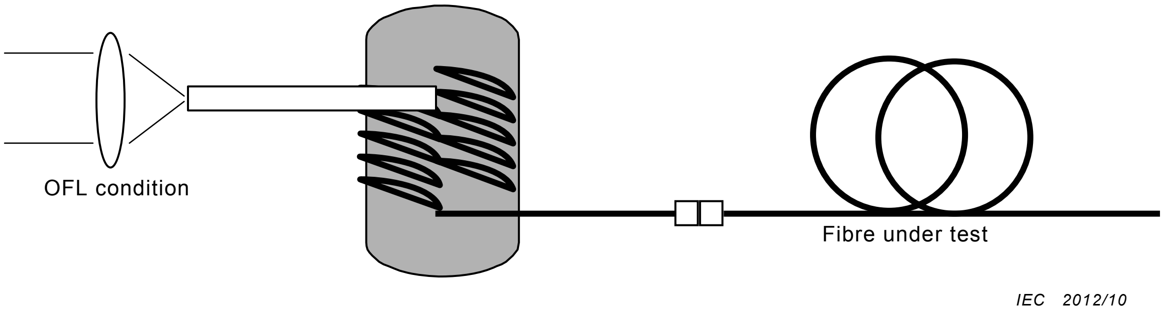

Figure 1 – Mandrel wrapped mode filter

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 below.

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 This subclause 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 subclauses 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 %. If method A-1 or B-1 is employed, it shall be determined on the basis of 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 6.1.2). In this latter case, the time interval may 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 may require the introduction of an attenuator into the optical path, if an attenuator, such as might be 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 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 sub-clause 4.2.

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

6 Procedure

6.1 Method A – Time domain (pulse distortion) measurement

6.1.1 Output pulse measurement

a) Inject power into the test fibre and adjust the optical attenuator or detection electronics, or both, such that one entire optical pulse from the fibre is displayed on the calibrated oscilloscope, including all leading and trailing edges having an amplitude greater than or equal to 1 % or -20 dB of the peak amplitude.

b) Record the detected amplitude and the calibrated oscilloscope sweep rate.

c) Record the fibre output pulse and calculate the Fourier transform of this pulse, per Annex B.

d) Determine the input pulse to the test sample by measuring the signal exiting the reference sample. This may be accomplished by using a reference length cut from the test sample or from a similar fibre.

6.1.2 Input pulse measurement method A-1: reference sample from test sample

a) Cut the test fibre near the input end according to 5.2. Create a new output end face, per 5.3, and align the end with respect to the optical detector as outlined in 6.1.1 a). Do not disturb the input end.

b) Apply the cladding mode stripper, if used (see 5.2).

c) If an optical attenuator is used, read just for the same displayed pulse amplitude as outlined in 6.1.1 a).

d) Record the system input pulse using the same oscilloscope sweep rate as for the test sample, and calculate the input pulse Fourier transform per Annex B.

6.1.3 Input pulse measurement method A-2: periodic reference sample

a) The following system calibration procedure employing the periodic reference sample shall be performed over substantially the same time interval as used to determine the SSFL (see 4.6). In most cases where adequate preparation of mode scrambler, laser diode, and alignment equipment has been made, it is acceptable to use a reference sample not taken from the test sample.

b) Prepare input and output ends per 5.3 on a reference sample of the same fibre class and same nominal optical dimensions as the test sample.

c) Align the input and output ends as outlined in 5.5 and, if an optical attenuator is used, adjust to obtain the correct displayed pulse amplitude.

d) Record the system input pulse using the same oscilloscope sweep rate as for the test sample, and calculate the input pulse Fourier transform per Annex B.

6.2 Method B – Frequency domain measurement

6.2.1 Output frequency response

a) Sweep the modulation frequency, f, of the source from a low frequency, to provide an adequate DC zero reference level, to high frequency in excess of the 3 dB bandwidth. Record the relative optical power exiting the test specimen as a function of f; denote this power as $P_{out}(f)$. If a network analyzer and the impulse response is desired, the high frequency should exceed -15 dB point and the phase $\varphi_{out}(f)$ should be recorded.

NOTE A function related to $P_{out}(f)$, such as log $P_{out}(f)$, may be recorded to finally obtain $|H(f)|$ in 7.1.

b) Determine the input modulated signal to the test sample by measuring the signal exiting the reference length of the fibre. This may be accomplished using a reference length from the test sample (method B-1; preferred method to be used in case of conflict in test results) or from a similar fibre (method B-2).

6.2.2 Method B-1: Reference length from test specimen

a) Cut the test sample near the input end and prepare flat end faces (see 5.3) at this newly created output end. Strip the cladding modes from the output end if necessary. Do not disturb the launching conditions to this short length.

b) Sweep the modulation frequency, f, of the source from a low frequency, to provide an adequate DC zero reference level, to a high frequency in excess of the 3 dB bandwidth. Record the relative optical power exiting the reference length as a function of f; denote this power as $P_{in}(f)$.

6.2.3 Method B-2: Reference length from similar fibre

a) If the apparatus exists to position a fibre at the same place in the mode scrambler output as was the input of the test sample, then another short length of fibre having the same nominal properties of the test sample may be substituted as the reference. Use the reference fibre to replace the test sample. Apply a cladding mode stripper, if necessary, and align the output end in front of the detector.

b) Sweep the modulation frequency, f, of the source from a low frequency, to provide an adequate DC zero reference level, to a high frequency in excess of the 3 dB bandwidth. Record the relative optical power exiting the reference length as a function of f; denote this power as $P_{in}(f)$.

NOTE A function related to $P_{in}(f)$, such as log $P_{in}(f)$, may be recorded to finally obtain $|H(f)|$ in 7.2.

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

a) Measure the differential mode delay of fibre in accordance with IEC 60793-1-49.

b) Calculate the overfilled modal bandwidth according to the formulae B2 of IEC 60793-1-49:2006" using weights given here in Table 1. Linear interpolation of the weight value shall be applied for any radial position of the actual scan that is known to lie between the integer positions listed in Table 1.

NOTE Table 1 weightings are only applicable for A1a fibres at 850 nm.