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

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OPTICAL FIBRES –

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

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 IEC 60793-1-41:2010. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

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

- reconfirmed,
- withdrawn, or
- revised.

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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~~ 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 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)

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 ~~A1a.2 (and A1a.3 in preparation)~~ 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 ~~should be~~ 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~~:2004 or later~~ and IEC 61280-4-1~~:2003 or later~~ 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 60793-1-42, *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, 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 $f_{3\ \mathrm{dB}}$.

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

$$\text{NIDL} = \frac{\text{IDF}}{\Delta\lambda} \text{ in GHz·km} \tag{1}$$

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 ~~may~~ 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) ~~A1a~~ 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 ~~may~~ 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 ~~more or less all~~ 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 ~~A1b~~ 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 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 <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~~ 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 ~~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~~ A1-OM1 fibres.

4.2.2.2 RML condition for A3 fibre

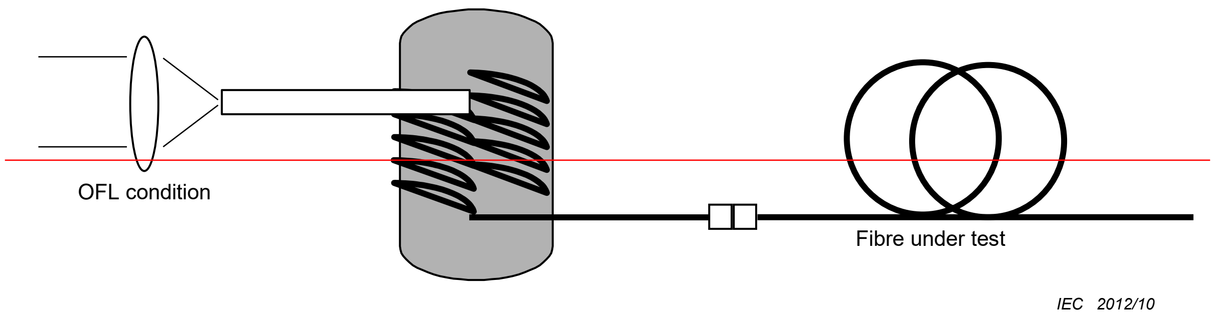
RML condition for A3 fibre is created with geometrical optic launch which corresponds to launch NA = 0,3.

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. To avoid redundant loss, the length of fibre should be 1 m. The diameter of the mandrel ~~should~~ shall be 20 times as large as that of the fibre cladding and the number of coils ~~may~~ shall be 5. Unwound parts of fibre should be set straight.

~~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.



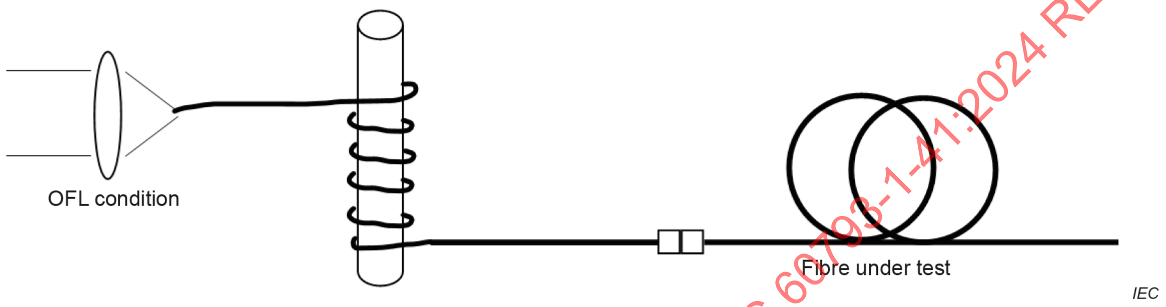


Figure 1 – Mandrel wrapped mode filter

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 ~~may~~ 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 ~~may~~ can require the introduction of an attenuator into the optical path, if an attenuator, such as ~~might be~~ 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.

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 ≥ 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~~ path. This ~~may~~ can be accomplished by using a reference length cut from the test sample (see 6.1.2), a reference length cut from a similar fibre (see 6.1.3) or by directly coupling the source output to the detector (see 6.1.4).

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.

6.1.4 Input pulse measurement method A-3: direct reference

a) The source can be coupled to the detection apparatus, directly or via a system of lenses and mirrors.

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

c) 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.

The use of the direct reference (6.1.4) requires that the input pulse Fourier transform calculated with the direct reference (6.1.4) and the input pulse Fourier transform calculated with the reference sample (6.1.2) are nearly identical. An acceptance criterion is to measure the system input pulses in both a test sample (6.1.2) and with the direct reference (6.1.4), calculate the input pulse Fourier transform per Annex B and verify that this frequency response is varying less than ±5,0 % from unity for all frequencies up to the system stability frequency limit (defined in 4.6).

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~~ can 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~~ path. This ~~may~~ can be accomplished using a reference length from the test sample (method B-1 is the preferred method to be used in case of conflict in test results), from a similar fibre (method B-2) or from the direct coupling of the source output to the detector (method B-3).

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~~ can 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~~ can be recorded to finally obtain $|H(f)|$ in 7.2.

6.2.4 Method B-3: Reference from direct coupling

a) The source can be coupled to the detection apparatus, directly or via a system of lenses and mirrors.

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 detector as a function of f; denote this power as $P_{in}(f)$.

The use of the direct reference (6.2.4) requires that the relative optical powers $P_{in}(f)$ recorded using the direct coupling (6.2.4) and using the reference length of the test sample (6.2.2) are varying less than ±5,0 % from unity for all frequencies up to the system stability frequency limit (defined in 4.6) (with an offset corresponding to the difference of those functions at 0 Hz).

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

Annex A: Measure the differential mode delay of fibre in accordance with IEC 60793-1-49.

Annex B: Calculate the overfilled modal bandwidth according to Formula B.2 of IEC 60793-1-49~~:2006~~ using weights given here in Table 2. 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 2.

NOTE Table 2 weightings are only applicable for ~~A1a~~ A1-OM2 to A1-OM5 fibres at 850 nm.

Table 2 – DMD weights for calculating overfilled modal bandwidth (OMBc) from DMD data for 850 nm only

r (µm)	DMD weights for OMBc
0	0
1	0,000 73
2	0,001 57
3	0,002 53
4	0,003 62
5	0,004 87
6	0,006 31
7	0,007 95
8	0,009 83
9	0,011 98
10	0,014 43
11	0,017 25
12	0,020 46
13	0,024 14
14	0,028 36
15	0,033 17
16	0,038 69
17	0,045 00
18	0,052 21
19	0,060 47
20	0,069 92
21	0,080 73
22	0,093 10
23	0,107 25
24	0,123 45
25	0,141 97

7 Calculations or interpretation of results

7.1 ~~−3 dB frequency~~ Bandwidth (−3 dB), $f_{3\ \mathrm{dB}}$

Calculate the frequency response, $H(f)$. Calculate the −3 dB fibre bandwidth, $f_{3\ \mathrm{dB}}$, in accordance with Annex B.

If the measured −3 dB frequency exceeds the NIDL (as calculated in 4.1.4) divided by the fibre length, L, in km, report the measured result. In this case, it is preferable to show that the measurement result ~~may~~ could have been limited by the equipment, as shown in Example 1.

EXAMPLE 1 A fibre 2,2 km long has a length normalized measured −3 dB frequency of 2,2 GHz·km, but the measurement system has a NIDL of 2 GHz·km at this wavelength. Preferably, the result is reported as ">normalized measured value" (">2,2 GHz·km", in this example). Similarly, the actual measured value is preferably reported as "> {measured value}" (">1,0 GHz", in this example). The ">" sign shows that the measured value ~~may~~ could have been limited by the test set. If the measured 3 dB frequency exceeds the SSFL (as determined in 4.6), report the result as being greater than the SSFL as shown in Example 2.

EXAMPLE 2 A fibre 2,2 km long has a measured 3 dB frequency of 0,95 GHz (2,09 GHz·km), which is greater than the SSFL for the test set, 0,9 GHz (1,98 GHz·km for this fibre length). Report the result as "> (SSFL)" ("> 0,9 GHz", here). Report the length normalized result as ">(SSFL times the sample length in km" ("> 1,98 GHz·km", here). The ">" sign ~~is required to show~~ shows that the measured value is limited by the test set.

7.2 Calculations for optional reporting methods

Other reporting methods ~~may~~ can be required by a detail specification in lieu of $f_{3\ \mathrm{dB}}$. Refer to the appropriate Annex:

B.1: Fibre transfer function, $H(f)$

B.2: Power spectrum, $|H(f)|$

C.1: Fibre impulse response, h(t)

C.2: RMS impulse response, exact method

C.3: RMS impulse response, difference of squares approximation

8 Length normalization

It ~~may~~ can be desirable to normalize the bandwidth or pulse broadening to a unit length, such as GHz·km, or ns/km. If the bandwidth or pulse broadening is normalized to a unit length, the length dependence formula used shall be reported.

9 Results

9.1 Information to be provided with each measurement

Report the following information with each measurement:

a) test procedure number and method used;
b) launch conditions used (RML or OFL, DMD);
c) test date;
d) test sample identification;
e) test results: $f_{3\ \mathrm{dB}}$ (7.1) or results of other reporting methods as required by the detail specification;
f) source wavelength (nominal or actual);
g) sample length;
h) length normalization formula, if used.

9.2 Information available upon request

The following information shall be available upon request:

- source: type, actual source wavelength, maximum specified or actual spectral width (FWHM) – state if not measured;
- description of mode scrambler and launch apparatus;
- normalized intermodal dispersion limit (NIDL), for each measurement wavelength;
- detector type and operating conditions;
- details of computational procedure to calculate bandwidth or other reporting methods;
- method of stripping cladding light;
- date of latest calibration of test equipment;
- title of test;
- test personnel.

10 Specification information

The detail specification shall specify the following information:

a) number and type of samples to be tested;

b) test procedure number;

c) reporting method to be used, if other than 7.1;

d) test wavelength(s).

Annex A
(normative)

Intramodal dispersion factor and the normalized intermodal dispersion limit

A.1 Intramodal dispersion factor, IDF

This test method is intended to measure the intermodal bandwidth of a fibre. However, additional dispersion caused by interaction of the laser spectrum with the fibre chromatic dispersion can reduce the measured value. The purpose of the IDF is to provide a means of limiting this source of measurement error. IDF has units of GHz·km·nm and is the frequency at which the measured bandwidth drops to 90 % of the intermodal bandwidth, per nanometre of source linewidth, per kilometre of fibre length. See A.3 for the derivation of the IDF. The data in Table A.1 represents the highest expected dispersion for any of the commercially available category A1 fibres, based on nominal dispersion performance. For table data lower than 1 200 nm, dispersion is greatest with fibre of maximum λ_0 (0,29 NA fibre). For table data greater than 1 400 nm, dispersion is greatest with fibre of minimum λ_0 (0,20 NA fibre). Here λ_0 is the zero-dispersion wavelength. IDF is not used between 1 200 nm and 1 400 nm.

Table A.1 – Highest expected dispersion for commercially available A1 fibres

λ (nm)	IDF (GHz·km·nm)	λ (nm)	IDF (GHz·km·nm)	λ (nm)	IDF (GHz·km·nm)
780	1,31				
790	1,37				
800	1,44	1 000	3,54	1 400	23,18
810	1,50	1 010	3,71	1 410	21,15
820	1,57	1 020	3,90	1 420	19,49
830	1,64	1 030	4,09	1 430	18,09
840	1,72	1 040	4,30	1 440	16,90
850	1,79	1 050	4,52	1 450	15,87
860	1,88	1 060	4,76	1 460	14,98
870	1,96	1 070	5,02	1 470	14,20
880	2,05	1 080	5,30	1 480	13,50
890	2,14	1 090	5,60	1 490	12,89
900	2,24	1 100	5,92	1 500	12,33
910	2,34	1 110	6,27	1 510	11,83
920	2,45	1 120	6,65	1 520	11,37
930	2,56	1 130	7,07	1 530	10,96
940	2,68	1 140	7,53	1 540	10,58
950	2,80	1 150	8,03	1 550	10,23
960	2,93	1 160	8,59	1 560	9,91
970	3,07	1 170	9,22	1 570	9,61
980	3,22	1 180	9,92	1 580	9,34
990	3,37	1 190	10,71	1 590	9,08
				1 600	8,84

NOTE Assumptions Used: S_0 = 0,095 62 ps/(nm^2·km); λ_0 = 1 344,5 nm for nominal MMF w/0,29 NA.

A.2 Normalized intermodal dispersion limit, NIDL

The maximum bandwidth that can be reported by a test set is limited by the normalized intermodal dispersion limit (NIDL). The NIDL is calculated for each measurement wavelength of a test set according to 4.1.4, using IDF values taken from Table A.1. The source spectral width used in the calculation may be either a maximum value for the device as specified by the device manufacturer, or, preferably, a measured value.

Since NIDL is based on the IDF, a measured, length-normalized bandwidth equal to the NIDL is 10 % less than the actual intermodal bandwidth. The error decreases for measured bandwidths less than the NIDL, and rapidly increases above it. The actual error will typically be a few percent less than this because the actual dispersion of the test sample will be less than the value used in the IDF, and the source spectral width ~~may~~ can be overstated. Because of these approximations and source spectral instability, correction for chromatic dispersion is not appropriate.

NIDL is not defined for wavelengths from 1 200 nm to 1 400 nm because intramodal dispersion in fibre measurements is negligible when used with lasers in this range.

NOTE The calculations in Table A.1 are derived from an assumption that the spectrum is Gaussian. If this assumption is not valid some care in the interpretation of the table is needed.

A.3 Derivation of the IDF

For the derivation of IDF, the following have been assumed to have Gaussian distributions:

a) chromatic and modal temporal pulse broadening, D_{chrom} and D_{modal}, respectively,

b) all frequency responses (amplitudes)

c) the optical source spectrum, expressed as $\Delta\lambda$s (nm, FWHM).

The relationship between dispersion and bandwidth is expressed as:

$$D = \frac{k}{BW} \tag{A.1}$$

where k = 187 for RMS dispersion in ps and −3 dB bandwidth in GHz. Assuming that the chromatic and modal dispersion are independent, the total (measured) dispersion, D_{meas}, can be written:

$$D_{\text{meas}} = \sqrt{D^2_{\text{chrom}} + D^2_{\text{modal}}} \tag{A.2}$$

Combining Formula (A.1) and Formula (A.2) produces the following result:

$$\left[\frac{BW^2_{\text{meas}}}{BW^2_{\text{chrom}}}\right] + \left[\frac{BW^2_{\text{meas}}}{BW^2_{\text{modal}}}\right] = 1 \tag{A.3}$$

Let ε represent an error in the measurement caused by chromatic dispersion such that

$$BW_{\text{meas}} = (1-\varepsilon)BW_{\text{modal}} \tag{A.4}$$

The chromatic bandwidth (in GHz) can be calculated as:

$$BW_{\text{chrom}} = \frac{440}{D(\lambda)L\Delta\lambda_s} \tag{A.5}$$

where $D(\lambda)$ is the fibre chromatic dispersion coefficient (in ps/(nm·km)) at wavelength λ, and L is fibre length in km. $D(\lambda)$ is defined in IEC 60793-1-42.

Combining Formula (A.3), Formula (A.4) and Formula (A.5) provides the definition of IDF:

$$\text{IDF} = BW_{\text{meas}}L\Delta\lambda_s = \frac{440\sqrt{2\varepsilon-\varepsilon^2}}{D(\lambda)} \tag{A.6}$$

Specifically, for ε = 0,1 (10 % error),

$$\text{IDF} = \frac{192}{D(\lambda)}\ (\text{GHz km nm}) \tag{A.7}$$

for $D(\lambda)$ in ps/(nm·km).

Annex B
(normative)

Fibre transfer function, *H(f)*, power spectrum, |*H(f)*|, and $f_{3\ \mathrm{dB}}$

B.1 Fibre transfer function

B.1.1 Method A – Time domain (pulse distortion) measurement

The time domain measurement begins with the input pulse, $a(t)$, and the output pulse, $b(t)$. The input pulse and fibre output pulse Fourier transforms shall be calculated using the following formula.

$$A(f) = \int_{-\infty}^{+\infty} a(t) e^{-j2\pi ft} dt \tag{B.1}$$

$$B(f) = \int_{-\infty}^{+\infty} b(t) e^{-j2\pi ft} dt \tag{B.2}$$

where

$a(t)$ is the temporal input pulse,

$b(t)$ is the temporal output pulse,

$A(f)$ is the input pulse Fourier transform, and

$B(f)$ is the fibre output pulse Fourier transform.

For the time domain method, the fibre transfer function shall be calculated as:

$$H(f) = \frac{B(f)}{A(f)} \tag{B.3}$$

NOTE $A(f)$, $B(f)$ and $H(f)$ are vectors of complex numbers usually expressed as real and imaginary pairs.

B.1.2 Method B – Frequency-domain measurement

When a network analyzer or equivalent phase-measuring equipment is used, the transfer function is calculated as:

$$A(f) = P_{\mathrm{in}}(f) \times [\cos(\varphi_{\mathrm{in}}(f)) + i \sin((\varphi_{\mathrm{in}}(f))] \tag{B.4}$$

$$B(f) = P_{\mathrm{out}}(f) \times [\cos(\varphi_{\mathrm{out}}(f)) + i \sin((\varphi_{\mathrm{out}}(f))] \tag{B.5}$$

$$H(f) = \frac{B(f)}{A(f)} \tag{B.6}$$

where $A(f)$, $B(f)$, and $H(f)$ are as defined in Formula (B.1).

B.2 Power spectrum

B.2.1 Method A – Time domain (pulse distortion) measurement

From the time domain (pulse distortion) measurement, the frequency response in dB, $|H(f)|$, is calculated as follows:

$$\left|H(f)\right| = 10Log_{10}\left[\sqrt{Re(H(f))^2 + Im(H(f))^2}\right] - 10Log_{10}\left[Re(H(0))\right] \tag{B.7}$$

where $Re(x)$ and $Im(x)$ are the real and imaginary parts of complex number x and the subtraction of the zero frequency term normalizes the power spectrum to be zero dB at zero frequency.

B.2.2 Method B – Frequency-domain measurement

For the frequency domain method, the frequency response in dB, $H(f)$, calculation ~~may~~ can be simplified to the following:

$$\left|H(f)\right| = 10Log_{10}\left[\frac{P_{out}(f)}{P_{in}(f)}\right] - 10Log_{10}\left[\frac{P_{out}(0)}{P_{in}(0)}\right] \tag{B.8}$$

where

– $P_{in}(f)$ is the input frequency response measured in 6.2.2 and

– $P_{out}(f)$ is the output frequency response measured in 6.2.1

and the subtraction of the zero frequency term normalizes the power spectrum to be zero dB at zero frequency.

B.2.3 ~~–3 dB Frequency~~ Bandwidth (−3 dB), $f_{3\ dB}$

The −3 dB (optical power) frequency, $f_{3\ dB}$, shall be determined as the lowest frequency at which $|H(f)|$ = −3 dB. Interpolation shall be employed to determine $f_{3\ dB}$.

Annex C
(normative)

Calculations for other reporting methods

C.1 Fibre impulse response, $h(t)$

The impulse response of the test fibre, $h(t)$, shall be calculated as

$$h(t) = \int_{-\infty}^{+\infty} H(f) e^{j2\pi ft} df \quad (C.1)$$

where $H(f)$ is the complex fibre transfer function (see Annex B).

At high frequencies, $H(f)$ will have poor signal to noise if aliasing requirements are reasonably met during data acquisition. To produce a sufficiently quiet impulse response, filtering (i.e. attenuating) of this high frequency noise is required. Any applied filter should not significantly distort the impulse response, and so should have a low-pass cut-off at frequencies no lower than the −15 dB point of the fibre transfer function.

~~NOTE~~ To perform this calculation for frequency domain measurements, method B, phase information should also be gathered for accurate impulse response calculations. This may be accomplished using an electrical network analyzer rather than an electrical spectrum analyzer.

C.2 RMS impulse response, exact method

The RMS pulse broadening shall be calculated from the test fibre impulse response, $h(t)$ (see C.1), as:

$$\sigma_{rms} = \sqrt{C_2^2 - C_1^2} \quad (C.2)$$

with

$$C_n = \int_0^{+\infty} t^n h(t) dt \quad (C.3)$$

where n = 0, 1, 2, …

C.3 RMS impulse response, difference of squares approximation

The RMS impulse response shall be calculated based on the root mean square difference of input and output pulses as:

$$\sigma_{\text{RMS}} = \sqrt{\sigma_B^2 - \sigma_A^2} \tag{C.4}$$

where

σ_B is the RMS fibre output pulse width,

σ_A is the RMS input pulse width.

σ_A and σ_B shall be calculated according to the formulae given in C.2, where $h(t)$ is replaced by $a(t)$ and $b(t)$ for σ_A and σ_B, respectively.

Annex D
(normative)

Mode scrambler requirements for overfilled launching conditions to multimode fibres

D.1 ~~Introduction~~ General

This procedure describes light launch conditions to the test fibre for the purpose of achieving a uniform overfilled launch with a laser diode or other light sources. Light launch conditions are established using a mode scrambler. The mode scrambler is positioned between the light source and test fibre to produce a radiation distribution overfilling the test fibre core and numerical aperture, irrespective of the spatial radiation properties of the light source.

For many mode scrambler designs, however, the launching conditions produced depend on the source~~/~~ and mode scrambler alignment and the interaction with any intermediary optics such as connectors or optical imaging systems. If the source or any component in the optical system is changed, the qualification tests shall be repeated. When applied to information transmission capacity measurements, the overfilled launch gives good measurement reproducibility; it is not intended to necessarily give the best bandwidth prediction for concatenated lengths. Also, a particular light source~~/~~ and mode scrambler combination ~~may~~ can be satisfactory for one size core diameter and numerical aperture test fibre, but not for another.

D.2 Apparatus

D.2.1 Light source

Use a light source such as a laser diode.

D.2.2 Mode scrambler

D.2.2.1 General

A "mode scrambler" is a device, which is positioned between the light source and test fibre to control launching conditions. A particular mode scrambler design is not specified. It should be emphasized that the performance of these scramblers depends upon the launch optics and fibre sizes (core and NA) used in the actual construction.

EXAMPLE The two designs given in Figure D.1 are for illustration purposes only. Other designs ~~may~~ can perform as well.

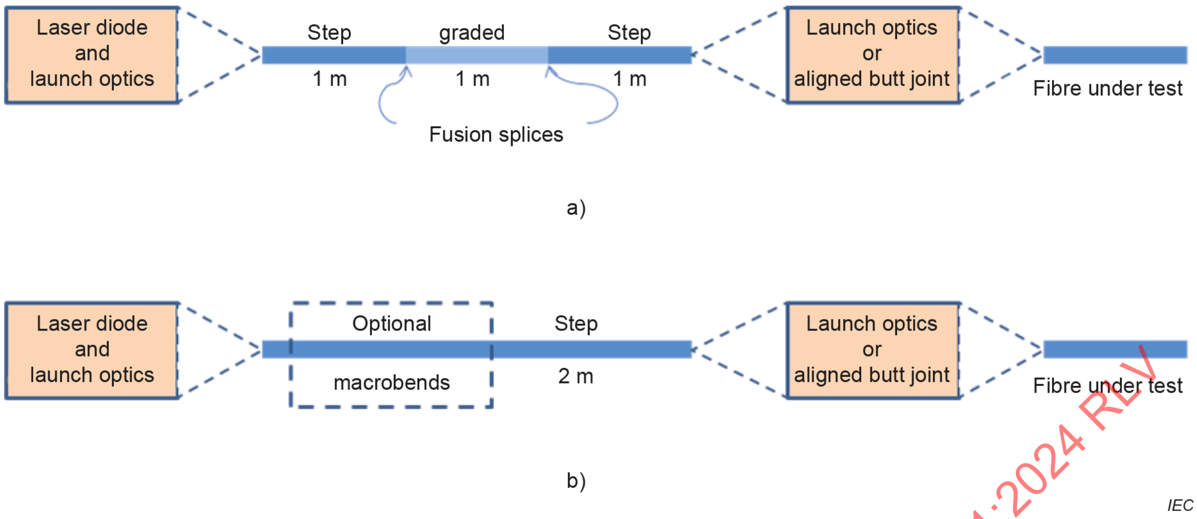


Figure D.1 – Two examples of optical fibre scramblers

D.2.2.2 Step-graded-step

The mode scrambler in Figure D.1 a) is a series combination of 1 m lengths of step-, graded-, and step-index fibres spliced together. See references [5] and [6] for information concerning fabrication of mode scramblers according to the step-graded-step design.

D.2.2.3 Step with bends

The mode scrambler in Figure D.1 b) utilizes a single length of step-index fibre. See references [7] and [8] for further information concerning the fabrication of step-index fibre mode scramblers. In some instances, macroscopic, serpentine bends or wrapping several turns of the step-index fibre around a mandrel will make the mode scrambler less sensitive to the laser diode alignment.

D.2.2.4 Test apparatus to qualify mode scrambler

To qualify the mode scrambler, it is necessary to measure near- and far-field radiation patterns of the output of the mode scrambler when coupled to the light source of D.2.1. Appropriate test apparatus is described in IEC 60793-1-20 and IEC 60793-1-43. If the qualification tests are performed on an image of the mode scrambler output, the appropriate test apparatus ~~may~~ can differ from that described in IEC 60793-1-20 and IEC 60793-1-43.

D.2.2.5 Micropositioning device~~/~~ or optics

Apparatus to couple light from the mode scrambler to the test fibre is needed. This may be a micropositioner along with optics to image the mode scrambler output to the input end of the test fibre. Spatial resolution and position repeatability shall be high enough to guarantee reproducible coupling conditions. Alternatively, a temporary splice to butt-couple the mode scrambler output to the input end of the test fibre may be employed.

D.2.3 Cladding mode strippers

If the mode scrambler is used in applications where fibre attenuation is measured, apply a cladding mode stripper to the test fibre unless the fibre buffer coating is sufficient to strip cladding light.

D.3 Sampling and specimens

The test sample includes the optical source and mode scrambler device, as well as the positioning devices, the associated optics such as connectors and optical imaging systems, and the fibre to be used in the measurement system.

D.4 Procedure

D.4.1 Qualification of mode scrambler

D.4.1.1 General

The mode scrambler, regardless of design, shall be sufficient to reliably reproduce the launching conditions of D.4.1.2 and D.4.1.3 and D.4.1.4 to the test fibre. If the launching conditions to the test fibre remain stable enough to meet the required launching conditions for all subsequent measurements, the qualification tests need not be made in situ and shall not be required for every test using the mode scrambler. Such stability ~~may~~ can be obtained, for example, by permanently pigtailing or permanently ~~connectorising~~ connecting the source to the mode scrambler. For many mode scrambler designs, however, the launching conditions produced depend on the source~~/~~ and mode scrambler alignment and interaction with any intermediary optics such as connectors or optical imaging systems. If the source or any component in the optical system is changed, the qualification tests shall be repeated.

D.4.1.2 Launch spot on test fibre

With the light source coupled to the mode scrambler fibre, the near-field radiation pattern which excites the test fibre core shall vary by less than 25 % across the test fibre core area. Speckles effects shall be avoided. If the core diameter of the test fibre is not known, it shall be determined by IEC 60793-1-20. If the mode scrambler is connected directly to the test fibre, the near-field radiation pattern which excites the test fibre core shall be measured. If the mode scrambler output is optically imaged onto the test fibre input, the launched near-field distribution shall be determined and referenced to a near-field defined by IEC 60793-1-20.

D.4.1.3 Launch radiation angle to test fibre

With the light source coupled to the mode scrambler fibre, the angular intensity distribution which excites the test fibre shall be measured. The launch numerical aperture, defined as the sine of the half-angle at which the launched angular intensity has decreased to 5 % of the maximum value, shall exceed the 5 % numerical aperture of the test fibre. If the 5 % numerical aperture of the test fibre is not known, it shall be determined by one of the procedures of IEC 60793-1-43. If the mode scrambler is connected directly to the test fibre, the angular intensity distribution from the mode scrambler fibre which excites the test fibre core shall be measured in accordance with IEC 60793-1-43. If the mode scrambler output is optically imaged onto the test fibre input, the launched angular intensity distribution shall be determined and referenced to a far field defined by IEC 60793-1-43.

D.4.1.4 Additional requirements on launch using restricted measurements

D.4.1.4.1 Overview

To achieve a truly uniform launch distribution, one of the following tests shall be performed and its requirements met. This is in addition to the measurements of D.4.1.2 and D.4.1.3. Either the near field is re-measured while the far-field exiting the mode scrambler is restricted (D.4.1.4.2) or the far field is re-measured while the near field exiting the mode scrambler is restricted (D.4.1.4.3).

D.4.1.4.2 Near-field measurements with restricted far field

The requirements of D.4.1.2 (launch spot) shall still be met when the numerical aperture launched by the mode scrambler (that is, the launch angle) is decreased by more than 50 %. An appropriate way to test for this is to use a standard single-mode fibre which has an NA of approximately 0,1; this is less than half the NA of the mode scrambler under test, which is typically 0,3. An additional near-field measurement is performed by scanning the single-mode fibre across the mode scrambler output to confirm that the near field still meets the requirement of D.4.1.2.

D.4.1.4.3 Far-field measurements with restricted near-field

The requirements of D.4.1.3 (launch radiation angle) shall still be met when the spatial extent launched by the mode scrambler (spot size) is decreased by more than 50 %. An appropriate way to test for this is to use an aperture placed in an image plane of the mode scrambler output. An additional far-field measurement is performed with the aperture restricting the image to confirm that the far field still meets the requirement of D.4.1.3.

D.4.2 Alignment of test fibre in mode scrambler output

D.4.2.1 General

If the qualification tests of D.4.1 were performed on an image of the mode scrambler output, use method A for alignment. If the tests were performed directly on the mode scrambler output, use either method B or C for alignment.

D.4.2.2 Method A – Imaging optics

If launching optics are used to image light from the mode scrambler output to the test fibre (Figure D.1), then a technique using micropositioners and lenses shall be employed to centre the test fibre core in the image of the mode scrambler output. The qualification tests for the mode scrambler shall include any influence from the imaging optics such as image or launch angle magnification. In case of conflict, this method or method B shall be preferred.

D.4.2.3 Method B – Demountable splice

If launching optics are not used, then the mode scrambler output may be connected to the test fibre by a temporary splice which aligns the mode scrambler to the core of the test fibre and brings the end faces into close contact. In this case, the core diameter of the mode scrambler fibre shall be greater than or equal to that of the test fibre.

D.4.2.4 Method C – Butt coupling

If launching optics are not used, and the test fibre is butt-coupled to the output end of the mode scrambler, then the test fibre shall be moved in the plane perpendicular to the axis to maximize coupled power.

D.4.3 Measurement test

After the mode scrambler has been qualified, and the output coupled to the test fibre by method A, method B, or method C, the fibre parameter test can begin.

D.5 Calculations or interpretation of results

The mode scrambler qualification uses the pass/fail criterion mentioned in the previous clauses. No further calculations are necessary.

D.6 Results

D.6.1 Information to be provided with each measurement

Report the following information with each measurement:

a) date of test;
b) identification of procedure used;
c) sample identification;
d) method of mode scrambler alignment: method A, method B, or method C;
e) wavelength of test.

D.6.2 Information available upon request

The following information shall be available upon request:

a) detailed description of the light source and mode scrambler combination;
b) proof of mode scrambler qualification with data showing uniformity of launch spot over test fibre core and launch numerical aperture relative to test fibre;
c) name(s) of test personnel;
d) test equipment used and date of latest calibration.

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[10] IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

Non-cited references

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IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

~~[1] To be published.~~

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

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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

- reconfirmed,
- withdrawn, or
- revised.

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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 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)

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 $f_{3\ \mathrm{dB}}$.

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:

$$\mathrm{NIDL} = \frac{\mathrm{IDF}}{\Delta\lambda} \text{ in GHz·km} \tag{1}$$

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 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 <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 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. 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.

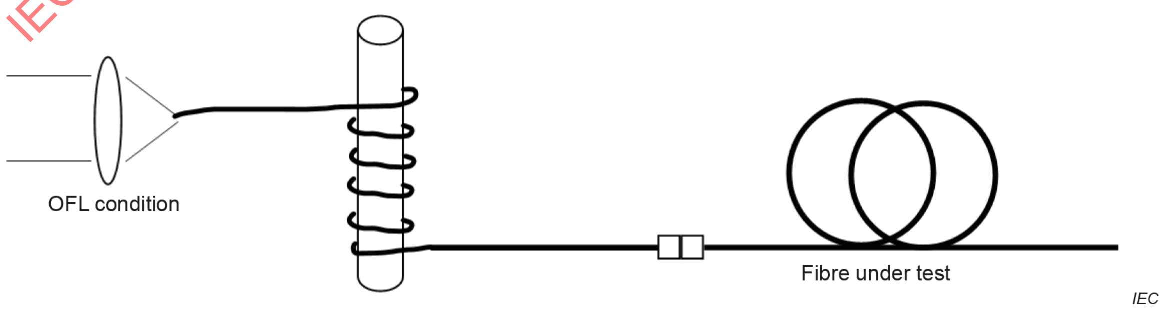

Figure 1 – Mandrel wrapped mode filter

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.

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 ≥ 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 path. This can be accomplished by using a reference length cut from the test sample (see 6.1.2), a reference length cut from a similar fibre (see 6.1.3) or by directly coupling the source output to the detector (see 6.1.4).

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.

6.1.4 Input pulse measurement method A-3: direct reference

a) The source can be coupled to the detection apparatus, directly or via a system of lenses and mirrors.

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

c) 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.

The use of the direct reference (6.1.4) requires that the input pulse Fourier transform calculated with the direct reference (6.1.4) and the input pulse Fourier transform calculated with the reference sample (6.1.2) are nearly identical. An acceptance criterion is to measure the system input pulses in both a test sample (6.1.2) and with the direct reference (6.1.4), calculate the input pulse Fourier transform per Annex B and verify that this frequency response is varying less than ±5,0 % from unity for all frequencies up to the system stability frequency limit (defined in 4.6).

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 $P_{out}(f)$, can 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 path. This can be accomplished using a reference length from the test sample (method B-1 is the preferred method to be used in case of conflict in test results), from a similar fibre (method B-2) or from the direct coupling of the source output to the detector (method B-3).

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 can 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 $P_{in}(f)$, can be recorded to finally obtain $|H(f)|$ in 7.2.

6.2.4 Method B-3: Reference from direct coupling

a) The source can be coupled to the detection apparatus, directly or via a system of lenses and mirrors.
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 detector as a function of f; denote this power as $P_{in}(f)$.

The use of the direct reference (6.2.4) requires that the relative optical powers $P_{in}(f)$ recorded using the direct coupling (6.2.4) and using the reference length of the test sample (6.2.2) are varying less than ±5,0 % from unity for all frequencies up to the system stability frequency limit (defined in 4.6) (with an offset corresponding to the difference of those functions at 0 Hz).

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

Annex A: Measure the differential mode delay of fibre in accordance with IEC 60793-1-49.

Annex B: Calculate the overfilled modal bandwidth according to Formula B.2 of IEC 60793-1-49 using weights given here in Table 2. 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 2.

NOTE Table 2 weightings are only applicable for A1-OM2 to A1-OM5 fibres at 850 nm.

Table 2 – DMD weights for calculating overfilled modal bandwidth (OMBc) from DMD data for 850 nm only

r (µm)	DMD weights for OMBc
0	0
1	0,000 73
2	0,001 57
3	0,002 53
4	0,003 62
5	0,004 87
6	0,006 31
7	0,007 95
8	0,009 83
9	0,011 98
10	0,014 43
11	0,017 25
12	0,020 46
13	0,024 14
14	0,028 36
15	0,033 17
16	0,038 69
17	0,045 00
18	0,052 21
19	0,060 47
20	0,069 92
21	0,080 73
22	0,093 10
23	0,107 25
24	0,123 45
25	0,141 97

7 Calculations or interpretation of results

7.1 Bandwidth (−3 dB), $f_{3\ \mathrm{dB}}$

Calculate the frequency response, $H(f)$. Calculate the −3 dB fibre bandwidth, $f_{3\ \mathrm{dB}}$, in accordance with Annex B.

If the measured −3 dB frequency exceeds the NIDL (as calculated in 4.1.4) divided by the fibre length, L, in km, report the measured result. In this case, it is preferable to show that the measurement result could have been limited by the equipment, as shown in Example 1.

EXAMPLE 1 A fibre 2,2 km long has a length normalized measured −3 dB frequency of 2,2 GHz·km, but the measurement system has a NIDL of 2 GHz·km at this wavelength. Preferably, the result is reported as ">normalized measured value" (">2,2 GHz·km", in this example). Similarly, the actual measured value is preferably reported as "> {measured value}" (">1,0 GHz", in this example). The ">" sign shows that the measured value could have been limited by the test set. If the measured 3 dB frequency exceeds the SSFL (as determined in 4.6), report the result as being greater than the SSFL as shown in Example 2.

EXAMPLE 2 A fibre 2,2 km long has a measured 3 dB frequency of 0,95 GHz (2,09 GHz·km), which is greater than the SSFL for the test set, 0,9 GHz (1,98 GHz·km for this fibre length). Report the result as "> (SSFL)" ("> 0,9 GHz", here). Report the length normalized result as ">(SSFL times the sample length in km" ("> 1,98 GHz·km", here). The ">" sign shows that the measured value is limited by the test set.

7.2 Calculations for optional reporting methods

Other reporting methods can be required by a detail specification in lieu of $f_{3\ \mathrm{dB}}$. Refer to the appropriate Annex:

B.1: Fibre transfer function, $H(f)$

B.2: Power spectrum, $|H(f)|$

C.1: Fibre impulse response, h(t)

C.2: RMS impulse response, exact method

C.3: RMS impulse response, difference of squares approximation

8 Length normalization

It can be desirable to normalize the bandwidth or pulse broadening to a unit length, such as GHz·km, or ns/km. If the bandwidth or pulse broadening is normalized to a unit length, the length dependence formula used shall be reported.

9 Results

9.1 Information to be provided with each measurement

Report the following information with each measurement:

a) test procedure number and method used;
b) launch conditions used (RML or OFL, DMD);
c) test date;
d) test sample identification;
e) test results: $f_{3\ \mathrm{dB}}$ (7.1) or results of other reporting methods as required by the detail specification;
f) source wavelength (nominal or actual);
g) sample length;
h) length normalization formula, if used.

9.2 Information available upon request

The following information shall be available upon request:

- source: type, actual source wavelength, maximum specified or actual spectral width (FWHM) – state if not measured;
- description of mode scrambler and launch apparatus;
- normalized intermodal dispersion limit (NIDL), for each measurement wavelength;
- detector type and operating conditions;
- details of computational procedure to calculate bandwidth or other reporting methods;
- method of stripping cladding light;
- date of latest calibration of test equipment;
- title of test;
- test personnel.

10 Specification information

The detail specification shall specify the following information:

a) number and type of samples to be tested;
b) test procedure number;
c) reporting method to be used, if other than 7.1;
d) test wavelength(s).

Annex A
(normative)

Intramodal dispersion factor and the normalized intermodal dispersion limit

A.1 Intramodal dispersion factor, IDF

This test method is intended to measure the intermodal bandwidth of a fibre. However, additional dispersion caused by interaction of the laser spectrum with the fibre chromatic dispersion can reduce the measured value. The purpose of the IDF is to provide a means of limiting this source of measurement error. IDF has units of GHz·km·nm and is the frequency at which the measured bandwidth drops to 90 % of the intermodal bandwidth, per nanometre of source linewidth, per kilometre of fibre length. See A.3 for the derivation of the IDF. The data in Table A.1 represents the highest expected dispersion for any of the commercially available category A1 fibres, based on nominal dispersion performance. For table data lower than 1 200 nm, dispersion is greatest with fibre of maximum λ_0 (0,29 NA fibre). For table data greater than 1 400 nm, dispersion is greatest with fibre of minimum λ_0 (0,20 NA fibre). Here λ_0 is the zero-dispersion wavelength. IDF is not used between 1 200 nm and 1 400 nm.

Table A.1 – Highest expected dispersion for commercially available A1 fibres

λ (nm)	IDF (GHz·km·nm)	λ (nm)	IDF (GHz·km·nm)	λ (nm)	IDF (GHz·km·nm)
780	1,31				
790	1,37				
800	1,44	1 000	3,54	1 400	23,18
810	1,50	1 010	3,71	1 410	21,15
820	1,57	1 020	3,90	1 420	19,49
830	1,64	1 030	4,09	1 430	18,09
840	1,72	1 040	4,30	1 440	16,90
850	1,79	1 050	4,52	1 450	15,87
860	1,88	1 060	4,76	1 460	14,98
870	1,96	1 070	5,02	1 470	14,20
880	2,05	1 080	5,30	1 480	13,50
890	2,14	1 090	5,60	1 490	12,89
900	2,24	1 100	5,92	1 500	12,33
910	2,34	1 110	6,27	1 510	11,83
920	2,45	1 120	6,65	1 520	11,37
930	2,56	1 130	7,07	1 530	10,96
940	2,68	1 140	7,53	1 540	10,58
950	2,80	1 150	8,03	1 550	10,23
960	2,93	1 160	8,59	1 560	9,91
970	3,07	1 170	9,22	1 570	9,61
980	3,22	1 180	9,92	1 580	9,34
990	3,37	1 190	10,71	1 590	9,08
				1 600	8,84

NOTE Assumptions Used: S_0 = 0,095 62 ps/(nm^2·km); λ_0 = 1 344,5 nm for nominal MMF w/0,29 NA.

A.2 Normalized intermodal dispersion limit, NIDL

The maximum bandwidth that can be reported by a test set is limited by the normalized intermodal dispersion limit (NIDL). The NIDL is calculated for each measurement wavelength of a test set according to 4.1.4, using IDF values taken from Table A.1. The source spectral width used in the calculation may be either a maximum value for the device as specified by the device manufacturer, or, preferably, a measured value.

Since NIDL is based on the IDF, a measured, length-normalized bandwidth equal to the NIDL is 10 % less than the actual intermodal bandwidth. The error decreases for measured bandwidths less than the NIDL, and rapidly increases above it. The actual error will typically be a few percent less than this because the actual dispersion of the test sample will be less than the value used in the IDF, and the source spectral width can be overstated. Because of these approximations and source spectral instability, correction for chromatic dispersion is not appropriate.

NIDL is not defined for wavelengths from 1 200 nm to 1 400 nm because intramodal dispersion in fibre measurements is negligible when used with lasers in this range.

NOTE The calculations in Table A.1 are derived from an assumption that the spectrum is Gaussian. If this assumption is not valid some care in the interpretation of the table is needed.

A.3 Derivation of the IDF

For the derivation of IDF, the following have been assumed to have Gaussian distributions:

a) chromatic and modal temporal pulse broadening, D_{chrom} and D_{modal}, respectively,

b) all frequency responses (amplitudes)

c) the optical source spectrum, expressed as $\Delta\lambda s$ (nm, FWHM).

The relationship between dispersion and bandwidth is expressed as:

$$D = \frac{k}{BW} \tag{A.1}$$

where k = 187 for RMS dispersion in ps and −3 dB bandwidth in GHz. Assuming that the chromatic and modal dispersion are independent, the total (measured) dispersion, D_{meas}, can be written:

$$D_{\text{meas}} = \sqrt{D^2_{\text{chrom}} + D^2_{\text{modal}}} \tag{A.2}$$

Combining Formula (A.1) and Formula (A.2) produces the following result:

$$\left[\frac{BW^2_{\text{meas}}}{BW^2_{\text{chrom}}}\right] + \left[\frac{BW^2_{\text{meas}}}{BW^2_{\text{modal}}}\right] = 1 \tag{A.3}$$

Let ε represent an error in the measurement caused by chromatic dispersion such that

$$BW_{\text{meas}} = (1-\varepsilon)BW_{\text{modal}} \tag{A.4}$$

The chromatic bandwidth (in GHz) can be calculated as:

$$BW_{\text{chrom}} = \frac{440}{D(\lambda)L\Delta\lambda_s} \tag{A.5}$$

where $D(\lambda)$ is the fibre chromatic dispersion coefficient (in ps/(nm·km)) at wavelength λ, and L is fibre length in km. $D(\lambda)$ is defined in IEC 60793-1-42.

Combining Formula (A.3), Formula (A.4) and Formula (A.5) provides the definition of IDF:

$$\text{IDF} = BW_{\text{meas}}L\Delta\lambda_s = \frac{440\sqrt{2\varepsilon-\varepsilon^2}}{D(\lambda)} \tag{A.6}$$

Specifically, for ε = 0,1 (10 % error),

$$\text{IDF} = \frac{192}{D(\lambda)} \text{ (GHz km nm)} \tag{A.7}$$

for $D(\lambda)$ in ps/(nm·km).

Annex B
(normative)

Fibre transfer function, $H(f)$, power spectrum, $|H(f)|$, and $f_{3\ \mathrm{dB}}$

B.1 Fibre transfer function

B.1.1 Method A – Time domain (pulse distortion) measurement

The time domain measurement begins with the input pulse, $a(t)$, and the output pulse, $b(t)$. The input pulse and fibre output pulse Fourier transforms shall be calculated using the following formula.

$$A(f) = \int_{-\infty}^{+\infty} a(t) e^{-j2\pi ft} dt \tag{B.1}$$

$$B(f) = \int_{-\infty}^{+\infty} b(t) e^{-j2\pi ft} dt \tag{B.2}$$

where

$a(t)$ is the temporal input pulse,

$b(t)$ is the temporal output pulse,

$A(f)$ is the input pulse Fourier transform, and

$B(f)$ is the fibre output pulse Fourier transform.

For the time domain method, the fibre transfer function shall be calculated as:

$$H(f) = \frac{B(f)}{A(f)} \tag{B.3}$$

NOTE $A(f)$, $B(f)$ and $H(f)$ are vectors of complex numbers usually expressed as real and imaginary pairs.

B.1.2 Method B – Frequency-domain measurement

When a network analyzer or equivalent phase-measuring equipment is used, the transfer function is calculated as:

$$A(f) = P_{\mathrm{in}}(f) \times [\cos(\varphi_{\mathrm{in}}(f)) + i \sin((\varphi_{\mathrm{in}}(f))] \tag{B.4}$$

$$B(f) = P_{\mathrm{out}}(f) \times [\cos(\varphi_{\mathrm{out}}(f)) + i \sin((\varphi_{\mathrm{out}}(f))] \tag{B.5}$$

$$H(f) = \frac{B(f)}{A(f)} \tag{B.6}$$

where $A(f)$, $B(f)$, and $H(f)$ are as defined in Formula (B.1).

B.2 Power spectrum

B.2.1 Method A – Time domain (pulse distortion) measurement

From the time domain (pulse distortion) measurement, the frequency response in dB, $|H(f)|$, is calculated as follows:

$$|H(f)| = 10 Log_{10}\left[\sqrt{Re(H(f))^2 + Im(H(f))^2}\right] - 10 Log_{10}\left[Re(H(0))\right] \tag{B.7}$$

where $Re(x)$ and $Im(x)$ are the real and imaginary parts of complex number x and the subtraction of the zero frequency term normalizes the power spectrum to be zero dB at zero frequency.

B.2.2 Method B – Frequency-domain measurement

For the frequency domain method, the frequency response in dB, $H(f)$, calculation can be simplified to the following:

$$|H(f)| = 10 Log_{10}\left[\frac{P_{out}(f)}{P_{in}(f)}\right] - 10 Log_{10}\left[\frac{P_{out}(0)}{P_{in}(0)}\right] \tag{B.8}$$

where

– $P_{\text{in}}(f)$ is the input frequency response measured in 6.2.2 and

– $P_{\text{out}}(f)$ is the output frequency response measured in 6.2.1

and the subtraction of the zero frequency term normalizes the power spectrum to be zero dB at zero frequency.

B.2.3 Bandwidth (−3 dB), $f_{3\ \text{dB}}$

The −3 dB (optical power) frequency, $f_{3\ \text{dB}}$, shall be determined as the lowest frequency at which $|H(f)|$ = −3 dB. Interpolation shall be employed to determine $f_{3\ \text{dB}}$.

Annex C
(normative)

Calculations for other reporting methods

C.1 Fibre impulse response, $h(t)$

The impulse response of the test fibre, $h(t)$, shall be calculated as

$$h(t) = \int_{-\infty}^{+\infty} H(f) e^{j2\pi ft} df \tag{C.1}$$

where $H(f)$ is the complex fibre transfer function (see Annex B).

At high frequencies, $H(f)$ will have poor signal to noise if aliasing requirements are reasonably met during data acquisition. To produce a sufficiently quiet impulse response, filtering (i.e. attenuating) of this high frequency noise is required. Any applied filter should not significantly distort the impulse response, and so should have a low-pass cut-off at frequencies no lower than the −15 dB point of the fibre transfer function.

To perform this calculation for frequency domain measurements, method B, phase information should also be gathered for accurate impulse response calculations. This may be accomplished using an electrical network analyzer rather than an electrical spectrum analyzer.

C.2 RMS impulse response, exact method

The RMS pulse broadening shall be calculated from the test fibre impulse response, $h(t)$ (see C.1), as:

$$\sigma_{rms} = \sqrt{C_2^2 - C_1^2} \tag{C.2}$$

with

$$C_n = \int_0^{+\infty} t^n h(t) dt \tag{C.3}$$

where n = 0, 1, 2, …

C.3 RMS impulse response, difference of squares approximation

The RMS impulse response shall be calculated based on the root mean square difference of input and output pulses as:

$$\sigma_{\mathrm{RMS}} = \sqrt{\sigma_B^2 - \sigma_A^2} \qquad \text{(C.4)}$$

where

σ_B is the RMS fibre output pulse width,

σ_A is the RMS input pulse width.

σ_A and σ_B shall be calculated according to the formulae given in C.2, where $h(t)$ is replaced by $a(t)$ and $b(t)$ for σ_A and σ_B, respectively.

Annex D
(normative)

Mode scrambler requirements for overfilled launching conditions to multimode fibres

D.1 General

This procedure describes light launch conditions to the test fibre for the purpose of achieving a uniform overfilled launch with a laser diode or other light sources. Light launch conditions are established using a mode scrambler. The mode scrambler is positioned between the light source and test fibre to produce a radiation distribution overfilling the test fibre core and numerical aperture, irrespective of the spatial radiation properties of the light source.

For many mode scrambler designs, however, the launching conditions produced depend on the source and mode scrambler alignment and the interaction with any intermediary optics such as connectors or optical imaging systems. If the source or any component in the optical system is changed, the qualification tests shall be repeated. When applied to information transmission capacity measurements, the overfilled launch gives good measurement reproducibility; it is not intended to necessarily give the best bandwidth prediction for concatenated lengths. Also, a particular light source and mode scrambler combination can be satisfactory for one size core diameter and numerical aperture test fibre, but not for another.

D.2 Apparatus

D.2.1 Light source

Use a light source such as a laser diode.

D.2.2 Mode scrambler

D.2.2.1 General

A "mode scrambler" is a device, which is positioned between the light source and test fibre to control launching conditions. A particular mode scrambler design is not specified. It should be emphasized that the performance of these scramblers depends upon the launch optics and fibre sizes (core and NA) used in the actual construction.

EXAMPLE The two designs given in Figure D.1 are for illustration purposes only. Other designs can perform as well.

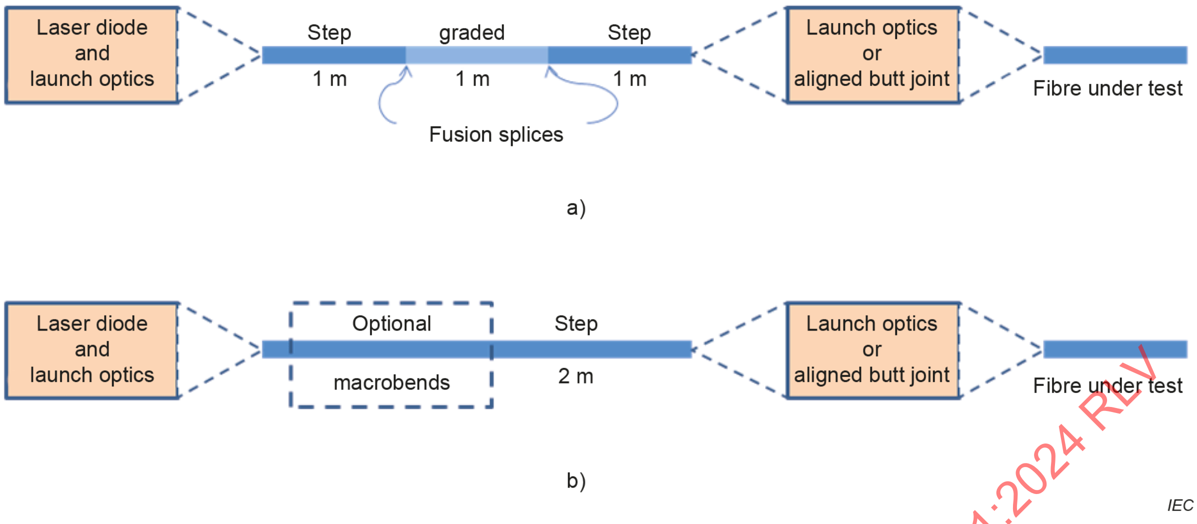

Figure D.1 – Two examples of optical fibre scramblers

D.2.2.2 Step-graded-step

The mode scrambler in Figure D.1 a) is a series combination of 1 m lengths of step-, graded-, and step-index fibres spliced together. See references [5] and [6] for information concerning fabrication of mode scramblers according to the step-graded-step design.

D.2.2.3 Step with bends

The mode scrambler in Figure D.1 b) utilizes a single length of step-index fibre. See references [7] and [8] for further information concerning the fabrication of step-index fibre mode scramblers. In some instances, macroscopic, serpentine bends or wrapping several turns of the step-index fibre around a mandrel will make the mode scrambler less sensitive to the laser diode alignment.

D.2.2.4 Test apparatus to qualify mode scrambler

To qualify the mode scrambler, it is necessary to measure near- and far-field radiation patterns of the output of the mode scrambler when coupled to the light source of D.2.1. Appropriate test apparatus is described in IEC 60793-1-20 and IEC 60793-1-43. If the qualification tests are performed on an image of the mode scrambler output, the appropriate test apparatus can differ from that described in IEC 60793-1-20 and IEC 60793-1-43.

D.2.2.5 Micropositioning device or optics

Apparatus to couple light from the mode scrambler to the test fibre is needed. This may be a micropositioner along with optics to image the mode scrambler output to the input end of the test fibre. Spatial resolution and position repeatability shall be high enough to guarantee reproducible coupling conditions. Alternatively, a temporary splice to butt-couple the mode scrambler output to the input end of the test fibre may be employed.

D.2.3 Cladding mode strippers

If the mode scrambler is used in applications where fibre attenuation is measured, apply a cladding mode stripper to the test fibre unless the fibre buffer coating is sufficient to strip cladding light.

D.3 Sampling and specimens

The test sample includes the optical source and mode scrambler device, as well as the positioning devices, the associated optics such as connectors and optical imaging systems, and the fibre to be used in the measurement system.

D.4 Procedure

D.4.1 Qualification of mode scrambler

D.4.1.1 General

The mode scrambler, regardless of design, shall be sufficient to reliably reproduce the launching conditions of D.4.1.2 and D.4.1.3 and D.4.1.4 to the test fibre. If the launching conditions to the test fibre remain stable enough to meet the required launching conditions for all subsequent measurements, the qualification tests need not be made in situ and shall not be required for every test using the mode scrambler. Such stability can be obtained, for example, by permanently pigtailing or permanently connecting the source to the mode scrambler. For many mode scrambler designs, however, the launching conditions produced depend on the source and mode scrambler alignment and interaction with any intermediary optics such as connectors or optical imaging systems. If the source or any component in the optical system is changed, the qualification tests shall be repeated.

D.4.1.2 Launch spot on test fibre

With the light source coupled to the mode scrambler fibre, the near-field radiation pattern which excites the test fibre core shall vary by less than 25 % across the test fibre core area. Speckles effects shall be avoided. If the core diameter of the test fibre is not known, it shall be determined by IEC 60793-1-20. If the mode scrambler is connected directly to the test fibre, the near-field radiation pattern which excites the test fibre core shall be measured. If the mode scrambler output is optically imaged onto the test fibre input, the launched near-field distribution shall be determined and referenced to a near-field defined by IEC 60793-1-20.

D.4.1.3 Launch radiation angle to test fibre

With the light source coupled to the mode scrambler fibre, the angular intensity distribution which excites the test fibre shall be measured. The launch numerical aperture, defined as the sine of the half-angle at which the launched angular intensity has decreased to 5 % of the maximum value, shall exceed the 5 % numerical aperture of the test fibre. If the 5 % numerical aperture of the test fibre is not known, it shall be determined by one of the procedures of IEC 60793-1-43. If the mode scrambler is connected directly to the test fibre, the angular intensity distribution from the mode scrambler fibre which excites the test fibre core shall be measured in accordance with IEC 60793-1-43. If the mode scrambler output is optically imaged onto the test fibre input, the launched angular intensity distribution shall be determined and referenced to a far field defined by IEC 60793-1-43.

D.4.1.4 Additional requirements on launch using restricted measurements

D.4.1.4.1 Overview

To achieve a truly uniform launch distribution, one of the following tests shall be performed and its requirements met. This is in addition to the measurements of D.4.1.2 and D.4.1.3. Either the near field is re-measured while the far-field exiting the mode scrambler is restricted (D.4.1.4.2) or the far field is re-measured while the near field exiting the mode scrambler is restricted (D.4.1.4.3).

D.4.1.4.2 Near-field measurements with restricted far field

The requirements of D.4.1.2 (launch spot) shall still be met when the numerical aperture launched by the mode scrambler (that is, the launch angle) is decreased by more than 50 %. An appropriate way to test for this is to use a standard single-mode fibre which has an NA of approximately 0,1; this is less than half the NA of the mode scrambler under test, which is typically 0,3. An additional near-field measurement is performed by scanning the single-mode fibre across the mode scrambler output to confirm that the near field still meets the requirement of D.4.1.2.

D.4.1.4.3 Far-field measurements with restricted near-field

The requirements of D.4.1.3 (launch radiation angle) shall still be met when the spatial extent launched by the mode scrambler (spot size) is decreased by more than 50 %. An appropriate way to test for this is to use an aperture placed in an image plane of the mode scrambler output. An additional far-field measurement is performed with the aperture restricting the image to confirm that the far field still meets the requirement of D.4.1.3.

D.4.2 Alignment of test fibre in mode scrambler output

D.4.2.1 General

If the qualification tests of D.4.1 were performed on an image of the mode scrambler output, use method A for alignment. If the tests were performed directly on the mode scrambler output, use either method B or C for alignment.

D.4.2.2 Method A – Imaging optics

If launching optics are used to image light from the mode scrambler output to the test fibre (Figure D.1), then a technique using micropositioners and lenses shall be employed to centre the test fibre core in the image of the mode scrambler output. The qualification tests for the mode scrambler shall include any influence from the imaging optics such as image or launch angle magnification. In case of conflict, this method or method B shall be preferred.

D.4.2.3 Method B – Demountable splice

If launching optics are not used, then the mode scrambler output may be connected to the test fibre by a temporary splice which aligns the mode scrambler to the core of the test fibre and brings the end faces into close contact. In this case, the core diameter of the mode scrambler fibre shall be greater than or equal to that of the test fibre.

D.4.2.4 Method C – Butt coupling

If launching optics are not used, and the test fibre is butt-coupled to the output end of the mode scrambler, then the test fibre shall be moved in the plane perpendicular to the axis to maximize coupled power.

D.4.3 Measurement test

After the mode scrambler has been qualified, and the output coupled to the test fibre by method A, method B, or method C, the fibre parameter test can begin.

D.5 Calculations or interpretation of results

The mode scrambler qualification uses the pass/fail criterion mentioned in the previous clauses. No further calculations are necessary.

D.6 Results

D.6.1 Information to be provided with each measurement

Report the following information with each measurement:

a) date of test;
b) identification of procedure used;
c) sample identification;
d) method of mode scrambler alignment: method A, method B, or method C;
e) wavelength of test.

D.6.2 Information available upon request

The following information shall be available upon request:

a) detailed description of the light source and mode scrambler combination;
b) proof of mode scrambler qualification with data showing uniformity of launch spot over test fibre core and launch numerical aperture relative to test fibre;
c) name(s) of test personnel;
d) test equipment used and date of latest calibration.

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[2] IEC 60793-2-30, *Optical fibres – Part 2-30: Product specifications – Sectional specification for category A3 multimode fibres*

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[9] IEC 61280-4-1, *Fibre-optic communication subsystem test procedures – Part 4-1: Installed cabling plant – Multimode attenuation measurement*

[10] IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

Non-cited references

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

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

SOMMAIRE

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FIBRES OPTIQUES –

Partie 1-41: Méthodes de mesure et procédures d’essai – Largeur de bande

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Cette quatrième édition annule et remplace la troisième édition parue en 2010. Cette édition constitue une révision technique.

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

a) l’ajout d’une "référence directe" pour la méthode A et la méthode B.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
86A/2302/CDV	86A/2365/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications/.

Une liste de toutes les parties de la série IEC 60793-1-4x, publiées sous le titre général *Fibres optiques – Méthodes de mesure et procédures d'essai*, se trouve sur le site Web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

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FIBRES OPTIQUES –

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

1 Domaine d'application

La présente partie de l'IEC 60793 décrit trois méthodes pour déterminer et mesurer la largeur de bande modale des fibres optiques multimodales (voir l'IEC 60793-2-10, l'IEC 60793-2-30 et l'IEC 60793-2-40). La réponse en fréquence de bande de base est directement mesurée dans le domaine fréquentiel en déterminant la réponse de la fibre à une source de lumière modulée de manière sinusoïdale. La réponse en bande de base peut aussi être mesurée en observant l'élargissement d'une impulsion étroite de lumière. La réponse calculée est déterminée en utilisant les données de retard différentiel de mode (DMD, *Differential Mode Delay*). Les trois méthodes sont les suivantes:

- Méthode A – Mesure dans le domaine temporel (distorsion d'impulsion)
- Méthode B – Mesure dans le domaine fréquentiel
- Méthode C – Largeur de bande modale avec injection saturée calculée à partir du retard différentiel de mode (OMBc, *Overfilled launch Modal Bandwidth calculated*)

Les méthodes A et B peuvent être réalisées en utilisant une méthode d'injection au choix entre: une condition d'injection saturée (OFL, *OverFilled Launch*) ou une condition d'injection en mode partiel (RML, *Restricted Mode Launch*). La méthode C est seulement définie pour les fibres multimodales A1-OM3 à A1-OM5 et utilise une sommation pondérée des réponses d'injection de DMD avec les pondérations correspondant à une condition d'injection saturée. La méthode d'essai et la condition d'injection appropriées sont choisies en fonction du type de fibre.

NOTE 1 Ces méthodes d'essai sont fréquemment utilisées dans les installations de production et de recherche et ne sont pas facilement réalisées sur site.

NOTE 2 La méthode OFL est utilisée depuis de nombreuses années pour la valeur de largeur de bande modale des applications à base de LED. Toutefois, aucune condition d'injection unique n'est représentative des sources laser (par exemple, les diodes laser à cavité verticale émettant par la surface [VCSEL, *Vertical-Cavity Surface-Emitting Laser*]) qui sont utilisées pour la transmission en gigabits et à des débits supérieurs. Ceci a conduit à l'élaboration de l'IEC 60793-1-49 pour la détermination de la largeur de bande modale effective des fibres à 50 µm optimisées pour les sources laser. Voir l'IEC 60793-2-10:2019 ou plus récente et l'IEC 61280-4-1:2019 ou plus récente pour plus d'informations.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils 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 60793-1-20, *Fibres optiques – Partie 1-20: Méthodes de mesure et procédures d'essai – Géométrie de la fibre*

IEC 60793-1-43, *Fibres optiques – Partie 1-43: Méthodes de mesure et procédures d'essai – Mesure de l'ouverture numérique*

IEC 60793-1-49, *Fibres optiques – Partie 1-49: Méthodes de mesure et procédures d'essai – Retard différentiel de mode*

3 Termes, définitions et abréviations

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

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

3.1.1
largeur de bande (–3 dB)
valeur numériquement égale à la fréquence de modulation la plus faible à laquelle l'amplitude de la fonction de transfert en bande de base d'une fibre optique devient égale à une fraction spécifiée, généralement la moitié (-3 dB), de sa valeur à la fréquence zéro

Note 1 à l'article: Dans le présent document, la largeur de bande est notée $f_{3\ \mathrm{dB}}$.

Note 2 à l'article: Il est reconnu qu'il peut exister différents calculs, parfois appelés minorations, pour éviter de reporter des valeurs très élevées associées à des "plateaux". Par exemple, la fréquence 1,5 dB, multipliée par $\sqrt{2}$ est un traitement utilisé dans l'IEC 60793-1-49. Si un tel calcul est utilisé, il convient que cela soit clairement consigné.

3.1.2
fonction de transfert
fonction discrète de nombres complexes, dépendant de la fréquence, qui représente la réponse dans le domaine fréquentiel de la fibre soumise à essai

Note 1 à l'article: La méthode A détermine la réponse en fréquence en traitant les données du domaine temporel avec des transformées de Fourier. La méthode B peut mesurer la fonction de transfert seulement si un instrument qui mesure la phase et l'amplitude est utilisé. La méthode C est similaire à la méthode A dans la mesure où elle utilise des transformées de Fourier d'une manière analogue. Dans le présent document, la fonction de transfert est notée $H(f)$.

3.1.3
spectre de puissance
fonction discrète de nombres réels, dépendant de la fréquence, qui représente l'amplitude de la réponse dans le domaine fréquentiel de la fibre soumise à essai

Note 1 à l'article: Les méthodes A et C déterminent le spectre de puissance à partir de la fonction de transfert. La méthode B détermine la fonction de transfert en prenant le rapport de l'amplitude mesurée à travers la fibre soumise à essai sur la référence. Dans le présent document, le spectre de puissance est noté $|H(f)|$.

3.1.4
réponse impulsionnelle
fonction discrète de nombres réels, dépendant du facteur temps, qui représente la réponse dans le domaine temporel de la fibre soumise à essai à un stimulus d'impulsion parfait

Note 1 à l'article: La réponse impulsionnelle est déduite, dans toutes les méthodes, par la transformée de Fourier inverse de la fonction de transfert.

Note 2 à l'article: Dans le présent document, la réponse impulsionnelle est notée $h(t)$.

3.2 Abréviations

Les abréviations sont données dans le Tableau 1.

Tableau 1 – Abréviations

Abréviation	Terme entier
CW	Continuous Wave (ondes continues)
DMD	Differential Mode Delay (retard différentiel de mode)
FWHM	Full Width Half Maximum (largeur d'impulsion à mi-hauteur)
NIDL	Normalized Intermodal Dispersion Limit (limite de dispersion intermodale normalisée)
OFL	OverFilled Launch (injection saturée)
OMBc	Overfilled Modal Bandwidth (largeur de bande modale saturée)
RML	Restricted Mode Launch (injection en mode restreint)
SSFL	System Stability Frequency Limit (limite de fréquence de stabilité du système)

4 Appareillage

4.1 Source de rayonnements

4.1.1 Méthode A – Mesure dans le domaine temporel (distorsion d'impulsion)

Utiliser pour la mesure une source de rayonnements telle qu'une diode laser à injection qui produit des impulsions de largeur spectrale étroite et de courte durée. La méthode de mesure de la distorsion d'impulsion exige la capacité de commuter l'énergie des sources de lumière électriquement ou optiquement. Certaines sources de lumière doivent être déclenchées électriquement pour produire une impulsion; dans ce cas, un moyen doit être mis à disposition pour produire les impulsions de déclenchement. Un générateur de fonction électrique ou équivalent peut être utilisé à cet effet. Il convient que son niveau de sortie soit utilisé à la fois pour induire des impulsions dans la source de lumière et pour déclencher le système d'enregistrement. D'autres sources lumineuses peuvent s'autodéclencher; dans ce cas, des moyens doivent être fournis pour synchroniser le système d'enregistrement avec les impulsions provenant de la source de lumière. Dans certains cas, ceci peut être réalisé électriquement; dans d'autres cas, des moyens optoélectroniques peuvent être utilisés.

4.1.2 Méthode B – Mesure dans le domaine fréquentiel

Utiliser pour la mesure, une source de rayonnements telle qu'une diode laser à injection d'onde continue (CW, *Continuous Wave*). La méthode de mesure dans le domaine fréquentiel exige la capacité de moduler l'énergie des sources de lumière électriquement ou optiquement. Connecter la sortie de modulation du générateur asservi ou de l'analyseur de réseaux au modulateur par l'intermédiaire de tout amplificateur actif exigé.

4.1.3 Méthode C – Largeur de bande modale avec injection saturée calculée à partir du retard différentiel de mode (OMBc, *Overfilled launch Modal Bandwidth calculated*)

Utiliser une source de rayonnement comme décrit dans l'IEC 60793-1-49.

4.1.4 Pour les méthodes A et B

Annexe A: Utiliser une source de rayonnements dont la longueur d'onde centrale est connue et se situe à ±10 nm de la longueur d'onde nominale spécifiée. Pour les diodes laser à injection, les émissions laser couplées dans la fibre doivent dépasser d'au moins 15 dB (optiques) les émissions spontanées.

Annexe B: Utiliser une source dont la largeur de raie soit suffisamment étroite pour assurer que la largeur de bande mesurée corresponde à au moins 90 % de la largeur de bande intermodale. Cela s'effectue en calculant la limite de dispersion intermodale normalisée (NIDL, *Normalized Intermodal Dispersion Limit*) (voir l'Annexe A). Pour les fibres A4, la largeur de raie d'une quelconque diode laser est suffisamment étroite pour pouvoir ignorer sa contribution à la mesure de la largeur de bande.

Annexe C: Pour les fibres A1 et A3, calculer la NIDL (voir l'Annexe A) pour chaque mesure de la longueur d'onde à partir de la largeur spectrale de la source optique pour la longueur d'onde concernée, comme suit:

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

où

$\Delta\lambda$ est la largeur spectrale de la source exprimée selon la largeur à mi-hauteur (FWHM, *Full Width Half Maximum*), en nm,

IDF (*Intramodal Dispersion Factor*) est le facteur de dispersion intramodale (GHz·km·nm) comme décrit à l'Annexe A, selon la longueur d'onde de la source.

NIDL n'est pas définie pour les longueurs d'onde comprises entre 1 200 nm et 1 400 nm. La largeur spectrale de la source pour ces longueurs d'onde doit être inférieure ou égale à 10 nm, FWHM.

NOTE L'acceptabilité d'une valeur de NIDL dépend des exigences d'essai spécifiques de l'utilisateur. Par exemple, une NIDL de 0,5 GHz·km serait satisfaisante pour vérifier que des fibres ont des largeurs de bande minimales supérieures à certaines valeurs inférieures à 500 MHz·km, mais ne serait pas satisfaisante pour vérifier que des fibres ont des largeurs de bande minimales supérieures à 500 MHz·km.

Dans le cas d'une NIDL trop faible, une source ayant une largeur spectrale plus petite est exigée.

Annexe D: La source de rayonnements doit être spectralement stable pendant toute la durée d'une impulsion unique et pendant le temps de réalisation de la mesure.

4.2 Système d'injection

4.2.1 Injection saturée (OFL, *Overfilled launch*)

4.2.1.1 Condition OFL pour une fibre de catégorie A1

Utiliser un embrouilleur de modes entre la source de lumière et l'échantillon d'essai pour produire une injection contrôlée quelles que soient les propriétés de rayonnements de la source de lumière. La sortie de l'embrouilleur de modes doit être couplée à l'extrémité d'entrée de l'échantillon d'essai, conformément à l'Annexe D. La position de la fibre doit rester stable pendant toute la durée de la mesure. Un système de visualisation peut être utilisé pour faciliter l'alignement de la fibre lorsqu'un dispositif d'imagerie optique est utilisé.

La prescription d'OFL à l'Annexe D, fondée sur la variance autorisée d'intensité lumineuse à l'entrée de la fibre soumise à essai, peut donner des variations importantes (> 25 %) dans les résultats mesurés à grande largeur de bande (> 1 500 MHz·km), pour les fibres A1-OM3, A1-OM4 et A1-OM5. Des différences subtiles dans les injections des équipements conformes sont à l'origine de ces différences. La méthode C est introduite comme un moyen pour obtenir une amélioration.

Fournir des moyens pour éliminer la lumière de la gaine de l'échantillon d'essai. Le revêtement de fibre est souvent suffisant pour assurer cette fonction. Sinon, il est nécessaire d'utiliser des suppresseurs de modes de gaine à proximité des deux extrémités de l'échantillon d'essai. Les fibres peuvent être retenues sur les suppresseurs de modes de gaine avec de petits poids, mais il doit être veillé à éviter toute microcourbure à ces emplacements.

NOTE Les mesures de la largeur de bande obtenues par une injection saturée (OFL) permettent l'utilisation des fibres multimodales de la catégorie A1, en particulier dans les applications de LED à 850 nm et 1 300 nm. Certaines applications laser peuvent également permettre cette injection mais sont susceptibles de donner lieu à des longueurs de liaisons réduites (à 850 nm) ou à des restrictions des sources laser (à 1 300 nm).

4.2.1.2 Condition OFL pour les fibres de catégories A3 et A4

L'OFL est obtenue avec un système géométrique d'injecteur optique dans lequel l'ouverture numérique théorique maximale de la fibre est dépassée par le cône d'injection et dans lequel le diamètre de la tache injectée est de l'ordre du diamètre du cœur de la fibre. La source de lumière doit être capable d'exciter à la fois les modes d'ordre inférieur et d'ordre supérieur, de la même façon dans la fibre.

NOTE Un embrouilleur de modes excite plus ou moins tous les modes. L'excitation de mode est très sensible à l'alignement entre source/embrouilleur de modes, et à l'interaction avec tout dispositif optique intermédiaire, tel que les connecteurs ou les systèmes d'imagerie optique. Une source de lumière à ouverture numérique et diamètre de cœur de grande dimension n'excite que des modes méridiens ou des modes $LP_{0,m}$.

4.2.2 Injection en mode partiel (RML)

4.2.2.1 Condition RML pour une fibre de catégorie A1-OM1

La RML pour la largeur de bande est créée en filtrant l'injection saturée (comme défini à l'Annexe D) avec une fibre RML. L'OFL est définie par l'Annexe D et il est nécessaire qu'elle soit suffisamment importante pour saturer la fibre RML à la fois de manière angulaire et spatiale. La fibre RML a un diamètre de cœur de 23,5 µm ± 0,1 µm et une ouverture numérique de 0,208 ± 0,01. La fibre doit avoir un profil à gradient d'indice avec un alpha d'environ 2 et une largeur de bande OFL supérieure à 700 MHz·km à 850 nm et 1 300 nm. Par commodité, il convient que le diamètre de la gaine soit de 125 µm. Il convient que la fibre RML ait une longueur minimale de 1,5 m pour éliminer les modes de fuite; il convient qu'elle ait une longueur inférieure à 5 m pour éviter les effets de perte transitoire. L'injection sortant de la fibre RML est ensuite couplée à la fibre soumise à essai.

Fournir des moyens pour éliminer la lumière de la gaine de l'échantillon d'essai. Le revêtement de fibre est souvent suffisant pour assurer cette fonction. Sinon, il est nécessaire d'utiliser des suppresseurs de modes de gaine à proximité des deux extrémités de l'échantillon d'essai. Les fibres peuvent être retenues sur les suppresseurs de modes de gaine avec de petits poids, mais il doit être veillé à éviter toute microcourbure à ces emplacements.

Pour obtenir la précision la plus élevée, des tolérances strictes sont exigées concernant la géométrie et le profil de la fibre RML. Pour obtenir la reproductibilité de mesure la plus élevée, des tolérances strictes d'alignement sont exigées dans la connexion entre la fibre RML d'injection et la fibre soumise à essai pour assurer que la fibre RML est centrée sur la fibre soumise à essai.

NOTE Les mesures de largeur de bande obtenues par une injection en mode restreint (RML) sont utilisées pour supporter les applications d'injection laser Ethernet à 1 gigabit. L'injection présente est particulièrement avérée pour les sources à 850 nm transportées par des fibres de type A1-OM1.

4.2.2.2 Condition RML pour une fibre de catégorie A3

La condition RML pour les fibres de catégorie A3 est créée avec un système géométrique d'injecteur optique qui correspond à une ouverture numérique d'injection de 0,3.

La taille de la tache doit être supérieure ou égale à la taille du cœur.

4.2.2.3 Condition RML pour une fibre de catégorie A4

La RML pour les fibres de catégorie A4 doit correspondre à une ouverture numérique de 0,3. Elle peut être créée en filtrant l'injection saturée avec un filtre de modes enroulé sur mandrin, comme représenté à la Figure 1. Le filtre de modes doit être réalisé avec une fibre de la même catégorie que celle soumise à essai. Pour éviter une perte redondante, il convient que la longueur de la fibre soit de 1 m. Il convient que le diamètre du mandrin soit 20 fois plus grand que celui de la gaine de fibre et le nombre de tours peut être de 5. Il convient que les parties non enroulées de la fibre soient placées droites.

Ne pas appliquer de contrainte excessive en enroulant la fibre sur le mandrin. La fibre enroulée peut être fixée au mandrin avec un adhésif.

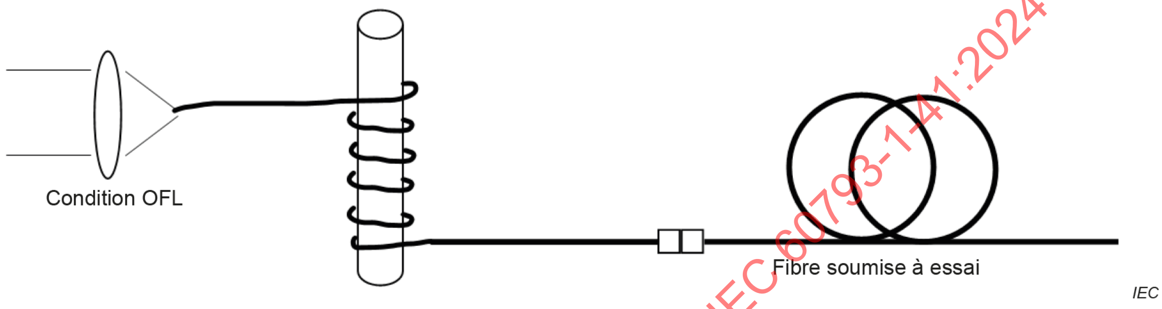

Figure 1 – Filtre de modes enroulé sur mandrin

4.2.3 Injection de retard différentiel de mode (DMD)

L'injection de DMD doit être conforme aux exigences d'injection de l'IEC 60793-1-49.

4.3 Système de détection

L'appareillage de détection optique en sortie doit être capable de coupler tous les modes guidés de l'échantillon d'essai à la zone active du détecteur de telle manière que la sensibilité de détection ne dépende pas du mode de façon significative.

Un dispositif doit être disponible pour positionner l'extrémité de sortie du spécimen avec une stabilité et une reproductibilité suffisantes pour satisfaire aux conditions de 4.6 ci-dessous.

Il doit être fait usage d'un détecteur optique adapté à une utilisation à la longueur d'onde d'essai, à réponse en amplitude linéaire, ayant une uniformité spatiale dans les limites de 10 % et de taille suffisante pour détecter toute la puissance émise. Un atténuateur optique peut être utilisé pour réguler l'intensité optique sur le détecteur. Il doit aussi être indépendant du mode.

L'électronique de détection ainsi que tout préamplificateur de signal doit être linéaire dans sa réponse en amplitude (non-linéarités inférieures à 5 %) sur la plage des signaux rencontrés.

Le système de détection pour la méthode C doit satisfaire aux exigences de l'IEC 60793-1-49.

4.4 Système d'enregistrement

Pour la mesure (de la distorsion d'impulsion) dans le domaine temporel (méthode A), utiliser un oscilloscope convenablement connecté à un dispositif d'enregistrement, tel qu'un calculateur numérique pour stocker l'amplitude d'impulsion reçue en fonction du temps. Pour les mesures temporelles, les données provenant de l'affichage de l'oscilloscope doivent être considérées comme secondaires par rapport à celles provenant du signal enregistré.

Pour la mesure dans le domaine fréquentiel (méthode B), utiliser une combinaison d'un générateur asservi et d'un analyseur de spectre, d'un analyseur de réseau scalaire, d'un analyseur de réseau vectoriel ou d'un dispositif équivalent pour détecter, afficher et enregistrer l'amplitude du signal de modulation RF provenant du détecteur optique. Ceci doit être réalisé de manière à réduire la distorsion harmonique à moins de 5 %.

Le système d'enregistrement pour la méthode C doit satisfaire aux exigences de l'IEC 60793-1-49.

4.5 Équipement de calcul

Pour la méthode (de distorsion d'impulsion) dans le domaine temporel (méthode A) et la largeur de bande modale avec injection saturée calculée à partir du retard différentiel de mode (méthode C), ou si une réponse impulsionnelle est exigée à partir de la méthode B, il doit être fait usage d'équipements de calcul capables de réaliser des transformées de Fourier sur les formes d'ondes d'impulsions optiques détectées, telles qu'elles ont été enregistrées par le système d'enregistrement des formes d'ondes. Cet équipement peut mettre en œuvre l'une des transformées rapides de Fourier ou d'autres algorithmes adaptés et il est utile pour d'autres fonctions de conditionnement de signal ainsi que de moyennage et de stockage de formes d'onde.

4.6 Performance du système global

NOTE Ce paragraphe fournit un moyen de vérifier la stabilité du système pendant la durée d'une mesure ou la période d'étalonnage du système, en fonction de la méthode utilisée (A, B ou C, voir respectivement les paragraphes 6.1, 6.2 et l'IEC 60793-1-49).

La stabilité du système de mesure est soumise à essai en comparant les transformées de Fourier des impulsions d'entrée du système (méthode B) ou les réponses fréquentielles en entrée (méthode A) sur un intervalle de temps. Comme représenté à l'Annexe B, une mesure de largeur de bande normalise la transformée d'impulsion de sortie de la fibre par la transformée d'étalonnage du système. Si un échantillon de référence prend la place de l'échantillon de fibre, la réponse qui en résulte, $H(f)$, représente une comparaison du système avec lui-même sur l'intervalle de temps. Cette stabilité d'amplitude du système normalisée est utilisée pour déterminer la limite de stabilité en fréquence du système (SSFL, *System Stability Frequency Limit*).

La SSFL est la fréquence la plus faible à laquelle la stabilité de l'amplitude du système s'écarte de 5 % de l'unité. La valeur de l'intervalle de temps utilisé pour la détermination de la SSFL dépend de la méthode utilisée pour la mesure. Si la méthode A-1 ou B-1 est utilisée, la SSFL doit être déterminée à partir d'une nouvelle mesure à un intervalle de temps similaire à celui utilisé pour une mesure de fibre réelle. Si la méthode A-2 ou B-2 est utilisée, elle doit être déterminée sur un intervalle de temps sensiblement identique à celui utilisé pour l'étalonnage périodique du système (voir 6.1.3). Dans ce dernier cas, l'intervalle de temps peut influencer la SSFL.

Pour déterminer la SSFL, affaiblir le signal optique atteignant le détecteur dans une proportion supérieure ou égale à l'affaiblissement de l'échantillon d'essai plus 3 dB. Cela peut exiger l'introduction d'un atténuateur dans le trajet optique, si un atténuateur tel que celui utilisé pour la normalisation du signal et la mise à l'échelle n'est pas déjà présent. Des écarts normaux d'emplacement et d'amplitude de la réponse en impulsion ou en fréquence sur le dispositif d'affichage doivent aussi être présents pendant la détermination de la SSFL.

5 Échantillonnage et spécimens

5.1 Échantillon d'essai

L'échantillon d'essai doit être constitué d'une longueur connue de fibre optique ou de câble à fibres optiques.

5.2 Échantillon de référence

L'échantillon de référence doit être constitué d'une courte longueur de fibre du même type que l'échantillon d'essai ou coupée à partir de cet échantillon d'essai. Sauf dans le cas de fibres de catégorie A4, la longueur de référence doit être inférieure à 1 % de la longueur de l'échantillon d'essai ou inférieure à 10 m, la valeur retenue étant la plus faible de ces deux valeurs.

Pour les fibres de catégorie A4, la longueur de référence doit être comprise entre 1 m et 2 m. Dans le cas de la RML, la sortie du filtre de mode constitue la référence.

5.3 Préparation des extrémités

Préparer des surfaces d'extrémité lisses et plates, perpendiculaires à l'axe de la fibre.

5.4 Conditionnement de l'échantillon d'essai

Pour les fibres de catégorie A1, le déploiement (type de bobine, tension d'enroulage, et autres caractéristiques d'enroulage) peut affecter les résultats par des valeurs significatives. Il est normal de conduire la plupart des mesures de contrôle de qualité avec la fibre déployée sur des bobines d'une manière adaptée au transport. Le déploiement de référence, toutefois, est un de ceux dans lesquels la fibre n'est pas soumise à des contraintes et dans lequel les microcourbures sont réduites le plus possible. Des fonctions de mappage peuvent être utilisées pour reporter la valeur attendue qui serait obtenue à partir d'une mesure de déploiement de référence fondée sur les mesures de la fibre telle qu'elle est déployée sur une bobine de transport. La fonction de mappage doit être développée à partir des mesures d'un ensemble de fibres qui ont été déployées des deux manières et qui représentent toute la gamme des valeurs de largeur de bande présentant un intérêt.

Pour les fibres de catégorie A4, l'échantillon d'essai doit être enroulé sur des bobines d'un diamètre d'au moins 300 mm, sans contrainte. On doit être certain que l'échantillon d'essai ne subit ni macrocourbures ni microcourbures et que la distribution d'énergie à la sortie du système d'injection est sensiblement constante.

5.5 Positionnement de l'échantillon d'essai

Positionner l'extrémité d'entrée de l'échantillon d'essai de manière à ce qu'elle soit alignée avec l'extrémité de sortie du système d'injection pour créer les conditions d'injection conformes au paragraphe 4.2.

Positionner l'extrémité de sortie de l'échantillon d'essai de manière qu'elle soit alignée avec le détecteur optique.

6 Procédure

6.1 Méthode A – Mesure dans le domaine temporel (distorsion d'impulsion)

6.1.1 Mesure de l'impulsion de sortie

a) Injecter la puissance dans la fibre d'essai et régler l'atténuateur optique ou l'électronique de détection, ou les deux, de manière à ce que l'impulsion optique complète provenant de la fibre soit affichée sur l'oscilloscope étalonné, y compris tous les fronts et flancs arrière ayant une amplitude supérieure ou égale à 1 % ou −20 dB de l'amplitude de crête.

b) Enregistrer l'amplitude détectée et la vitesse de balayage de l'oscilloscope étalonné.

c) Enregistrer l'impulsion de sortie de la fibre et calculer la transformée de Fourier de cette impulsion, selon l'Annexe B.

d) Déterminer l'impulsion d'entrée sur l'échantillon d'essai en mesurant le signal qui sort du trajet optique de référence. Ceci peut être réalisé en utilisant une longueur de référence prélevée sur l'échantillon d'essai (voir 6.1.2), ou une longueur de référence prélevée sur une fibre similaire (voir 6.1.3), ou en couplant directement la sortie de la source au détecteur (voir 6.1.4).

6.1.2 Méthode A-1 de mesure de l'impulsion d'entrée: échantillon de référence provenant de l'échantillon d'essai

a) Couper la fibre d'essai à proximité de l'extrémité d'entrée selon 5.2. Créer une nouvelle surface d'extrémité de sortie, selon 5.3, et aligner l'extrémité par rapport au détecteur optique comme indiqué en 6.1.1 a). Ne pas perturber l'extrémité d'entrée.

b) Appliquer le suppresseur de modes de gaine, s'il est utilisé (voir 5.2).

c) Si un atténuateur optique est utilisé, ne rechercher que la même amplitude d'impulsion affichée que celle indiquée en 6.1.1 a).

d) Enregistrer l'impulsion d'entrée du système en utilisant la même vitesse de balayage de l'oscilloscope que pour l'échantillon d'essai et calculer la transformée de Fourier de l'impulsion d'entrée selon l'Annexe B.

6.1.3 Méthode A-2 de mesure de l'impulsion d'entrée: échantillon de référence périodique

a) La procédure suivante d'étalonnage du système qui utilise l'échantillon de référence périodique doit être effectuée dans un intervalle de temps sensiblement identique à celui utilisé pour déterminer la SSFL (voir 4.6). Dans la plupart des cas où la préparation appropriée de l'embrouilleur de modes, de la diode laser et de l'équipement d'alignement a été réalisée, il est acceptable d'utiliser un échantillon de référence qui ne soit pas prélevé sur l'échantillon d'essai.

b) Préparer les extrémités d'entrée et de sortie selon 5.3 sur un échantillon de référence de la même classe de fibre et avec les mêmes dimensions optiques nominales que l'échantillon d'essai.

c) Aligner les extrémités d'entrée et de sortie comme indiqué en 5.5 et, si un atténuateur optique est utilisé, régler pour obtenir l'amplitude d'impulsion affichée correcte.

d) Enregistrer l'impulsion d'entrée du système en utilisant la même vitesse de balayage de l'oscilloscope que pour l'échantillon d'essai et calculer la transformée de Fourier de l'impulsion d'entrée selon l'Annexe B.

6.1.4 Méthode A-3 de mesure de l'impulsion d'entrée: référence directe

a) La source peut être couplée à l'appareillage de détection, directement ou par l'intermédiaire d'un système de lentilles et de miroirs.

b) Si un atténuateur optique est utilisé, réajuster pour obtenir la même amplitude d'impulsion affichée que celle indiquée en 6.1.1 a).

c) Enregistrer l'impulsion d'entrée du système en utilisant la même vitesse de balayage de l'oscilloscope que pour l'échantillon d'essai et calculer la transformée de Fourier de l'impulsion d'entrée selon l'Annexe B.

L'utilisation de la référence directe (6.1.4) exige que la transformée de Fourier de l'impulsion d'entrée, calculée à partir de la référence directe (6.1.4), et la transformée de Fourier de l'impulsion d'entrée, calculée à partir de l'échantillon de référence (6.1.2), soient quasi identiques. Un critère d'acceptation consiste à mesurer les impulsions d'entrée du système dans un échantillon d'essai (6.1.2) et avec la référence directe (6.1.4), de calculer la transformée de Fourier de l'impulsion d'entrée conformément à l'Annexe B et de vérifier que cette réponse en fréquence varie de moins de ±5,0 % par rapport à l'unité pour toutes les fréquences jusqu'à la limite de stabilité en fréquence du système (définie en 4.6).