IEC 60793-1-49

Edition 3.0 2018-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

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

IEC 60793-1-49:2018-08(en-fr)

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CONTENTS

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OPTICAL FIBRES –

Part 1-49: Measurement methods and test procedures – Differential mode delay

FOREWORD

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International Standard IEC 60793-1-49 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2006. This edition constitutes a technical revision.

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

a) better alignment with original intent by filling some omissions and therefore improving measurement rigor;

b) the measurement of fibres with smaller differential mode delay (and higher modal bandwidth) such as type A1a.3 fibres of IEC 60793-2-10 [1][1] that are used in constructing OM4 performance category cables; new requirements on specifying detector amplitude and temporal response, specimen deployment conditions, four-quadrant scanning, and uniformity of radial locations for calculating bandwidth.

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

CDV	Report on voting
86A/1812/CDV	86A/1860/RVC

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

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

This International Standard is to be used in conjunction with IEC 60793-1-1:2017.

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

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

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- withdrawn,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

1 Numbers in square brackets refer to the Bibliography.

OPTICAL FIBRES –

Part 1-49: Measurement methods and test procedures – Differential mode delay

1 Scope

This part of IEC 60793 applies only to multimode, graded-index glass-core (category A1) fibres. The test method is commonly used in production and research facilities, but is not easily accomplished in the field.

This document describes a method for characterizing the modal structure of a graded-index multimode fibre. This information is useful for assessing the bandwidth performance of a fibre especially when the fibre is intended to support a range of launch conditions, for example, those produced by standardized laser transmitters.

With this method, the output from a probe fibre that is single-moded at the test wavelength excites the multimode fibre under test. The probe spot is scanned across the end-face of the fibre under test at specified radial positions, and a set of response pulses are acquired at these positions.

Three specifiable parameters can be derived from the collected set of data.

- The first parameter, differential modal delay (*DMD*), is the difference in optical pulse delay time between the fastest and slowest mode groups of the fibre under test. *DMD* specifications place limits on modal delay over a specified range of probe fibre radial offset positions. *DMD* specifications are determined by modeling and experimentation to correspond to a minimum effective modal bandwidth (*EMB*) for the expected range of transmitters used in a link at a given performance level.
- The second specifiable parameter is derived by combining the pulses using sets of specific radial weights to determine an approximation of a set of pulses from typical transmitters. Using Fourier transforms, the calculated effective modal bandwidth (EMB_c) is determined for each weight set. The minimum of these EMB_c values ($minEMB_c$) is the specifiable parameter.
- The third specifiable parameter, the computed overfilled launch bandwidth, OMB_c, is determined in a manner similar to EMB_c, but by applying just one weight set to the set of pulses; this weight set corresponds to the overfilling condition, where all mode groups are equally excited.

The test's intent is to quantify the effects of interactions of the fibre modal structure and the source modal characteristics excluding the source's spectral interaction with fibre chromatic dispersion. Adding the effects of fibre chromatic dispersion and the source spectral characteristics will reduce the overall transmission bandwidth, but this is a separate calculation in most transmission models. In this test, the contribution of chromatic dispersion is controlled by limiting the spectral width of usable test sources. Practical test sources will have non-zero spectral width and will thus slightly distort the *DMD*, $minEMB_c$ and OMB_c values. These chromatic dispersion effects are considered in Annex A.

NOTE Comparison between IEC 60793-1-49 and ITU recommendations: ITU-T Recommendation G.650.1 [2] contains no information on how to measure the *DMD* of a graded-index multimode fibre.

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 60793-1-1:2017, *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*

IEC 60793-1-41, *Optical fibres – Part 1-41: Measurement methods and test procedures – Bandwidth*

IEC 60793-1-45, *Optical fibres – Part 1-45: Measurement methods and test procedures – Mode field diameter*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

IEC 61280-1-4, *Fibre optic communication subsystem test procedures – Part 1-4: General communication subsystems – Light source encircled flux measurement method*

3 Terms and definitions

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

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

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

3.1
maximum *DMD*
maximum *DMD* occurring between the outer (R_{OUTER}) and inner (R_{INNER}) limits of radial offset position over which the probe spot is scanned for one or more sets of R_{OUTER} and R_{INNER}

3.2
minimum EMB_c
$minEMB_c$
minimum EMB_c among the EMB_c values calculated from a sequence of *DMD* weightings

Note 1 to entry: The user of this document may also specify the calculated overfilled modal bandwidth (OMB_c).

3.3
differential mode delay
DMD
estimated difference in optical pulse delay time between the fastest and slowest modes excited for all radial offset positions between and including R_{INNER} and R_{OUTER}

Note 1 to entry: This note applies to the French language only.

3.4
effective modal bandwidth
EMB
bandwidth associated with the transfer function, $H(f)$, of a particular laser/fibre combination

Note 1 to entry: This note applies to the French language only.

3.5
calculated overfilled modal bandwidth
OMB_c
bandwidth associated with the transfer function, $H(f)$, when the fibre is overfilled

3.6
quadrant
radial section at one of four possible azimuthal angles over which a radial set of pulse data can be collected

Note 1 to entry: For example, a radial section may be taken from one of the sets x-positive, x-negative, y-positive or y-negative.

3.7
mode field diameter
MFD
diameter of the mode emanating from the end-face of a single-mode fibre, as determined by IEC 60793-1-45

Note 1 to entry: This note applies to the French language only.

3.8
reference test method
RTM

test method in which a given characteristic of a specified class of optical fibres or optical cables (and associated components) is measured strictly according to the definition of this characteristic, and which gives results that are accurate, reproducible and relatable to practical use

Note 1 to entry: This note applies to the French language only.

3.9
full width quarter maximum
FWQM
full width at 25 % of maximum amplitude of an optical pulse

Note 1 to entry: This note applies to the French language only.

4 Apparatus

4.1 Overview

The apparatus shall provide a means to inject and detect short-duration pulses of light of a small spot size launched into known locations of the core of the multimode fibre to be measured. An example is diagrammed in Figure 1.

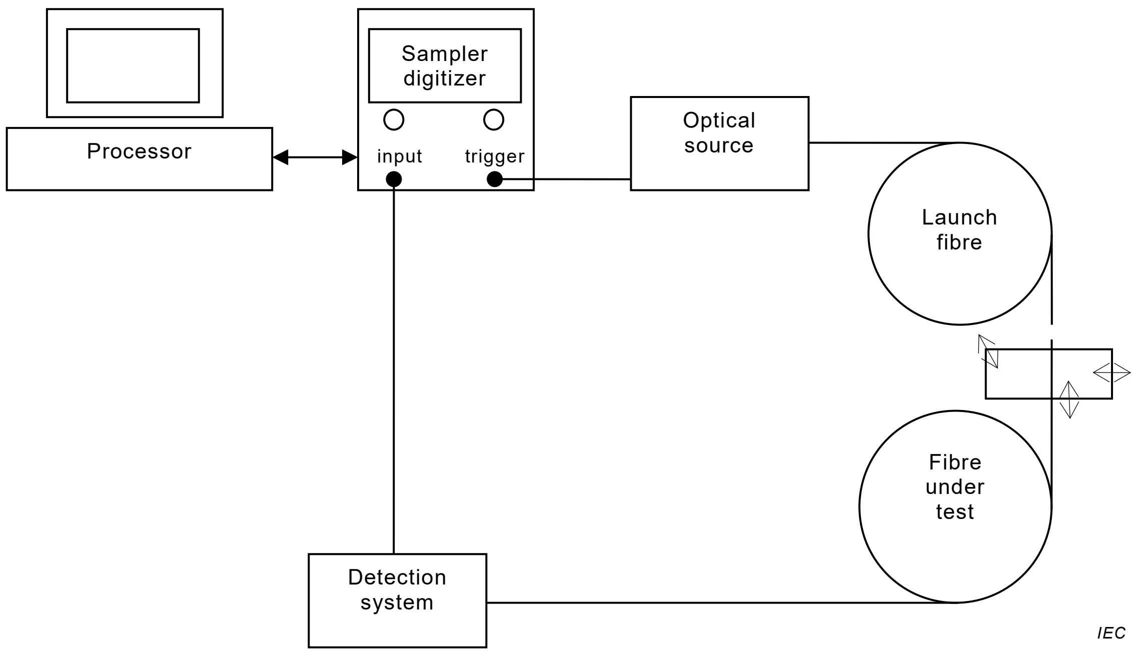

Figure 1 – Example apparatus

4.2 Optical source

Use an optical source that introduces short duration, narrow spectral width pulses into the probe fibre.

The temporal duration of the optical pulse shall be short enough to measure the intended differential delay time. The maximum duration allowed for the optical pulse, characterized as full width at 25 % of maximum amplitude ($FWQM$), will depend both on the value of DMD to be determined and the sample length. For example, if the desired length-normalized DMD limit is 0,20 ps/m over a sample of length 500 m, the DMD to be measured is 100 ps, so the maximum allowable $FWQM$ of the probe pulse is ~110 ps. Testing to the same DMD limit in a 10 000 m length of fibre requires measuring a DMD of 2 000 ps, therefore a pulse as wide as ~2 200 ps may be used. Detailed limits are given in 6.1, and may depend on the source spectral width.

Source spectral width shall meet the requirements of Annex A. Chromatic dispersion induced broadening resulting from source spectral width is limited through the methodologies described in Annex A. The requirement on spectral width may be met either by using a spectrally narrow source, or alternatively by the use of appropriate optical filtering at either the source or detection end. This requirement is challenging when measuring the highest performance fibres (whose DMD can be as low as 0,1 ps/m). In these circumstances, the pulse source's spectrum may be transform limited, in which case, no improvement can be made.

The source centre wavelength requirement is given by the product specification documents, which may require measurements at more than one wavelength. Each wavelength is considered in this document as a single measurement (if no default wavelength specification is defined for the product to be measured, the default of 850 nm ± 10 nm shall be used).

A mode-locked titanium-sapphire laser, pulsed semiconductor laser or mode-locked fibre laser are examples of sources suitable for this application.

Reference shall be made to IEC 60825-1 and to IEC 60825-2 for an explanation of the safe usage of these sources.

4.3 Probe fibre

The optical source shall be coupled to a fibre which is single-moded at the wavelength of measurement. It is required that this fibre be nominally of step-index design, and so shall have a mode field diameter (MFD) satisfying the following equation:

$$MFD = (8{,}7\lambda - 2{,}39) \pm 0{,}5\ \mu m \quad (1)$$

where

λ is the source wavelength in µm;

and the mode field diameter is determined using IEC 60793-1-45.

This equation produces a mode field diameter of 5 µm at 850 nm and 9 µm at 1 310 nm, which corresponds to commercially available single-mode fibres.

Ensure that the output of the probe fibre is single-moded by limiting the ability for higher-order modes to propagate. Winding the probe fibre around a mandrel of a given diameter is an example mode control device; a common example is three turns around a 25 mm diameter mandrel.

4.4 Scanning stage

Either the probe fibre or the test sample shall be mounted to a scanning stage capable of scanning the test sample relative to the probe fibre over the entire diameter of the test sample's core in both x- and y-direction. The scanning stage x- and y-actuators shall be capable of positioning the probe fibre to within 0,5 µm of the desired position. Often, the scanning stage is used to adjust the gap between the probe fibre and the test sample's end-face or, when an optical system is employed, to focus the probe spot image onto the sample end-face.

The probe fibre output beam's angle of propagation shall be aligned with the test sample's axis of propagation to within 1°.

The apparatus shall employ algorithms to reproducibly centre (with respect to the test sample's core) the output spot of the probe fibre to within ±1,0 µm. Refer to Annex B for a discussion of end-face centring.

4.5 Probe to test sample coupling

If directly coupled to the test sample, the gap between the output end of the probe fibre and the end-face of the test sample shall be no more than 10 µm. Alternatively, a free-space optics system of lenses or mirrors may be used to image the output spot of the probe fibre onto the end-face of the test sample. When optics are employed, it is required that at each radial scan position of the measurement, substantially the same modes are excited in the test fibre as would be if the beam were coupled directly from the output of the single-mode probe fibre.

4.6 Cladding mode stripper

A cladding mode stripper provides means to remove cladding light from the test sample. Often, the fibre coating is sufficient to perform this function. Otherwise, use cladding mode strippers near both ends of the test sample. If the fibre is retained on the cladding mode stripper(s) with small weights, care shall be taken to avoid microbending at these sites.

4.7 Detection system

Use an optical detection apparatus suitable for the test wavelength. The detection apparatus shall couple all of the guided modes from the test sample onto the detector's active area.

Amplifiers and signal conditioning electronics may be employed, but typically biased PIN photodetectors or avalanche-mode photodiodes are employed which are coupled directly to the electronics of the sampling system. The detector, in combination with any amplifiers and other electronics, shall have a combined amplitude nonlinearity no greater than 5 % over the expected range of signals. Ringing of the detector system shall be limited such that maximum overshoot or undershoot be less than 5 % of the peak amplitude of the detected optical signal as measured on the reference pulse.

These detection systems may exhibit modally dependent amplitude responses. The determination of DMD depends little on this modal response error since each pulse's relative amplitude is used to determine the location of its leading and training edges. However, the determination of EMB_c and OMB_c (defined in IEC 60793-1-41) rely on the pulse amplitudes in relation to all the pulses in the data set, so a modally dependent detector can distort these measurements. Annex C describes a method for qualifying modally dependent detectors by scanning the detector's spatial uniformity and computing a coupling function, $C(r)$. It is required that the detector's coupling function satisfy 0,9 ≤ $C(r)$ ≤ 1,1 over the range of radii to be measured.

4.8 Sampler and digitizer

The waveform of the detected optical signal shall be recorded and displayed on a suitable instrument, such as a high-speed sampling oscilloscope with calibrated time sweep. The recording system should be capable of averaging the detected waveform for multiple optical pulses.

Use a delay device, such as a digital delay generator, to provide a means of triggering the detection electronics at the correct time. The delay device may trigger the optical source or be triggered by it. The delay device may be an integral part of the recording instrument or it may be an external device.

When averaging is employed to improve the signal-to-noise ratio (SNR) of the measurement, pulse-to-trigger jitter or wander statistics may affect the measurement in various ways. For example, if significant high-frequency jitter is present, averaging several pulses will effectively widen the probe pulse, and the jitter statistics may be dependent on the amount of delay employed; the averaging scheme shall be consistent when measuring the reference pulse and the scanned pulses so that the effective reference pulse remains constant. Some delay systems have difficult jitter statistics and attention shall be paid to these effects to ensure good measurements.

4.9 Computational equipment

This test method generally requires a computer to automate the procedure, including the control of the scanning stage and waveform acquisition, storage of the intermediate data and calculation of the results.

4.10 System performance

4.10.1 General

The stability of the system in both the temporal and frequency domains is critical to ensure valid, repeatable measurements. Subclause 4.10 defines a characterization process that shall be performed when a measurement system is commissioned, serviced and checked at regular intervals to ensure the measurement system is performing as expected. Both tests begin by coupling the output of the probe fibre into the detection apparatus and adjusting the signal level and time base. Each shares the following common steps:

- Couple the pulse directly into the detection apparatus using one of these three methods:
  - the probe fibre can be coupled directly to the detection apparatus.

  - the probe fibre's output can be coupled by using a short length of fibre (< 10 m of the same type fibre as the test fibre) mounted between the launch system and the detection system.
  - the probe output can be coupled to the detector via a system of lenses and mirrors.
- Adjust the amplitude of the optical pulse to ensure good SNR without causing signal compression in the receiver.
- Adjust the sampling window of the detection system to match the smallest time window used to acquire data from the expected range of test samples. Ensure the entire pulse is captured and the Nyquist limit is not violated.

These characterizations test the system stability to ensure the system's suitability for measurement. Each characterization should be performed over a time interval, T, which should be no shorter than the time required to perform a four-quadrant measurement at 1 µm intervals at maximum averaging. Over T, several reference pulse waveforms are acquired, and, computing intermediate results, the particular stability parameter is characterized. The number of waveforms taken over the time interval, T, should be approximately the number of waveforms in a four-quadrant scan of 1 µm intervals (i.e., 102 samples for a 50 µm fibre).

4.10.2 Pulse temporal stability

This test characterizes the system's temporal limits and stability.

At each time t, record the 25 % width ($FWQM$) using linear interpolation to improve precision. Record $FWQM$ as a function of time over T. Determine the temporal stability parameter, $\Delta FWQM_{\text{stab}}$:

$$\Delta FWQM_{\text{stab}} = 100 \times \frac{FWQM_{\text{MAX}} - FWQM_{\text{MIN}}}{\overline{FWQM}} \qquad (2)$$

where

$\overline{FWQM}$ is the average $FWQM$ over the interval.

$\Delta FWQM_{\text{stab}}$ shall be less than 5 % to satisfy the temporal stability requirement. If $\Delta FWQM_{\text{stab}}$ lies outside this range, the system is disqualified.

4.10.3 System stability frequency limit ($SSFL$)

Define

$$G_{\text{ref}}(f) = \frac{\text{FT}(R\ (t))}{\text{FT}(R_0(t))} \qquad (3)$$

where

R_0 is a reference pulse taken at the beginning of the characterization;

R is any subsequent reference pulse;

FT means Fourier transform.

At each t, record R and compute G_{ref} and then, for that time t, record $F_{\text{MAX}}(t)$ as the lowest frequency where $|G(f)|$ exceeds 1,0 ± 0,05. Over the complete interval, record the minimum of the set of $F_{\text{MAX}}(t)$ as the system's $SSFL$.

Both R and R_0 should be acquired with enough averaging to reduce the noise of the ratio to be less than 1 % over the frequency range of interest.

If the calculated $minEMB_c$ or OMB_c for a fibre/laser combination exceeds the $SSFL$, report the normalized bandwidth value as greater than $SSFL$ multiplied by the length.

5 Sampling and specimens

5.1 Test sample

The test sample shall be graded-index glass-core (category A1) multimode fibre.

5.2 Specimen end-faces

Prepare flat end-faces at the input and output ends of the specimen. The quality of the input end-face is critical; they shall have end angles no greater than 1,5°.

5.3 Specimen length

The length of the fibre shall be measured using IEC 60793-1-22. The length of the sample shall be known to ±1 %. To resolve disputes, the reference test length shall be specified by the product specification.

5.4 Specimen deployment

Support the test fibre in a manner that relieves tension and minimizes microbending, such as on a measurement spool having a minimum radius of 150 mm that imparts less than 5 g of fibre tension. Deployment shall not impart macrobends of radius less than 40 mm.

The thermal stability of the specimen shall meet the required measurement precision. This requirement can be quite demanding for high performance fibres. The thermal coefficient of optical transit time for these fibres is approximately 0,035 ps/m·K. If the sample undergoes a 3 K temperature change during the time of measurement, the error will be 0,1 ps/m, which subsumes the entire specification for high-performance fibres.

5.5 Specimen positioning

Position the input end of the test sample such that it is aligned to the output end of the probe fibre as described in 4.3.

Position the output end of the test sample such that it is aligned with the detection system, as described in 6.2 (careful centring is part of the measurement procedure below).

6 Procedure

6.1 Fibre coupling and system setup

Launch the light from the probe fibre into the test fibre. Adjust the time scale and trigger delay of the detection system such that, for all relevant radial offsets of the probe spot, the pulses are completely contained inside the digitisation window ("contained" means that all leading and trailing edges having amplitude greater than or equal to 1 % of the peak amplitude are inside the window). All data from the test fibre shall be obtained without further adjustment of the delay and time scale. The reference pulse acquisition may use a different amount of delay, but shall use the same time scale.