Edition 1.0
2002-05

PRE-STANDARD

Optical fibres –

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

PUBLICLY AVAILABLE SPECIFICATION

INTERNATIONAL
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FOREWORD

A PAS is a technical specification not fulfilling the requirements for a standard, but made available to the public.

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The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:
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OPTICAL FIBRES –

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

1 Introduction

1.1 Intent

This technical specification 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 when used with laser sources.

With this method, the output from a fibre that is single-mode at the test wavelength excites the multimode fibre under test. The probe spot is scanned across the endface of the fibre under test, and the optical pulse delay is determined at specified offset positions. The difference in optical pulse delay time between the fastest and slowest modes of the fibre under test is determined. The user specifies the upper and lower limits of radial offset positions over which the probe fibre is scanned in order to specify desired limits of modal structure.

1.2 Scope

This technical specification 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.

1.3 Definitions

The user of this standard specifies the inner (R_{INNER}) and outer (R_{OUTER}) limits of radial offset positions on the endface of the fibre under test over which the probe spot is scanned. The 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} will be called Differential Mode Delay (DMD).

2 Normative References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this technical specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60825-1: *Safety of laser products – Part 1: Equipment classification, requirements and user's guide.*
IEC 60825-2: *Safety of laser products – Part 2: Safety of optical fibre communication systems.*
IEC 60793-1-1: *Optical fibres – Part 1: Generic specification – Section 1: General*
IEC 60793-1-22: *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*
IEC 60793-1-42: *Optical fibres – Part 1-42:* Measurement methods and test procedures – Chromatic dispersion
IEC 60793-1-45: *Optical fibres – Part 1-45: Measurement methods and test procedures – Mode field diameter*

3 Apparatus

3.1 Optical source

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

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, will depend both on the value of DMD to be determined and the sample length. For example, if the desired DMD limit is 0.20 ps/m over a sample of length 500 m, the DMD to be measured is 100 ps, and a pulse of duration less than ~110 ps is needed. Testing to the same DMD limit in a 10 000 m length of fiber requires measuring a DMD of 2000 ps, and a pulse a wide as ~2200 ps may be used. Detailed limits are given in section 6.1, and may depend on the source spectral width.

Chromatic dispersion induced broadening resulting from source spectral width shall be within the limits indicated in Annex B. 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.

The centre wavelength shall be within ± 10 nm of the nominal specified wavelength.

A mode locked Titanium-Sapphire laser is an example of a source usable for this application.

3.2 Stability

Devices shall be available to position the input and output ends of the test specimen with sufficient stability and reproducibility to meet the conditions of sections 3.3.3 to 3.3.6 and section 3.4.1.

3.3 Launch system

3.3.1 The probe fibre between the light source and test sample shall propagate only a single mode at the measurement wavelength. The mode field diameter of the probe fibre at λ shall be $(8.7\lambda - 2.39) \pm 0.5$ µm, where λ is the measurement wavelength in micrometers, 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 1310 nm, which corresponds to commercially available single-mode fibres.

3.3.2 Ensure that the output of the probe fibre is single-mode. One method to do this is to strip higher order modes by wrapping the probe fibre three turns around a 25-mm diameter mandrel.

3.3.3 The output spot of the probe fibre shall be scanned across the endface of the test sample with a positional accuracy less than or equal to ± 0.5 µm.

3.3.4 The output beam from the probe fibre shall be perpendicular to the endface of the test sample to within an angular tolerance of less than 1.0 degree.

3.3.5 The launch system shall be capable of reproducibly centring the output spot of the probe fibre to within ±1.0 µm.

3.3.6 If directly coupled to the test sample, the gap between the output end of the probe fibre and the endface of the test sample shall be no more than 10 µm.

3.3.7 A free space optics system of lenses or mirrors may be used to image the output spot of the probe fibre onto the endface of the test sample. When using this type of launch system, care should be taken to ensure that 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. For example, a free space optics launch system shall not vignette the beam, shall preserve the size of the probe spot on the fibre under test, and shall preserve the wavefront coherence of the beam from the probe fibre.

3.3.8 Provide 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.

3.4 Detection system

3.4.1 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, such that the detection sensitivity is not significantly mode dependent. The detector, along with any signal preamplifier, shall respond linearly (within ± 5%) over the range of power detected.

If an optical attenuator is used to control the optical intensity on the detector, the attenuator shall not be significantly mode dependent. Additionally, the temporal response of the detection apparatus shall not be significantly mode dependent.

A specific test for mode dependence is given in section 5.1.4.3. Alternatively, the detector's temporal response may be a function of offset as long as it is stable over the course of the measurement (i.e. $\Delta T_{PULSE}(r)$ shall fulfil the ± 5% requirement of sections 5.1.4.1 and 5.1.4.2).

3.4.2 Ringing of the detector system shall be limited such that maximum overshoot or undershoot shall be less than 5% of the peak amplitude of the detected optical signal as measured on the reference.

3.4.3 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.

3.4.4 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 internal or external to the recording instrument.

3.4.5 The combined effect of timing jitter and noise in the detection system shall be small enough that the difference between successive measurements of optical delay times for any fixed launch used in the measurement shall be less than 5% of the measured value of DMD. Averaging the detected waveform for multiple optical pulses may be used to reduce the effects of timing jitter and noise. If averaging is used, the same number of averages shall be used in recording all waveforms. The system shall maintain this level of stability over the course of the measurement.

3.5 Computational equipment

This test method generally requires a computer to store the intermediate data and calculate the test results.

4 Sampling and specimens

4.1 Test sample

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

4.2 Specimen endfaces

Prepare flat endfaces at the input and output ends of the specimen.

4.3 Specimen length

The length of the fibre shall be measured using a suitably accurate method such as IEC 60793-1-22.

4.4 Specimen packaging

Support the test fibre in a manner that relieves tension and minimizes microbending.

4.5 Specimen positioning

Position the input end of the test sample such that it is aligned to the output end of the launch system as described in section 3.2.

Position the output end of the test sample such that it is aligned with the detection system, as described in section 3.3.

5 Procedure

5.1 Adjust and measure system response

5.1.1 Couple the output of the probe fibre into the detection apparatus. This may be accomplished by mounting the probe fibre in the detection apparatus, or by using a short (< 10 m) length of fibre mounted between the launch system and the detection system, or by directly coupling the probe output to the detector via a system of lenses and mirrors. If using a short fibre, it can be of the same or different type fibre as the test fibre.

5.1.2 Adjust the amplitude of the optical pulse to match the smallest peak amplitude expected from the test fibre during the measurement. The smallest peak amplitude from the test fibre will usually occur for the largest radial offset.

5.1.3 Adjust the time scale of the detection system to match the time scale used in acquiring data from the test sample to ensure that the entire pulse is captured (see section 5.2.1).

5.1.4 Measure the waveform of the optical pulse, and determine it's temporal width at 25% of the peak amplitude. This value will be used to calculate the test results, and will be called ΔT_{PULSE}. Linear interpolation may be used between successive time points to calculate ΔT_{PULSE} for improved accuracy.

5.1.4.1 Repeated measurements of ΔT_{PULSE} shall differ by no more than 5% of the value of DMD being measured

5.1.4.2 If using either a short length of fibre, or a system of lenses and mirrors, the values of ΔT_{PULSE} shall differ by no more than 5% from the values obtained by coupling the probe fibre directly into the detection apparatus.

5.1.4.3 To test and verify that the detector apparatus is not significantly mode dependent, prepare a special short-length test sample of the same type as the fibre to be tested. Measure the value of ΔT_{PULSE} for each radial offset to be used in the measurement. This value shall meet the requirement of 5.1.4.1.

5.1.5 Use Annex B to calculate a value of ΔT_{REF} appropriate for the values of ΔT_{PULSE}, source spectral width, and fibre chromatic dispersion.

5.2 Adjust detection system

5.2.1 Launch light from the probe fibre into the test fibre. Adjust the time scale and trigger delay of the detection system such that one entire optical pulse is displayed for all relevant offsets of the probe spot, including all leading and trailing edges having amplitude greater than or equal to 1% of the peak amplitude. All data from the test fibre shall be obtained without further adjustment of the delay and time scale.

5.2.2 Find the centre of the core of the test fibre. One method for finding the centre is to scan the position of the probe spot across the face of the test fibre. Find both edges of the core of the fibre along some arbitrary “x” axis, with the edge defined as the position for which the total received power reaches a threshold of about 15% of maximum. Centre the probe spot along the “x” axis. Now scan the probe spot along the orthogonal “y” axis, finding the fibre core edges and centering along the “y” axis. Iterate, as necessary, to achieve the required positional tolerance. When the probe spot is centred, the DMD will be symmetric between positive and negative offsets along the “x” or “y” axes.

5.3 Measure the test sample

5.3.1 Measure the response of the test sample for radial offsets R of the probe spot from $R_{INNER} \le R \le R_{OUTER}$ at intervals of ≤ 2 µm. R_{INNER} and R_{OUTER} are to be provided in the specification (see item 3 in section 8). Depending on the values specified for R_{INNER} and R_{OUTER}, intervals less than 2 µm may be required.

Example: If the specification calls for R_{INNER} = 0 and R_{OUTER} = 17 µm, the fewest number of radial offsets will be ten. Either (0, 2, …, 16, 17) µm or (0, 1, …, 15, 17) µm would meet the minimum requirement. Alternatively, one could use 18 offsets at (0, 1, 2, …, 16, 17) µm.

5.3.2 At each radial offset, measure the waveform of the optical pulse, and determine the temporal position of the leading and trailing edges at 25% of the maximum amplitude of the resulting waveform (see Annex C). Linear interpolation may be used between successive time points to estimate the leading and trailing edge times for improved accuracy. Record the leading and trailing edge times for each radial offset position.

6 Calculations and interpretation of results

6.1 Differential Mode Delay (DMD)

6.1.1 Find T_{FAST}, the minimum of the leading edge times for excitation between R_{INNER} and R_{OUTER} from among the output pulses recorded in section 5.3.

6.1.2 Find T_{SLOW}, the maximum of the trailing edge times for excitation between R_{INNER} and R_{OUTER} from among the output pulses recorded in section 5.3.

6.1.3 Calculate DMD:

6.1.3.1 Option 1 (See Annex B):

Using the value of ΔT_{REF} from section 5.1.5, $DMD = (T_{SLOW} - T_{FAST}) - \Delta T_{REF}$

The lower reporting limit for DMD using this equation is $0.9(\Delta T_{REF})$ because of the practical measurement problems discussed in Annex C. Consequently, if the value calculated for DMD using the above equation is less than $0.9(\Delta T_{REF})$, report the result as being "less than $0.9(\Delta T_{REF})$".

6.1.3.2 Option 2

DMD can alternatively be calculated by deconvolving the reference pulse from the pulses gathered exiting the test fibre. To utilize deconvolution, the algorithm shall not introduce significant error for the pulse shapes encountered in the measurement, especially arising from the choice of a high-frequency noise filter.

6.1.4 Multiple DMD values

A fibre may be characterized by multiple DMD values with each value evaluated for a different range of R_{INNER} and R_{OUTER}. In this case, all DMD values may be evaluated from among the output pulses recorded in section 5.3, provided that the radial offset requirements of 5.3.1 are met for each of the ranges of R_{INNER} and R_{OUTER}.

6.2 Length normalization

It may be desirable to normalize the value of DMD to a unit length, such as ps/m. If the DMD is normalized to a unit length, the length dependence formula shall be reported.

7 Documentation

7.1 Report the following information for each test:

1) Test sample identification
2) Test sample length
3) Length normalization formula, if used
4) Test date
5) Source wavelength (nominal or actual)
6) Minimum and maximum radial offsets, R_{INNER}, R_{OUTER}
7) DMD result for a given R_{INNER}, R_{OUTER} range

7.2 The following information shall be available upon request:

1) The measurement method used.
2) Description of the test equipment, including: source type and actual source centre wavelength, maximum specified or actual spectral width (rms)
3) Documentation of method used to calculate ΔT_{REF}
4) Detector type and operating conditions
5) Mode field diameter of probe fibre at measurement wavelength (nominal or actual)
6) Method of stripping cladding light
7) Date of latest calibration of test equipment

8 Specification information

When specifying fibre performance using this test method, the following information shall be specified:

1) Number and type of samples to be tested.
2) Test procedure (IEC 60793-1-49)
3) Required DMD value for a stated range of minimum and maximum radial offsets, DMD(R_{INNER}, R_{OUTER}). Evaluation of several different DMD values for different stated ranges in R_{INNER} and R_{OUTER} may be required.
4) Reporting method to be used, if other than the two options in section 6.1.3.
5) Test wavelength(s).

Annex A
(informative)

Comparison between this Technical Report and ITU recommendations

ITU-T Recommendation G.650 contains no information on how to measure the DMD of a graded-index multimode fibre

Annex B
(normative)

Source spectral width limitation

B.1 Limiting the effect of chromatic dispersion on the value of DMD

The effect of errors introduced by chromatic dispersion on the value of DMD shall be less than 10%. This requirement may be met either by using a source with a spectral width small enough that chromatic dispersion can be ignored, or by accurately determining the spectral shape of the source and calculating the appropriate value of ΔT_{REF}.

The chromatic dispersion $D(\lambda)$ may be estimated using the data given in section B.2. Alternatively, one may use $D(\lambda)$ obtained using IEC 60793-42 for the particular type of fibre being tested. The requirement on spectral width may be met either by using a spectrally narrow source, or by using an optical filter at either the source or detection end.

Several examples of methods for meeting the requirement of this Annex are now given.

B.1.1 Use a source with sufficiently narrow spectral width such that the value of

$$\Delta t_{chrom} = 4 \cdot \sqrt{\ln(2)} \cdot \delta\lambda \cdot D(\lambda) \cdot L \qquad \text{(B.1.1)}$$

is less than 10% of the DMD to be measured. This gives a constraint on rms spectral width $\delta\lambda$,

$$\delta\lambda \le \frac{0.1 \cdot DMD_{\min}}{4\sqrt{\ln(2)} \cdot D(\lambda) \cdot L} = 0.030 \cdot \frac{DMD_{\min}}{D(\lambda) \cdot L} \qquad \text{(B.1.2)}$$

Here, DMD_{min} is the smallest value of DMD to be determined, $D(\lambda)$ is the chromatic dispersion, and L is the sample length. Under the typical assumption that the modal delays of a fibre scale linearly with length, this constraint has no length dependence.

Use $\Delta T_{REF} = \Delta T_{PULSE}$ in section 5.1.5 and for calculating the value of DMD.

Example: DMD values as small as 100 ps are to be tested on fibre lengths of 0.5 km at a wavelength of 850 nm. From Table 1 in section B.2, the value of $D(\lambda)$ at 850 nm is 107 ps/nm-km. Substituting this information in equation B.1.2, the source rms spectral width $\delta\lambda$ should be $\le$ (0.03 × 100 ps)/(107 ps/nm-km × 0.5 km) = 0.056 nm. The same source would work for a 10 km test length with DMD values as low as 2000 ps.

B.1.2 Use a source with sufficiently narrow spectral width that ignoring Δt_{chrom} in relation to ΔT_{PULSE} changes the value of ΔT_{REF} by less than 10%. This gives a constraint on rms spectral width $\delta\lambda$,

$$\delta\lambda \le \frac{\sqrt{0.21} \cdot \Delta T_{PULSE}}{4\sqrt{\ln(2)} \cdot D(\lambda) \cdot L} = 0.138 \cdot \frac{\Delta T_{PULSE}}{D(\lambda) \cdot L} \qquad \text{(B.1.3)}$$

Use $\Delta T_{REF} = \Delta T_{PULSE}$ in section 5.1.5, and for calculating the value of DMD.

In this case, there is no explicit dependence of source spectral width $\delta\lambda$ on the value of DMD being measured. Instead, the minimum value of DMD that can be measured is set directly by ΔT_{PULSE}. Note that there is an explicit dependence of the maximum allowed spectral width on sample length. For fixed spectral width, chromatic broadening will become too large to ignore above a certain sample length.

Example: A particular laser source and optical detector having the value ΔT_{PULSE} = 60 ps is used to measure 0.5 km samples at 850 nm. Substituting this information into equation B.1.3, the source rms spectral width $\delta\lambda$ should be $\leq$ (0.138 $\times$ 60 ps)/(107 ps/nm-km $\times$ 0.5 km) = 0.15 nm.

B.1.3 Calculate the appropriate value of ΔT_{REF} for the source being used. ΔT_{REF} is the full width at 25% of each mode at the output of the fibre under test. For near-Gaussian pulse and spectral shapes use,

$$\Delta T_{REF} = \left(\Delta T_{PULSE}^2 + \Delta t_{chrom}^2\right)^{1/2}. \qquad \text{(B.1.4)}$$

In this case, the upper limit on the spectral width of the source is set indirectly by the requirement in section 6.1.3.1 that the minimum value of DMD reported by the measurement is 0.9(ΔT_{REF}).

If a source has multiple spectral peaks, or is otherwise sufficiently non-Gaussian, this formula may be inaccurate. If Equation B.1.4 is used to calculate the value of ΔT_{REF}, the error introduced to the calculation of DMD must be less than 10%.

B.2 Chromatic dispersion in multimode fibres

The data in Table 1 represents the highest expected dispersion for any of the commercially available Category A1 fibres, based on nominal dispersion performance and Numerical Aperture (NA). At wavelengths lower than 1200 nm, dispersion is greatest with fibre having maximum λ_0 (0.29 NA fibre). At wavelengths greater than 1400 nm, dispersion is greatest with fibre having minimum λ_0 (0.20 NA fibre). Here λ_0 is the zero-dispersion wavelength. Table 1 is not used for wavelengths between 1200 and 1400 nm. Instead, use D = 16.6 ps/nm-km.

Table 1*

λ (nm)	D (ps/nm-km)	λ (nm)	D (ps/nm-km)	λ (nm)	D (ps/nm-km)
780	146				
790	140				
800	133	1000	54.2	1400	8.28
810	128	1010	51.8	1410	9.08
820	122	1020	49.2	1420	9.85
830	117	1030	46.9	1430	10.6
840	112	1040	44.7	1440	11.4
850	107	1050	42.5	1450	12.1
860	102	1060	40.3	1460	12.8
870	98.0	1070	38.2	1470	13.5
880	93.7	1080	36.2	1480	14.2
890	89.7	1090	34.3	1490	14.9
900	85.7	1100	32.4	1500	15.6
910	82.1	1110	30.6	1510	16.2
920	78.4	1120	28.9	1520	16.9
930	75.0	1130	27.2	1530	17.5
940	71.6	1140	25.5	1540	18.1
950	68.6	1150	23.9	1550	18.8
960	65.5	1160	22.4	1560	19.4
970	62.5	1170	20.8	1570	20.0
980	59.6	1180	19.4	1580	20.6
990	57.0	1190	17.9	1590	21.1
				1600	21.7

*Assumptions:

for λ<1200 nm: S_0 =0.09562 ps/(nm^2 ·km); λ_0 = 1344.5 nm for a nominal multimode fibre with 0.29 NA

for λ>1400 nm: S0 =0.101 ps/(nm2 ·km); λ_0 = 1310 nm for a nominal multimode fibre with 0.20 NA