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Measurement methods and test
procedures — Differential mode delay
of multimode optical fibers

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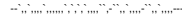
Foreword

This Japanese Industrial Standard has been revised by the Minister of Economy, Trade and Industry based on the provision of Article 14, paragraph (1) of the Industrial Standardization Act applied mutatis mutandis pursuant to the provision of Article 16 of the said Act in response to a proposal for revision of Japanese Industrial Standard with a draft being attached, submitted by Japanese Standards Association (JSA), an accredited standards development organization. This edition replaces the previous edition (**JIS C 6864** : 2008), which has been technically revised.

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Measurement methods and test procedures — Differential mode delay of multimode optical fibers

Introduction

This Japanese Industrial Standard has been prepared based on **IEC 60793-1-49** : 2018, Edition 3, with some modifications of the technical contents.

The dotted underlines indicate changes from the corresponding International Standard. A list of modifications with the explanations is given in Annex JA.

1 Scope

This Standard specifies test methods for differential mode delay of multimode, graded-index glass-core fibers. The test method is commonly used in production and research facilities, but is not easily accomplished in the field.

This Standard describes a method for characterizing the modal structure of a graded-index multimode fiber. This information is useful for assessing the bandwidth performance of a fiber especially when the fiber 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 fiber that is single-moded at the test wavelength excites the multimode fiber under test. The probe spot is scanned across the end-face of the fiber 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 fiber under test. *DMD* specifications place limits on modal delay over a specified range of probe fiber 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 fiber modal structure

and the source modal characteristics excluding the source's spectral interaction with fiber chromatic dispersion. Adding the effects of fiber 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*, *minEMBc* and *OMBc* values. These chromatic dispersion effects are considered in Annex A.

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

NOTE 2 The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows.

IEC 60793-1-49 : 2018 *Optical fibres — Part 1-49 : Measurement methods and test procedures — Differential mode delay* (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), MOD (modified), and NEQ (not equivalent) according to **ISO/IEC Guide 21-1**.

2 Normative references

Part or all of the provisions of the following standards, through reference in this text, constitute provisions of this Standard. For standards with the year indication, only the editions of the indicated year shall be applied and the revisions (including amendments) made thereafter shall not be applied. For those without the indication of the year, the most recent editions (including amendments) shall be applied.

JIS C 6820 : 2018 *General rules of optical fibers*

NOTE Normative reference in the corresponding International Standard : IEC 60793-1-1 : 2017 *Optical fibres — Part 1-1 : Measurement methods and test procedures — General and guidance*

JIS C 6822 *Test methods for structural parameters of optical fibers — Dimensional characteristics*

NOTE Normative reference in the corresponding International Standard : IEC 60793-1-22 *Optical fibres — Part 1-22 : Measurement methods and test procedures — Length measurement*

JIS C 6824 *Test methods for bandwidth of multimode optical fibers*

NOTE Normative reference in the corresponding International Standard : IEC 60793-1-41 *Optical fibres — Part 1-41 : Measurement methods and test procedures — Bandwidth*

JIS C 6825 *Test methods for structural parameters of optical fibers — Optical characteristics*

NOTE Normative reference in the corresponding International Standard : IEC

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

3 Terms and definitions

For the purpose of this Standard, the following terms and definitions, and those given in JIS C 6820 apply.

3.0A

inner limit (r_{inner})

inner limits of radial offset positions on the end-face of the fiber under test over which the probe spot is scanned

3.0B

outer limit (r_{outer})

outer limits of radial offset positions on the end-face of the fiber under test over which the probe spot is scanned

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 *EMBC*, min*EMBC*

minimum *EMBC* among the *EMBC* values (calculated effective modal bandwidth) calculated from a sequence of DMD weightings

Note 1 to entry The user of this Standard may also specify the calculated overfilled modal bandwidth (*OMBc*).

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}

3.4

effective modal bandwidth, EMB

bandwidth associated with the transfer function, $H(f)$, of a particular laser/fiber combination

3.5

calculated overfilled modal bandwidth, OMBc

bandwidth associated with the transfer function, $H(f)$, when the fiber 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

3.7

mode field diameter, *MFD*

diameter of the mode emanating from the end-face of a single-mode fiber, as determined by **JIS C 6825**

3.8

reference test method, *RTM*

test method in which a given characteristic of a specified class of optical fibers 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 reliable to practical use

3.9

full width quarter maximum, *FWQM*

full width at 25 % of maximum amplitude of an optical pulse

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 fiber to be measured. An example is diagrammed in Figure 1.

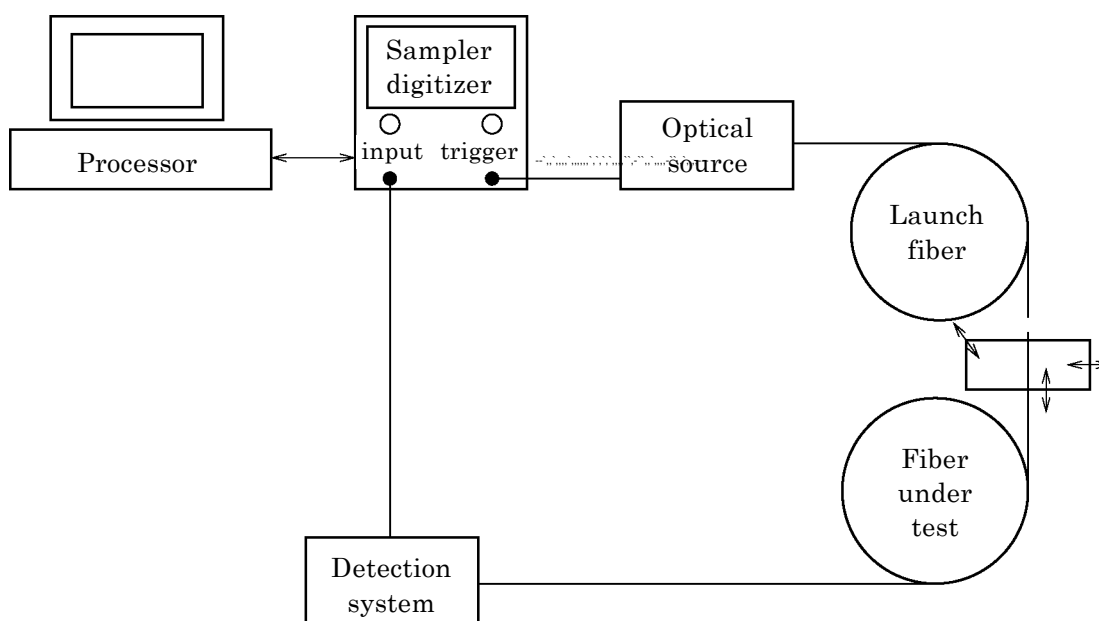


Figure 1 Example apparatus

4.2 Optical source

Use an optical source that introduces short duration, narrow spectral width pulses into the probe 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 (*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 fiber 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 fibers (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 Standard 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 fiber laser are examples of sources suitable for this application.

Reference shall be made to **JIS C 6802** and to **JIS C 6803** for an explanation of the safe usage of these sources.

4.3 Probe fiber

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

$$MFD = (8.7\lambda - 2.39) \pm 0.5 \mu\text{m} \quad \cdots \cdots \cdots (1)$$

where, λ : source wavelength (μm)

The mode field diameter is determined using **JIS C 6825**.

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 fibers.

Ensure that the output of the probe fiber is single-moded by limiting the ability for higher-order modes to propagate. Winding the probe fiber 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 fiber or the test sample shall be mounted to a scanning stage capable of scanning the test sample relative to the probe fiber 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 fiber to within 0.5 μm of the desired position. Often, the scanning stage is used to adjust the gap between the probe fiber 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 fiber 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 fiber to within $\pm 1.0 \mu\text{m}$. 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 fiber 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 fiber 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 fiber as would be if the beam were coupled directly from the output of the single-mode probe fiber.

4.6 Cladding mode stripper

A cladding mode stripper provides means to remove cladding light from the test sample. Often, the fiber coating is sufficient to perform this function. Otherwise, use cladding mode strippers near both ends of the test sample. If the fiber is retained on the cladding mode stripper(s) with small weights, care shall be taken to avoid micro-bending 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 trailing edges. However, the determination of *EMBc* and *OMBc* (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 $0.9 \leq C(r) \leq 1.1$ 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.

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 fiber 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 fiber can be coupled directly to the detection apparatus.
- the probe fiber's output can be coupled by using a short length of fiber (<10 m of the same type fiber as the test fiber) 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 fiber).

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, $\Delta FWQM_{\text{stab}}$:

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

where, $\overline{FWQM}$: 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

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

where, R_0 : reference pulse taken at the beginning of the characterization
 R : subsequent reference pulse
 FT : 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