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Edition 2.0 2007-04

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical fibres –
Part 1-42: Measurement methods and test procedures – Chromatic dispersion

Fibres optiques –
Partie 1-42: Méthodes de mesure et procédures d'essai – Dispersion chromatique

IEC 60793-1-42:2007

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OPTICAL FIBRES –

Part 1-42: Measurement methods and test procedures – Chromatic dispersion

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International Standard IEC 60793-1-42 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2001. It constitutes a technical revision. The main changes in this second edition concern the addition of a new Annex E on chromatic dispersion fitting and the applicability to A4 fibres.

This bilingual version replaces the monolingual version (2007) and its corrigendum (2007).

This standard is to be read in conjunction with IEC 60793-1.

This bilingual version, published in 2007-04, corresponds to the English version.

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

FDIS	Report on voting
86A/1136/FDIS	86A/1146/RVD

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

The French version of this standard has not been voted upon.

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

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

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

- reconfirmed;
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OPTICAL FIBRES –

Part 1-42: Measurement methods and test procedures – Chromatic dispersion

1 Scope

This part of IEC 60793 establishes uniform requirements for measuring the chromatic dispersion of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

Chromatic dispersion varies with wavelength. Some methods and implementations measure the group delay as a function of wavelength and the chromatic dispersion and dispersion slope are deduced from the derivatives (with respect to wavelength) of this data. This differentiation is most often done after the data are fitted to a mathematical model. Other implementations can allow direct measurement (of the chromatic dispersion) at each of the required wavelengths.

For some categories of fibre, the chromatic dispersion attributes are specified with the parameters of a specific model. In these cases, the relevant recommendation or standard defines the model appropriate for the definition of the specified parameters. For other fibre categories, the dispersion is specified to be within a given range for one or more specified wavelength intervals. In the latter case, either direct measurements may be made at the wavelength extremes or some fitting model may be used to allow either group delay measurement methods or implementations or storage of a reduced set of parameters that may be used to calculate the interpolated dispersion for particular wavelengths which may not have actual direct measurement values.

Annex E gives a general description of chromatic dispersion fitting and outlines a number of fitting equations suitable for use with any of the measurement methods or fibre categories.

This standard gives four methods for measuring chromatic dispersion:

– method A: phase shift;
– method B: spectral group delay in the time domain;
– method C: differential phase shift;
– method D: interferometry.

Methods A, B, and C apply to the measurement of chromatic dispersion of the following fibres over a specified wavelength range:

– class A1 graded-index multimode fibres;
– category A4f, A4g and A4h multimode fibres;
– class B single-mode fibres (all categories).

Method D applies to the measurement of chromatic dispersion values of single-mode fibres categories B1, B2, B4 and B5 over the 1 000 nm to 1 700 nm wavelength range.

The methods can be applied to laboratory, factory and field measurements of chromatic dispersion, and the wavelength range of the measurements can be tailored as required. Measurements are made at temperature as stated in IEC 60793-1-1, Table 1 – Standard range of atmospheric conditions (Temperature 23 °C ±5 °C).

The methods are suitable for fibre or cable lengths greater than 1 km. They may also be applied to shorter lengths, but accuracy and repeatability may be compromised. Method D is the preferred method for shorter piece fibres (1 m to 10 m).

Information common to all methods is contained in Clauses 1-8, and information pertaining to each individual method appears in Annexes A, B, C, and D, respectively.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60793-1-1:2002, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

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

3 Overview of methods

3.1 Method A, phase shift

This method describes a procedure for determining the chromatic dispersion of all categories of type B single-mode fibres, category A1 graded-index multimode fibres and category A4f, A4g and A4h fibres, over a specified wavelength range using the relative phase shifts among sinusoidally modulated optical sources of different wavelengths. The sources are typically laser diodes or filtered light emitting diodes or filtered amplified spontaneous emission (ASE) sources. Relative phase shifts are converted to relative time delays, and the resultant spectral group delay data are then fitted to an equation defined for each fibre type.

3.2 Method B, spectral group delay in the time domain

This method describes a procedure for determining the chromatic dispersion of all categories of type B single-mode fibres, category A1 graded-index multimode fibres and category A4f, A4g and A4h fibres with the use of a Nd:YAG/fibre Raman laser source or multiple laser diodes operating at a number of wavelengths both greater than and less than the typical zero-dispersion wavelength.

In this method, the time difference of optical pulse delay through a known length of fibre at several wavelengths is measured. A reference set of measurements shall also be taken through a short reference fibre and data are subtracted from data taken from the fibre under test to obtain relative spectral group delay. The resultant spectral group delay data are then fitted to an equation defined for each fibre type.

3.3 Method C, differential phase shift

This method describes a procedure for determining the chromatic dispersion of all categories of type B single-mode fibres, category A1 graded-index multimode fibres and category A4f, A4g and A4h fibres. The dispersion coefficient at a particular wavelength is determined from the differential group delay between two closely spaced wavelengths.

In this procedure, a modulated light source is coupled into the fibre under test, and the phase of the light exiting the fibre at a first wavelength is compared with the phase of the light exiting at a second wavelength. Average chromatic dispersion over the interval between the two wavelengths is determined from differential phase shift, wavelength interval and fibre length.

The chromatic dispersion coefficient at a wavelength medial to the two test wavelengths is assumed to be equal to the average chromatic dispersion over the interval between the two wavelengths. The resultant chromatic dispersion data are then fitted to an equation defined for each fibre type.

3.4 Method D, interferometry

This method describes a procedure for determining the chromatic dispersion of single-mode fibres categories B1, B2, B4 and B5 over the 1 000 nm to 1 700 nm wavelength range. By using this test method, the chromatic dispersion of a short piece of fibre can be measured.

In this test method, the wavelength-dependent time delay between the test sample and the reference path is measured by Mach-Zehnder interferometer. The reference path can be an air path or a single-mode fibre with known spectral group delay.

It should be noted that extrapolation of the chromatic dispersion values derived from the interferometric test in fibres of a few metres length to long fibre sections assumes longitudinal homogeneity of the fibre. This assumption may not be applicable in every case.

4 Reference test methods

4.1 Category A1 and category A4f, A4g and A4h multimode fibres

For category A1 and category A4f, A4g and A4h multimode fibres, method B, spectral group delay in the time domain, is the reference test method (RTM), which shall be the one used to settle disputes.

4.2 Class B single-mode fibres

For all categories of class B single-mode fibres, method A, phase shift, is the reference test method (RTM). Method C, differential phase shift, may also be used to resolve disputes.

5 Apparatus

The following apparatus is common to all measurement methods. Annexes A, B, C, and D include layout drawings and other equipment requirements that individually apply for each of the methods, A, B, C, and D, respectively.

5.1 Launch optics

The output from the signal sources shall be coupled to the fibre under test or the reference fibre such that the physical path length for each source is held constant during the measurement. (This requirement ensures that the relative phases of the sources do not change due to path-length changes.) Suitable devices may include multichannel single-mode optical switches or demountable optical connectors.

For measurement of category A1, A4f, A4g, A4h multimode fibre, launch conditions shall comply with method A, impulse response, of IEC 60793-1-41.

5.2 High-order mode filter (single-mode)

For measurement of single-mode fibre, use a method to remove high-order propagating modes in the wavelength range of interest. An example of such a high-order mode filter is a single loop of radius sufficiently small to shift cut-off wavelength below the minimum wavelength of interest.

5.3 Input positioning apparatus

Provide means to couple the input of the specimen to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling methods such as connectors, vacuum splices, three-rod splices, etc. The position of the fibre shall remain stable over the duration of the test.

5.4 Output positioning apparatus

Provide means of positioning the output end of the specimen such that the guided optical power is coupled to the system detector. Such coupling may include the use of lenses, or may be a mechanical connection to a detector pigtail.

5.5 Computation equipment

A digital computer may be used for purposes of equipment control, data acquisition, and numerical evaluation of the data.

6 Sampling and specimens

6.1 Specimen length

Methods A, B, and C require the specimen to be a fibre or cable of known length sufficiently long to produce adequate phase measurement accuracy. A typical minimum length is 1 km. Because category A4f, A4g and A4h fibres have higher loss than category A1 fibres, for these A4 fibres a minimum length of 100 m is acceptable.

NOTE Reproducibility is affected when using shorter measuring length. Longer lengths generally yield better reproducibility.

Method D (interferometry) requires a typical specimen length in the range of 1 m to 10 m.

6.2 Specimen end face

Prepare a flat end face, orthogonal to the fibre axis, at the input and output ends of each specimen.

6.3 Reference fibre

A single mode fibre with known dispersion characteristics shall be used to compensate for chromatic delays in the optical sources and other equipment components. The length of this fibre shall be less than or equal to 0,2 % of the specimen length.

In case of A4f, A4g and A4h fibres, the length of the reference fibre shall be less than or equal to 2 m. If this length is longer than 0,2 % of the length of the specimen under test, the chromatic dispersion of the reference fibres shall be taken into account by subtracting its chromatic dispersion value from the results measured on the specimen length.

NOTE The temperature of the specimen should be stable during the measurement within 0,1 °C to 1 °C, depending upon the temporal behaviour due to this change.

7 Procedure

See Annexes A, B, C and D for the procedures for methods A, B, C and D, respectively.

Reference fibre measurements are required for all methods. Reference fibre data can be stored for use in making measurements on the specimens. The reference fibre measurement procedure should be repeated when equipment changes on the source or receive optics or electronics occur.

8 Calculations

The calculation of relative delay appropriate for each method is given in Annexes A, B, C and D, respectively.

The remainder of this clause describes the numerical fit that can be applied for all methods to the spectral group delay data normalized by length, $\tau(\lambda)$, see also Annex E.

λ	is the wavelength	[nm]
$\tau(\lambda)$	is the normalized spectral group delay data fit	[ps/km]
$D(\lambda)$	is the chromatic dispersion coefficient, with $D(\lambda) = \mathrm{d}\tau(\lambda)/\mathrm{d}\lambda$	[ps/(nm.km)]
λ_0	is the zero-dispersion wavelength	[nm]
$\tau(\lambda_0)$	is the relative delay minimum at the zero-dispersion wavelength	[ps/km]
$S(\lambda)$	is the dispersion slope, with $S(\lambda) = \mathrm{d}D(\lambda)/\mathrm{d}\lambda$.	[ps/(nm^2·km)]
S_0	is the dispersion slope at the zero-dispersion wavelength	[ps/(nm^2·km)]

NOTE $\tau(\lambda)$ and $D(\lambda)$ may either be direct measurements or the result of fitting the direct measurements to a specified function.

Where, for example, a data fitting function is specified, the parameters of the expression on the right side of the equation are determined so as to minimize the sum of squared errors with regard to the direct measurements. Once determined, this expression is used to determine the values of other various parameters.

The fit parameters are given as the variables *A*, *B*, *C*, *D*, or *E*, see also Annex E.

8.1 Category A1 and A4f, A4g, A4h multimode and B1.1 and B1.3 single-mode fibres

The following applies to category A1 and A4f, A4g and A4h multimode fibres, and to category B1.1 and B1.3 single-mode fibres around 1 310 nm.

The delay or dispersion data fit shall be fitted with the 3-term Sellmeier fit type, see Annex E. Calculations for the chromatic dispersion coefficient $D(\lambda)$, the zero-dispersion wavelength λ_0 and the dispersion slope at the zero-dispersion wavelength S_0 are shown in Annex E.

In the 1 550 nm region only, the chromatic dispersion can be approximated as a linear function with wavelength (quadratic fit type to the delay data), see Annex E.

8.2 Category B1.2 single-mode fibres

The following applies to category B1.2 single-mode fibres.

Depending on accuracy requirements, for wavelength intervals of up to 35 nm, the quadratic fit type is allowed in the 1 550 nm region. This fitted equation should not be used to predict chromatic dispersion at wavelengths outside the range used for the fit. For longer wavelength intervals, either the 5-term Sellmeier fit type or the 4th order polynomial fit type is recommended. It is not meant to be used in the 1 310 nm region.

Calculations for the chromatic dispersion coefficient $D(\lambda)$ and the dispersion slope $S(\lambda)$ are shown in Annex E.

8.3 Category B2 single-mode fibres

The following applies to category B2 single-mode fibres.

Depending on accuracy requirements, for wavelength intervals of up to 35 nm, the quadratic fit type is allowed in the 1 550 nm region. The fitted equation should not be used to predict chromatic dispersion at wavelengths outside the range used for the fit.

For longer wavelength intervals, either the 5-term Sellmeier fit type or the 4th order polynomial fit type is recommended. It is not meant to be used in the 1 310 nm region.

The corresponding chromatic dispersion coefficient $D(\lambda)$, the zero-dispersion wavelength λ_0 and the dispersion slope at the zero-dispersion wavelength S_0 are shown in Annex E.

8.4 Category B4 and B5 single-mode fibres

The following applies to category B4 and B5 single-mode fibres.

For normal use over longer wavelength intervals (> 35 nm), either the 5-term Sellmeier fit type or the 4th order polynomial fit type is recommended. The fitted equation should not be used to predict chromatic dispersion at wavelength outside the range used for the fit.

NOTE For B4 fibres only, the quadratic fit type may be used in case of a short wavelength interval (≤ 35 nm). The fit type should not be used to predict chromatic dispersion at wavelengths outside the range used for the fit.

The corresponding chromatic dispersion coefficient $D(\lambda)$ and the dispersion slope $S(\lambda)$ are shown in Annex E.

9 Results

9.1 Report the following information with each measurement:

– date and title of measurement;
– equation(s) used to calculate the results;
– identification of specimen;
– length of specimen used for length normalization;
– measurement results as required by the detail specification.

NOTE Examples of the information that the detail specification may require:

a) Dispersion coefficient values measured at certain specified wavelengths.

b) Dispersion minimum and / or maximum over a specified range of wavelengths.

c) The zero-dispersion wavelength and dispersion slope at this wavelength.

9.2 The following information shall be available upon request:

– method used: A, B, C or D;
– description of optical source(s) and measurement wavelengths used;
– modulation frequency (if applicable);
– description of signal detector, signal detection electronics, and delay device;
– description of computational techniques used;
– date of latest calibration of measurement equipment.

10 Specification information

The detail specification shall specify the following information:

– type of fibre to be measured;
– failure or acceptance criteria;
– information to be reported;
– any deviations to the procedure that apply.

Annex A
(normative)

Requirements specific to method A, phase-shift

A.1 Apparatus

A.1.1 Light source

The light source shall be stable in position, intensity, and wavelength over a time period sufficiently long to complete the measurement procedure. Multiple laser diodes (for an example, see Figure A.1), wavelength-tunable laser diodes, light-emitting diodes (for example, see Figure A.3), or broadband sources (for example, a Nd:YAG laser with a Raman fibre or an ASE source) may be used, depending on the wavelength range of the measurement.

The wavelength launched into the fibre under test may be selected using an optical switch, a monochromator, dispersive devices, optical filters, optical couplers, or by tuning the laser, depending on the type of light sources and measurement set-up. The wavelength selector may be used either at the input or at the output of the fibre under test.

For category B1 fibres measured with a three-wavelength system in which the source wavelengths bracket the zero-dispersion wavelength, λ_0 (see Figure A.2), the tolerance or instability, $\delta\lambda$, in center wavelength will lead to maximum errors of $3\delta\lambda$ in measuring λ_0. Maximum errors in dispersion slope, S_0, are directly proportional to $\delta\lambda/\Delta\lambda$ (where $\Delta\lambda$ = source wavelength spacing) and will be approximately 0,012 ps/(nm^2·km) for $\delta\lambda/\Delta\lambda$ = 1 nm/30 nm.

Errors smaller than the above maximum errors can be achieved by selecting optical sources with an average wavelength close to the expected λ_0 of the specimen and by using more than three wavelengths, or both.

When laser sources are used, typically, a temperature-controlled, single longitudinal-mode laser diode with output power stabilization (e.g., PIN feedback) is sufficient. An additional laser may be required for the reference link for field measurement sets (see A.1.4).

A.1.2 Spectral width

The spectral width of the source, as measured in the specimen, shall be less than or equal to 10 nm at 50 % power points (FWHM).