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Calibration of fibre optic chromatic dispersion test sets

Etalonnage des ensembles d'essai de la dispersion chromatique des fibres optiques

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61744 has been prepared by IEC technical committee 86: Fibre optics.

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

FDIS	Report on voting
86/170/FDIS	86/173/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A and B form an integral part of this standard.

Annexes C and D are for information only.

The committee has decided that the contents of this publication will remain unchanged until 2002. At this date, the publication will be

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- withdrawn;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

INTRODUCTION

Chromatic dispersion in optical fibres

Chromatic dispersion is the variation with optical light wavelength of the light propagation delay time in a length of fibre. This variation can cause bandwidth limitation in the fibre when used to transmit communication signals. For a more detailed explanation, refer to annex C and IEC 60793-1-1.

Chromatic dispersion (CD) test sets

CD test sets are used to measure the chromatic dispersion properties of optical fibres and typically comprise an optical source of known wavelength(s), a fibre light input coupling and output coupling means, optical detection means, and electronic or optical means of determining the optical delay or dispersion at the source wavelength. There are several variants each requiring slightly different calibration techniques. Refer to annex C for further details.

In general, all CD test sets produce an output of fibre delay or dispersion versus the light wavelength, typically in graphical form. Thus, wavelength constitutes the 'x-axis' and delay or dispersion the 'y-axis'.

Overview of calibration procedures described in this standard

The requirement to calibrate the CD test set, traceable to known standards, is essential for quality control in fibre optic production, fibre research and similar activities. This standard describes the detailed procedures used to establish calibration of a CD test set.

Calibration of a CD test set is established by applying known artefacts or standards (themselves calibrated to reference standards) to the CD test set, measuring its response and adjusting (correcting) the CD test set to achieve results that match the standards used. In this way the CD test set results will be brought to close agreement with other CD test sets also calibrated in the manner described in this standard.

Primarily the artefacts or standards used are as follows:

a) wavelength artefact(s) used to calibrate the light source wavelength(s) used by the CD test set. This is to establish the correct excitation wavelength for the system (the 'x-axis') in order that the correct delay or dispersion (the 'y-axis') be determined subsequently;

b) delay or dispersion artefact(s) used to calibrate the delay or dispersion response of the CD test set (the 'y-axis').

Calibration can only be carried out using these artefacts. After a calibration has been completed, a calibration period is defined over which the CD test set is deemed to remain calibrated. At the end of this period, it would be necessary to establish if the CD test set calibration requires updating (changing); this can be performed using the artefact described above, or by use of a known standard fibre (reference fibre) whose chromatic dispersion is known. This is referred to as calibration checking. The fibre forms a stable source of known dispersion and may be used as a simple dispersion artefact.

If it is found that the calibration has not changed within the required uncertainty limits, then it is possible to simply extend the calibration period again by a defined amount.

If, however, it is found that the CD test set measurement results have changed significantly compared to the user requirements (i.e. the test set has drifted), then calibration using the artefacts (if not already carried out at this time) should be carried out and the calibration renewed.

The above rationale ensures that the CD test set calibration is only ever performed using known standards (artefacts), but that if the CD test set is sufficiently stable over the calibration period selected, then a simple check of calibration can suffice to ascertain this and to (justify) allow the extension of the calibration period. The extension can be repeated indefinitely over many calibration periods, provided the CD test set continues to remain within uncertainty limits over the entire set of calibration periods.

In order to be considered calibrated and in conformance with this standard, a CD test set must have its calibration adjusted based on comparison to artefacts for the primary parameters of wavelength and delay [dispersion]. In all cases, this calibration of primary parameters is necessary, but may or may not be sufficient, to ensure calibration of the CD test set to the required uncertainty.

In addition, it may be necessary to also confirm or compensate the calibration state of a CD test set using a calibrated reference fibre. The CD test set calibration compensation is explained more fully in annex D. It should be noted that use of a calibrated reference fibre alone is not sufficient to ensure calibration of a CD test set.

It should also be noted that if a calibrated CD test set undergoes calibration compensation using a calibrated reference fibre, the scope and extent of its calibration is limited to the conditions used at the time of calibration compensation (i.e. wavelength, fibre type, loss regime, etc.) Care should be exercised that test sets calibrated and compensated in this manner are used only within the appropriate limits of their calibration extent. The adjustments required to effect compensation on one set of wavelengths for one fibre type may increase the uncertainty of measurement of other fibre types with different minimum dispersion wavelengths.

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

1 Scope

This International Standard provides standard procedures for the calibration of optical fibre chromatic dispersion (CD) test sets. It also provides procedures to perform calibration checking on CD test sets whereby an extension to the test set calibration period may be obtained.

This standard is applicable to all types of CD test sets, with the exception that measurements on multimode optical fibres are excluded.

The purpose of this standard is to define a standard procedure for calibrating optical fibre chromatic dispersion (CD) test sets. The detailed calibration steps used vary according to the measurement technique used in the CD test set.

Whilst it is acknowledged that chromatic dispersion also occurs in multimode fibre and this fibre may be measured on many CD test sets, this standard will restrict discussion to single mode fibre measurements only.

The purpose of the procedures outlined in this standard is to focus manufacturers and users of CD test sets toward the reduction of measurement uncertainty in chromatic dispersion determination in optical fibres under all applicable conditions. The procedures apply to calibration laboratories and to the manufacturers or users of CD test sets for the purpose of

a) calibrating CD test sets,

b) setting specifications of CD test sets,

c) extending the calibration period of an already calibrated CD test set.

Use of the procedures also allows correct evaluation of CD test set uncertainty, relative and traceable to appropriate (for example, National) standards.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard 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 60050(731):1991, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication*

IEC 60793-1-1:1995, *Optical fibres – Part 1: Generic specification – Section 1: General* [1)]

IEC 60825-1:1993, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide* [2)]

[1)] A consolidated edition 1.1 exists (1999) that includes IEC 60793-1-1 (1995) and its amendment 1 (1998).

IEC 62129, *Calibration of optical spectrum analyzers* [3)]

ISO 9000 (all parts), *Quality management and quality assurance standards*

ISO 10012-1:1992, *Quality assurance requirements for measuring equipment – Part 1: Metrological confirmation system for measuring equipment*

ISO 10012-2:1997, *Quality assurance for measuring equipment – Part 2: Guidelines for control of measurement processes*

Guide to the Expression of Uncertainty in Measurement, 1993, ISO, ISBN 02-67-10188-9

EN 45001:1989, *General criteria for the operation of testing laboratories*

3 Terms and definitions

For the purpose of this International Standard, IEC 60050(731) and the following definitions apply.

3.1
accredited calibration laboratory
calibration laboratory authorized by the appropriate national standards laboratory to issue calibration certificates with a minimum specified uncertainty, which demonstrate traceability to national standards

3.2
adjustment
modifying the hardware or firmware of a CD test set with the intention of making the measurement result of the CD test set equal to that of a national standard or a similar calibrated CD test set. This has the effect of correcting all subsequent measurements on that CD test set

3.3
artefact
device, instrument or equipment used in the process of calibrating a CD test set, for both wavelength and delay [dispersion]. The artefact is a means of transferring calibration of these parameters to a CD test set

3.4
calibration
process by which the relationship between the values indicated by the infant CD test set and known values of the calibration standard is established under specified conditions. The intention of calibration is to bring all CD test sets into substantial agreement with a suitable national standards laboratory. This may be performed by first comparing the relevant parameter of a measurement artefact with that produced by the CD test set, followed by transfer of that result, either by adjustment of the CD test set or by documentation of a calibration factor(s) in a calibration certificate. The pertaining environmental conditions and instrument state are usually recorded. Calibration includes estimation of all uncertainties. The use of reference fibres is for calibration checking only

[2)] A consolidated edition 1.1 exists (1998) that includes IEC 60825-1 (1993) and its amendment 1 (1997).

[3)] To be published.

3.5
calibration chain
unbroken chain of transfers from a primary standard to the CD test set via reference standards, intermediate and/or working standards (see figure 1)

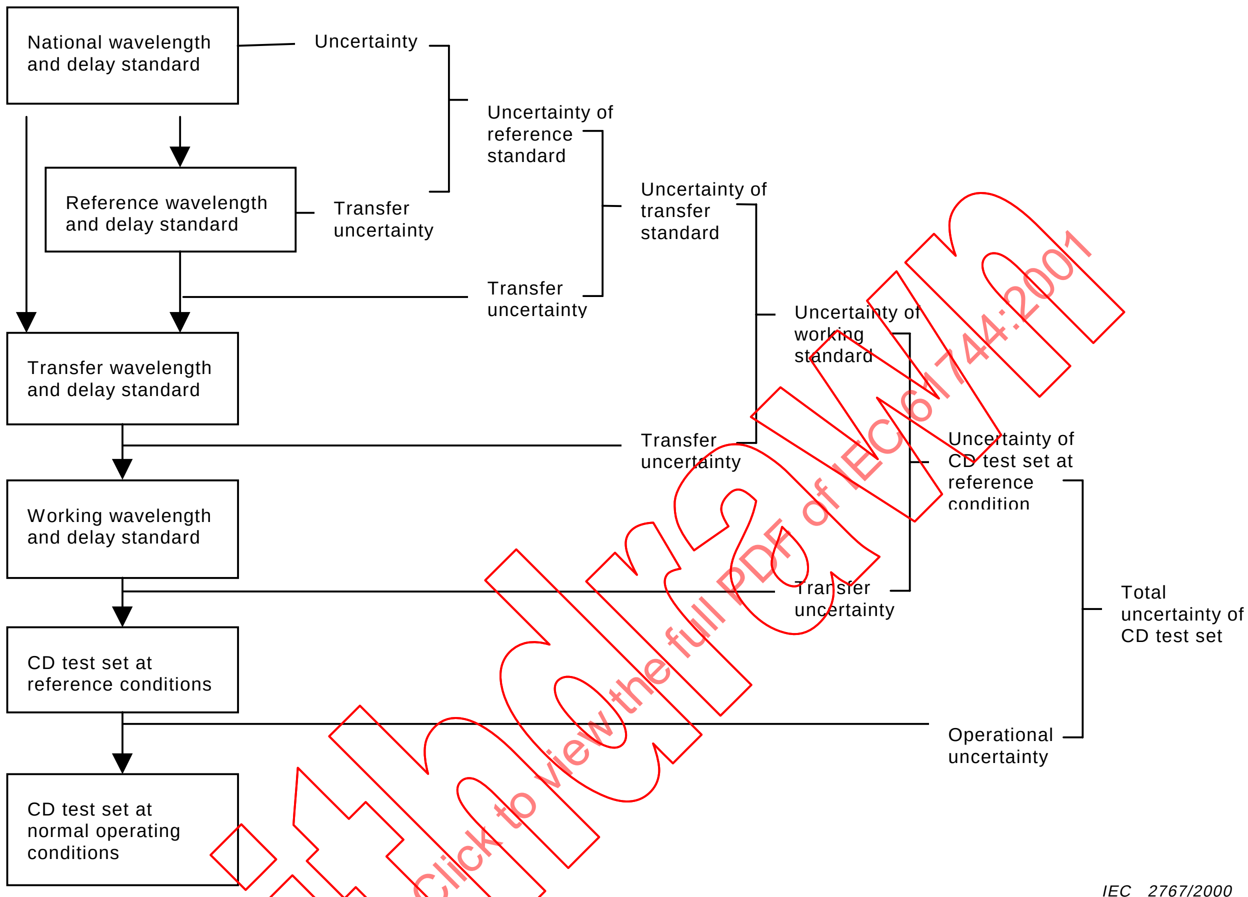


Figure 1 – Typical calibration chain for CD test sets

3.6
calibration checking
process of establishing that a CD test set which has been previously calibrated, but is nearing the end of its calibration period, remains within specified uncertainty limits. If the CD test set has drifted outside these limits, then calibration is required. Otherwise, the calibration period can be extended for a stated period, and calibration checking may be repeated indefinitely if the CD test set remains stable over successive calibration periods. Calibration checking is performed using a reference fibre or working standard. Essentially calibration checking is the first part of the process of calibration, but without the additional process of transfer or adjustment

3.7
calibration period
interval of confirmation
time period over which a calibration performed in accordance with the procedures in this standard is deemed to remain within the uncertainty limits set. (i.e. remain valid). The time allotted will be governed by individual user requirements, CD test set characteristics, past experience, environmental conditions, etc. and by monitored CD test set measurement result experience in normal use (see also ISO 10012-1 and ISO 10012-2)

3.8
calibration standard
artefact that is calibrated against a reference standard and is used to calibrate CD test sets. The artefact may be a delay [dispersion] or a wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

3.9
central wavelength
power-weighted mean wavelength of a light source in air, in units of nanometers (nm)

For a continuous source spectrum, the central wavelength λ_c in air is defined by the following integral, where the integration limits enclose the entire spectrum of the source:

$$\lambda_c = (1/\ P_{total}) \times [\int p(\lambda) \times \lambda \ d\lambda] \tag{1}$$

where

$P_{total} = \int p(\lambda)\ d\lambda$ is the total optical source power.

For a spectrum consisting of i discrete lines, the centre wavelength in air λ_c is defined as:

$$\lambda_c = (1/\ P_{total}) \times \left[\sum_i p_i \lambda_i \right] \tag{2}$$

where

$p(\lambda)$	is the spectral power density of the source in W/nm;
λ_c	is the central wavelength in air in nanometers;
λ_i	is the i^{th} discrete line in nm;
p_i	is the power levels at λ_i in W;
$P_{total} = \sum_i p_i$	is the total power in W.

3.10
chromatic dispersion (CD) test sets
instrument capable of measuring the chromatic dispersion of a single mode fibre at various wavelengths in the transmission windows of interest, typically the 1 310 nm and/or 1 550 nm wavebands

3.11
combined standard uncertainty
combination of a number of individual standard uncertainties

NOTE The term “accuracy” should be avoided in this context.

All calibration reports and technical data sheets should report the combined standard uncertainty of the CD test set as an overall expanded uncertainty, *U*, with the applicable confidence level, for example 95,5 % or 99,7 %.

3.12
confidence level
estimation of the probability that the true value of a measured parameter lies in the given range (the expanded uncertainty)

3.13
correction offset, *CO*
number that is added to or subtracted from the measurement result of a CD test set to correct for a known physical effect or systematic uncertainty

3.14
coverage factor, *k*
used to calculate the expanded uncertainty, U, from the standard uncertainty σ (see 3.15)

3.15
expanded uncertainty, U
(confidence interval)
range of values within which the measurement parameter, at the stated confidence level, can be expected to lie. It is equal to the coverage factor k times the standard uncertainty σ :

$$U = k \times \sigma \tag{3}$$

NOTE When the distribution of uncertainties is assumed to be normal and a large number of measurements are made, then confidence levels of 68,3 %, 95,5 % and 99,7 % correspond to values of k of 1, 2 and 3, respectively.

The measurement uncertainty of a CD test set should be specified in the form of expanded uncertainty U.

3.16
infant reference fibre
fibre whose dispersion is measured against a parent reference fibre. The infant reference fibre would then be intended for calibration checking of a CD test set

3.17
instrument state
complete description of the measurement conditions and state of the CD test set during the calibration process

NOTE Typical parameters of the instrument state are the wavelength range in use, the data fit model (as applicable), warm-up time and other instrument settings.

3.18
measurement result
displayed or electrical output of any CD test set, in dispersion D in units of

- ps $\times$ nm^{-1} $\times$ km^{-1}, lambda zero λ_0 in units of nm, or zero dispersion slope S_0 in units of
- ps $\times$ nm^{-2} $\times$ km^{-1}, after completing all actions suggested by the operating instructions, for example warm-up.

3.19
national standard
standard whose measurement is traceable to fundamental properties, such as the speed of light, which is recognized by an official national decision and used as the basis for fixing the value, in a country, of all other standards of the quantity concerned

3.20
national standards laboratory
body or laboratory that maintains and operates the national standard

3.21
operating range
all conditions of, for example the dispersion, temperature and other influencing quantities, over which the CD test set is designed to perform within the stated expanded uncertainty

3.22
parent reference fibre
reference fibre which is used as the reference for generating an infant reference fibre. The parent reference fibre may be used for calibration checking of a CD test set

3.23
reference standard
artefact calibrated against a national standard and used to calibrate CD test sets. The artefact may be a delay [dispersion] or wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

NOTE In this standard, reference standard can also be taken to mean the fibre (infant or parent) which is used as the reference for calibration checking of a CD test set.

3.24
scaling factor, *SF*
ratio of known standard values for a standard artefact to the values indicated by the CD test set when no correction offsets are applied The factors can apply to wavelength, delay [dispersion] calibration, as well as to recorded zero dispersion wavelength, slope and actual dispersion data values when using a calibrated reference fibre (see annex D)

3.25
spectral bandwidth
full-width half-maximum (FWHM) spectral width of the source

If the source exhibits a continuous spectrum, then the spectral bandwidth, *B*, shall be the full-width-half-maximum (FWHM) of the spectrum.

If the source exhibits a spectrum consisting of i discrete line (for example, a laser diode with a multiple-longitudinal mode spectrum), then the FWHM spectral bandwidth B shall be the r.m.s. spectral bandwidth, multiplied by 2,35 (assuming the source has a Gaussian envelope):

$$B = 2{,}35 \times [\{ (1/ P_{total}) \times (\sum_{i} p_i \, \lambda_i^2)\} - \lambda_c^2]^{½} \qquad (4)$$

where

λ_c is the central wavelength (see 3.9) of the laser diode, in nm;

$P_{total} = \sum_i p_i$ is the total power, in W;

p_i is the power of i^{th} longitudinal mode, in W;

λ_i is the wavelength of i^{th} longitudinal mode, in nm.

3.26
standard uncertainty
standard deviation
uncertainty of a measurement result expressed as a standard deviation σ

For further information, refer to annex A, and the *Guide to the Expression of Uncertainty in Measurement.*

NOTE In order to combine standard uncertainties from different sources (see annex A) it is important that they are all stated at the same confidence level, i.e. for normally distributed data, at a confidence level of 68,3 %. This may be achieved by the use of each respective coverage factor k which is determined with reference to student's t-distribution for each individual uncertainty component.

3.27
traceability
ability to demonstrate, for a measurement result or a CD test set, an unbroken calibration chain originating from a national standard

CD test sets calibrated by the procedures of this standard are traceable. In the sense of this standard, direct traceability of the measurement result to either a national standards laboratory or to an accredited calibration laboratory is demonstrated. Such traceability includes the calibration schedules of all artefacts in the calibration chain and detailed calculations of all (cumulative) transfer uncertainties in the calibration chain. The use of a reference fibre or working standard alone to compare/monitor CD test set calibration will not establish or re-establish traceability, but only extend the duration of the traceability certification (calibration period) if no change is found.

3.28
transfer
part of the calibration process where, following comparison of the relevant parameter of a calibrated artefact to that of a CD test set, the artefact result is applied to the CD test set

Transfer may be performed either by adjustment of the CD test set, or by documentation of a calibration factor in a calibration certificate.

3.29
transfer standard
intermediary artefact, for example a delay [dispersion] or wavelength artefact used to calibrate new working standards of a corresponding type

3.30
transfer uncertainty
estimate, characterizing the additional uncertainty of a CD test set caused by uncertainties in the calibration process, at the given confidence level

These uncertainties may arise from the calibration standards or artefacts as well as from the CD test set.

3.31
uncertainty type A
type A uncertainty is obtained by statistical analysis of a series of observations, such as when evaluating certain random effects of measurement (see *Guide to the Expression of Uncertainty in Measurement)*

3.32
uncertainty type B
type B uncertainty is obtained by means other than a statistical analysis of a series of observations, for example an estimation of probable sources of uncertainty, such as when evaluating systematic effects of measurement (see *Guide to the Expression of Uncertainty in Measurement)*

NOTE Other means may include previous measurement data, experience with or general knowledge of the behavior and properties of relevant materials, artefacts and instruments, manufacturer's specifications, data provided in calibration and other certificates, and uncertainties assigned to reference data taken from handbooks.

3.33
uncertainty limits
limits of permissible error (of a measuring instrument)
bounds or extreme values of expanded uncertainty permitted by user requirements, manufacturer's specification, regulatory documentation, etc. (see ISO 10012-1)

3.34
working standard
standard which, usually calibrated against a reference standard or transfer standard, is used on a routine basis to check CD test sets

4 Calibration

This clause summarizes the action of calibrating a chromatic dispersion (CD) test set and details the recommendations for the environmental requirements of the calibration facility.

4.1 Rationale for calibration of CD test sets

4.1.1 (Full) calibration

There are two fundamental and common aspects of the various chromatic dispersion measurement techniques (refer to annex C):

a) the use of a series of known (i.e. fixed) or programmable (i.e. variable) source test wavelengths, injected into the test fibre(s);

b) the electronic or optical measurement of the pulse delay, phase shift, differential phase shift or interference fringe peak position (according to CD test set type) produced by the test fibre(s). Fibre dispersion is obtained by appropriate calculations on the measured data.

In essence, all CD test sets operate with wavelength as a programmed (independent) variable, usually the ordinate (x-axis) and dispersion or time delay as the abscissa (y-axis) as a measured (dependent) variable. By their nature, fibre chromatic dispersion measurements require multiple wavelengths to be programmed. Even in the case of a single dispersion point obtained using the differential phase shift method, two separate wavelength values are used. It is also typical to expect a wide range of dispersion values over a range of wavelengths to be measured. This makes it impossible merely to transfer calibration from one CD test set to another by exposing them to a single appropriate dispersion source, unless the use of the CD test set is to be restricted in the range of fibre dispersion values measured (see introduction). Rather, it is necessary to independently calibrate wavelength and delay [dispersion] response to establish the minimum possible uncertainty in each.

The process of CD test set calibration shall therefore be broken down into two parts:

a) ensuring that the programmed wavelengths are calibrated;

b) exposing the CD test set, to known delays [dispersions] in order to calibrate the delay [dispersion] response.

These two separate calibration stages are generally independent but ideally should always be carried out as unified sequential operations. The detailed procedure is given in 4.3.

In each case, calibration is achieved by exposing the test set to independent transfer standards or artefacts of wavelength and delay [dispersion]. These standards form the calibration chain (figure 1).

4.1.2 Calibration checking

The rationale of 4.1.1 describes (full) calibration. However, typical routine operational calibration verification (such as may frequently be carried out on CD test sets in use) may be sufficient to perform calibration checking of CD test sets using a reference fibre as a working standard.

The distinction between calibration checking and calibration (i.e. adjustment of correction offsets, etc.) shall be clearly made. While it is sufficient to establish stability of the CD test set using the reference fibre, this is not a substitute for actual calibration (see introduction). The use of this fibre is described in clause 7.

NOTE It is envisaged that (full) calibration would be essential in the manufacture of CD test sets, while the reference fibre would be used mainly for calibration checking.

It is not possible to use the reference fibre for full calibration for the following reasons:

a) To correctly evaluate the full wavelength range and fibre length range of the CD test set, several reference fibres with differing dispersions would be needed. This is expensive, complex and will introduce a multiplicity of transfer and calibration uncertainty values.

b) The effect of the data fit and wavelength range used on the reference fibre zero dispersion wavelength, λ_0, slope, S_0, and dispersion values means that comparison of systems shall be made only within the wavelength range used.

c) The "λ_0-slope" representation, while perfectly adequate for a fibre, cannot cover the possibility that a given CD test set exhibits non-linear delay [dispersion] or wavelength behaviour – a more complete test of the delay [dispersion] and wavelength responses of the CD set is required.

d) Comparison of CD test sets using a reference fibre requires a standard length value for that fibre to be used in the measurements. Any physical reduction in the length of the fibre (for example, by re-cleaving) shall be kept track of and accounted for and represents a source of potential uncertainty.

Use of a reference fibre allows calibration traceability to national standards to be extended, if it can be satisfactorily established that the instrument and existing correction offsets and scaling factors, etc. are sufficient to provide dispersion results within the applicable uncertainty limits without alteration. This simply means that the CD test set has remained stable since the last actual calibration. Indeed, it is permissible to extend the calibration period indefinitely until such time that the calibration checking indicates that the CD test set has drifted outside these uncertainty limits. At this point, full re-calibration would be required.

It is anticipated that the reference fibre be used also for comparison, as distinct from calibration, between CD test sets under identical (for example, controlled or reference) conditions, test wavelengths, fibre type, fibre length ranges, etc. (see introduction).

4.2 Preparation for calibration

4.2.1 General advice and organization

The following recommendations apply:

Calibrations should be carried out where possible with facilities (refer to ISO 10012-1, ISO 10012-2 and EN 45001) that are independent of the other functions of the laboratory/ organization. This independence should include measurement equipment.

The environmental conditions shall be commensurate with the degree of uncertainty that is required for calibration:

a) the environment shall be clean;

b) temperature monitoring and control is required;

c) humidity monitoring and control is required;

d) all laser sources shall be safely operated (see IEC 60825-1).

All standards used in the calibration process shall be calibrated according to a documented programme with traceability to national standards laboratories or to accredited standards (see figure 1). It is advisable to maintain more than one standard on each hierarchical level of the calibration chain so that the performance of standards can be verified by comparisons on the same level.

There shall be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used. There should be pro-forma result sheets, uncertainty budgets and calibration certificates.

The calibration laboratory should operate a quality system appropriate to the range of measurements it performs (for example, ISO 9000). There should be an independent scrutiny of measurement results, intermediary calculations and preparation of calibration certificates.

4.2.2 Test environmental requirements

The following requirements shall be observed:

a) all tests shall be performed at an ambient temperature of 23 °C ± 3 °C with a relative humidity of (50 ± 20) % unless otherwise specified;

b) the CD test set, test apparatus and equipment shall be given sufficient time to reach thermal equilibrium with the environment in accordance with the manufacturer's recommendations for each item of equipment, before commencement of any part of the calibration procedure;

c) the instrument state of the CD test set and test equipment shall be recorded, a precondition for reproducible measurements;

d) connectors and optical input ports, etc. should always be cleaned before measurement.

At the time of calibration transfer, there may be some uncertainty in the calibration artefact that was not present at its generation, for example ageing, temperature difference, optical power level, optical reflections, etc. In each case, the transfer uncertainty using the calibration artefact shall be accumulated from the uncertainties of the artefact from each possible source.

4.2.3 Measurement equipment requirements

Calibration

Calibration of test equipment traceable to national or international standards laboratories is mandatory. The tests described require the use of some or all of the following:

a) a variable optical attenuator;

b) a wavelength measuring device (for example, optical spectrum analyzer or wavemeter) for discrete wavelength sources such as lasers;

c) a wavelength calibration means (for example, He-Ne laser or wavelength standard) for tunable monochromator based systems;

d) an optical delay line artefact [differential optical delay line artefact] for delay [dispersion] calibration.

Calibration checking

For calibration checking, a reference fibre with traceable dispersion data values is required.

4.2.4 Traceability

Ensure that all test equipment which has significance to the calibration result has been calibrated in an unbroken chain to the appropriate national standard. The recalibration period(s) shall be defined and documented. The details of traceability for this test equipment shall be made available on request (see clause 8).

4.3 Calibration procedure

The calibration methods for all types of CD test sets have a common theme, namely to independently and sequentially calibrate

a) the (programmed) source wavelength(s), and

b) the delay [dispersion] response of the set.

In each case correction offset, scaling factor and linearity shall be determined.

The user shall first ascertain which type of light source(s) (for example lasers or LED/filter/ monochromator) is in use and which measurement technique is in use in the CD test set in use.

NOTE Some CD test sets can perform more than one measurement technique, in which case it would be necessary to separately calibrate the CD test set for all measurement techniques in use, under the auspices of this standard.

For each CD test set calibration, the following outline procedure shall be performed in sequence:

a) Use the procedure appropriate to the CD test set measurement method for calibration of the wavelength parameter (see clause 5):

   1) for discrete wavelength source systems, use the procedure of 5.2;

   2) for continuously tunable source systems, use the procedure of 5.3.

   Calculate all the relevant calibration adjustments for the wavelength calibration. Apply these to the CD test set (typically by appropriate hardware and/or software adjustments IEC 62129 to achieve wavelength uncertainty within the specified limits;

b) Using equipment appropriate to the CD test set measurement method, calibrate the delay [dispersion] parameter using the procedure of 6.3.

   Calculate all the relevant calibration adjustments for the delay [dispersion] calibration. Apply these to the CD test set (typically by appropriate hardware and/or software adjustments) to achieve delay [dispersion] uncertainty within the specified limits.

c) Report and record on a certificate, the calibration results according to clause 8. The CD test set is now fully calibrated to national standards with the specified uncertainty.

NOTE Calibration offsets and scaling factors may be used to manually adjust the 'raw' results from the (unadjusted) CD test set.

4.4 Calibration checking procedure

This procedure is used for checking the calibration of a CD test set that has already been calibrated according to 4.3. So long as the reference fibre measurement does not reveal dispersion uncertainty greater than the appropriate uncertainty limits, that the calibration check can be used to extend the calibration period.

The exact procedures and reporting are detailed in clause 7.

5 Wavelength calibration procedure

5.1 General

This clause describes procedures for calibration of wavelength in CD test sets. The technical principle is to apply calibrated wavelength artefacts such as external sources, optical transmission elements or other artefacts to determine the central wavelength(s) used in the CD test set for dispersion measurement. The actual wavelengths used may then be adjusted. The process of calibration differs according to the light source used in the CD test set under consideration. For sets using lasers or other discrete wavelength sources, see 5.2; for continuously variable (tunable) sources see 5.3. In either case see 5.4 to report the calibration results.

5.2 Discrete sources

Many CD test sets use discrete laser diodes or discrete filtered LED/lamp sources and the procedure below shall be used to calibrate the wavelength. Any additional measurement apparatus, artefact or equipment used in this calibration procedure shall be prior calibrated to traceable standards. In these instruments, the following procedure shall be used:

a) establish that the test equipment requirements have been met (see 4.2.3);

b) establish that the test environmental conditions have been met (see 4.2.2);

c) set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2);

d) refer to annex B to consider the effects and technical origins of uncertainty sources;

e) for each discrete source, measure the wavelength using one of the following items, first ensuring that it is itself calibrated:

   1) an optical spectrum analyzer;

   2) a wavelength meter;

   3) a monochromator based detection system.

f) for each discrete source, measure the central wavelength λ_c and the spectral bandwidth B (as defined in 3.9 and 3.25 respectively);

g) the possibility of wavelength shift under different conditions of source modulation (chirp) shall be taken into account. Evaluation of the individual uncertainties of the source wavelengths shall also be carried out. The wavelength uncertainty may vary with the actual wavelength (region) used, so that in the subsequent evaluation of dispersion uncertainties, the correct uncertainty value(s) shall be used. Use the central wavelength λ_c and spectral bandwidth B for subsequent calculation of the time delay and or dispersion curve. Suitable wavelength uncertainty fitting techniques are described in IEC 62129;

h) the certified wavelengths of the source(s) chosen are to be used in the calculation of the monochromator tuning relation (calibration curve).

5.3 Tunable sources

For CD test sets employing continuously variable (tunable) sources, the wavelength calibration involves determining the wavelength calibration of the monochromator used for wavelength selection over the wavelength range of the CD test set. This may be accomplished in one of three ways (see 5.3.1, 5.3.2, 5.3.3), or a combination of these as detailed below. All and any additional apparatus, artefacts or equipment used in these calibration procedures shall be calibrated to traceable standards.

NOTE In all cases of standard sources and filters, the spectral bandwidth should be 5 nm or less FWHM. Similarly, the spectral resolution of wavelength measurement apparatus should be commensurate with the wavelength uncertainty required.

5.3.1 Method A

This method uses a sufficient number of external sources of known optical wavelengths (or set of wavelengths) at the input to the monochromator.

a) Each known external light source shall be calibrated, stable and of well-defined wavelength and of discrete line character. The monochromator calibration may be referenced to a fundamental physical phenomenon by deriving the test wavelengths from classical sources of discrete wavelengths. These could take the form of a 633 nm He-Ne laser, argon laser, mercury lamp, etc. to which the monochromator within the CD test set may be tuned using various diffraction orders. The intention is to obtain a sufficient number of calibration points for the monochromator drive to fully cover the wavelength range of the CD test set IEC 62129. It is also possible to obtain calibration points by using a suitable (broadband) source and known calibrated monochromator. The spectral width of the sources, in any case, should be less than 5 nm (see B.1.2).

b) Care shall be taken to ensure that the optical path of the calibration artefact exactly replicates the normal operating conditions in the CD test set. It is important to assess the uncertainties due to variations in the optical alignment between calibration and normal use of the CD test set.

c) Establish that the test equipment requirements have been met (see 4.2.3).

d) Establish that the test environmental conditions have been met (see 4.2.2).

e) Set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2).

f) Refer to annex B to consider the effects and technical origins of uncertainty sources.

g) For each source wavelength or diffraction order setting the central wavelength λ_c and spectral bandwidth B (see 3.9 and 3.25) shall be measured.

h) Evaluation of the individual uncertainties of the source wavelength(s) and the overall uncertainty of wavelength when the tuning relation has been calculated shall be carried out. The wavelength uncertainty may vary with the actual wavelength (region) used, so that in the subsequent evaluation of dispersion uncertainties, the correct uncertainty value(s) shall be used. Suitable wavelength uncertainty fitting techniques are described in IEC 62129.

i) The certified wavelengths of the source(s) chosen are to be used in the calculation of the monochromator tuning relation (calibration curve).

5.3.2 Method B

This method inserts calibration artefacts, such as an etalon or a sufficient number of optical filters, of known central wavelength(s) in the optical path of the CD test set, typically in place of the test fibre itself. In this case, the complete CD test set is in use during the calibration procedure.

a) It is possible to obtain several calibration points at or near the usual 1 310 nm and 1 550 nm wavebands using a multiple wavelength standard to reduce wavelength non-linearity or monochromator sine bar uncertainties. This standard may take the form of bandpass filters or etalons of calibrated central wavelengths placed in line with the CD source monochromator and detector. A sufficient number of wavelengths shall be used. The monochromator and/or filter/etalon spectral resolution shall be sufficient to resolve the calibration points with the required uncertainty. It may be required to make appropriate adjustments to the CD test set to achieve this.

b) Care shall be taken to ensure that the optical path of the calibration artefact exactly replicates the normal operating conditions in the CD test set. It is important to assess the uncertainties due to variations in the optical alignment between calibration and normal use of the CD test set.

c) Establish that the test equipment requirements have been met (see 4.2.3).

d) Establish that the test environmental conditions have been met (see 4.2.2).

e) Set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2).

f) Refer to annex B to consider the effects and technical origins of uncertainty sources.

g) Using each of the sources/filters in turn enables a detailed monochromator drive calibration law to be fitted to the data points.

h) A sufficient number of filter/source wavelengths shall be used and may be chosen to lie within the usual 1 310/1 550 nm wavebands.

i) It is important to assess the effect of launch conditions (for example, filter tilt angle) for each artefact used.

j) For each wavelength used, the central wavelength λ_c and spectral bandwidth B shall be measured as defined in 3.9 and 3.25, respectively.

k) Evaluation of the individual uncertainties of the artefact wavelength and the overall uncertainty of wavelength when the tuning relation has been calculated shall be carried out. The wavelength uncertainty may vary with the actual wavelength (region) used, so that in the subsequent evaluation of dispersion uncertainties, the correct uncertainty value(s) shall be used. Suitable wavelength uncertainty fitting techniques are described in IEC 62129.

l) The certified wavelengths of the source(s) chosen shall be used in the calculation of the monochromator tuning relation (calibration curve).

5.3.3 Method C

This method measures the wavelength emanating from the monochromator using an instrument, for example an optical spectrum analyzer; wavelength meter; or monochromator based detection system.

NOTE The spectral width of the monochromator is typically less than 5 nm (see B.1.2), and sufficient spectral resolution within the CD test set shall be ensured.

a) For various agreed wavelength settings of the CD test set monochromator, perform a measurement of the wavelength emanating from the CD test set monochromator using an optical spectrum analyzer, wavelength meter or monochromator based detection system.

b) Care shall be taken to ensure that the optical path of the calibration artefact exactly replicates the normal operating conditions in the CD test set. It is important to assess the uncertainties due to variations in the optical alignment between calibration and normal use of the CD test set.

c) Establish that the test equipment requirements have been met (see 4.2.3).

d) Establish that the test environmental conditions have been met (see 4.2.2).

e) Set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2).

f) Refer to annex B to consider the effects and technical origins of uncertainty sources.

g) It is important to assess the uncertainty due to launch conditions in the wavelength meter each time light is presented to it.

h) For each wavelength used, the central wavelength λ_c and spectral bandwidth B of the CD test set light shall be measured as defined in 3.9 and 3.35, respectively.

i) The central wavelengths and spectral widths shall be the values used for evaluation of the monochromator tuning relation (calibration curve).

j) Evaluation of the individual uncertainty of wavelength when the tuning relation has been calculated shall be carried out. The wavelength uncertainty may vary with the actual wavelength (region) used, so that in the subsequent evaluation of dispersion uncertainties, the correct uncertainty value(s) shall be used. Suitable wavelength uncertainty fitting techniques are described in IEC 62129.

k) The certified wavelengths of the source(s) chosen are to be used in the calculation of the monochromator tuning relation (calibration curve).

5.4 Uncertainties and reporting

Refer to annexes A and B for discussion on handling uncertainties and sources of uncertainty pertaining to wavelength calibration, respectively.

Refer to clause 8 for details of calibration results reporting.

6 Delay [dispersion] calibration procedure

6.1 General

This clause describes procedures for calibration of delay [dispersion] in CD test sets. The procedure is described in 6.3, and reporting in 6.4.

6.2 Equipment and preparation

This subclause describes the delay [dispersion] artefacts and their use.

In order to characterize the optical propagation delay [dispersion] response of a complete CD system, it is necessary to simulate the fibre delay [dispersion] using a calibrated optical set-up. This is because the delay changes over the wavelength range involved are too small to be established electronically with sufficient accuracy.

The principle is to use a variable optical delay line artefact formed by a moving mirror or mirrored corner prism (figures 2 and 3) placed in line with the CD test set optical system.

NOTE Differential phase shift CD test sets employing the wavelength modulation method (refer to annex C) are calibrated using a dispersion "simulator" (for example figure 3, consisting of a fixed optical delay line and a variable optical delay line each alternately selected by a chopper synchronized to the wavelength modulation clock signal). The differential delay between the two optical arms simulates the chromatic dispersion of a fibre.

All other CD test sets use a simple delay line such as shown in figure 2 which simulates the delay time in the fibre.

In the artefact, a displacement of the mirror/prism by an amount x results in a optical delay [dispersion] change of $2x/c$ s, where c is the velocity of light in air. A corresponding pulse delay, phase shift, interference fringe position shift or differential phase shift (i.e. dispersion) results, which is observed by the CD test set. By repeating the measurements for each mirror/prism position used, this allows for a curve of measured delay [dispersion] versus true delay time to be built up for the CD test set.

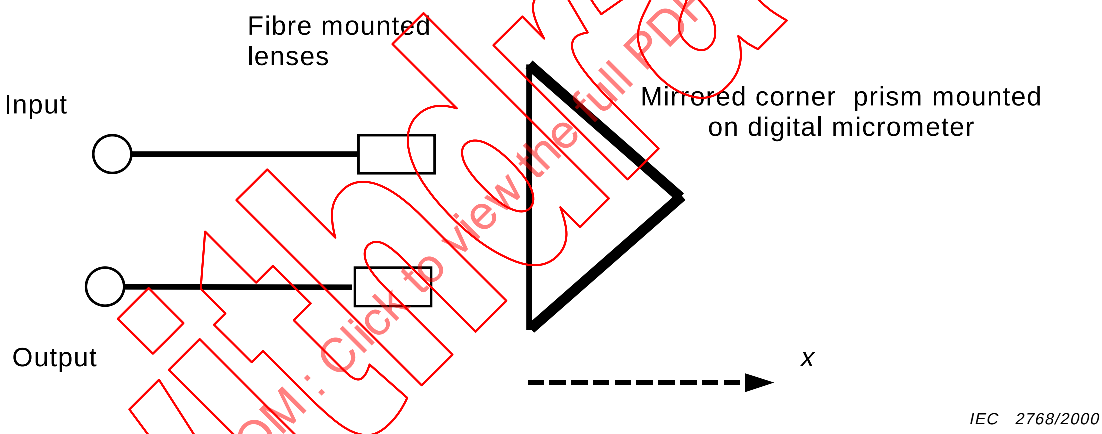


Figure 2 – Typical optical delay line artefact for CD test set delay calibration

The optical delay line technique is traceable to national standards since c is, for this purpose, wavelength independent, while the linear motion calibration of the mirror/prism is calibrated via a chain traceable to national standards.

The optical delay line artefact (figures 2 and 3) shall be at least long enough to cover the full range of relative delay [dispersion] values encountered in the test fibre lengths used by the test set. The linear motion resolution shall be at a level commensurate with the required uncertainty.

6.2.1 Pulse delay CD test sets

For pulse delay test sets the delay line artefact (figure 2) shall be used several times with different delay values at the origin, i.e. by adding various lengths of fibre up to the expected maximum length. This is in order to ensure that the entire delay response is linear with the same scale uncertainty for typical absolute and relative delay values encountered in normal fibre tests.

6.2.2 Phase shift CD test sets

For phase shift CD test sets, the delay line artefact (figure 2) shall have sufficient range to cover an entire phase cycle (2π) of the RF modulation frequency and shall be used several times with different phase conditions at the origin, spaced over the entire phase cycle (2π) of the RF modulation frequency . This is in order to ensure that the entire delay response is linear with the same scale uncertainty for all possible delay and phase conditions.

6.2.3 Interferometric CD test sets

For interferometric systems the delay line artefact (figure 2) shall be used several times with different delay values at the origin, i.e. by adding various lengths of fibre up to the expected maximum length. This is in order to ensure that the entire delay response is linear with the same scale uncertainty for all total delay values encountered in normal tests. The delay line artefact (figure 2) shall have sufficient range to cover the entire expected instrument delay range.

6.2.4 Differential phase shift CD test sets

Dispersion response for differential phase shift systems is calibrated using the optical delay line principle. The method used differs slightly for the type of differential phase shift method used in the CD test set.

- *differential phase shift systems which operate by the principle of differences between delays:*

  These CD test sets should be calibrated using the apparatus similar to that shown in figure 2. The delay line artefact shall be used over sufficient range to cover an entire phase cycle (2π) of the RF modulation frequency.

- *differential phase shift systems employing the wavelength modulation method:*

  These shall use apparatus similar to that shown in figure 3. The delay line shall be used over sufficient range to cover an entire differential phase cycle (2π) of the RF modulation frequency.

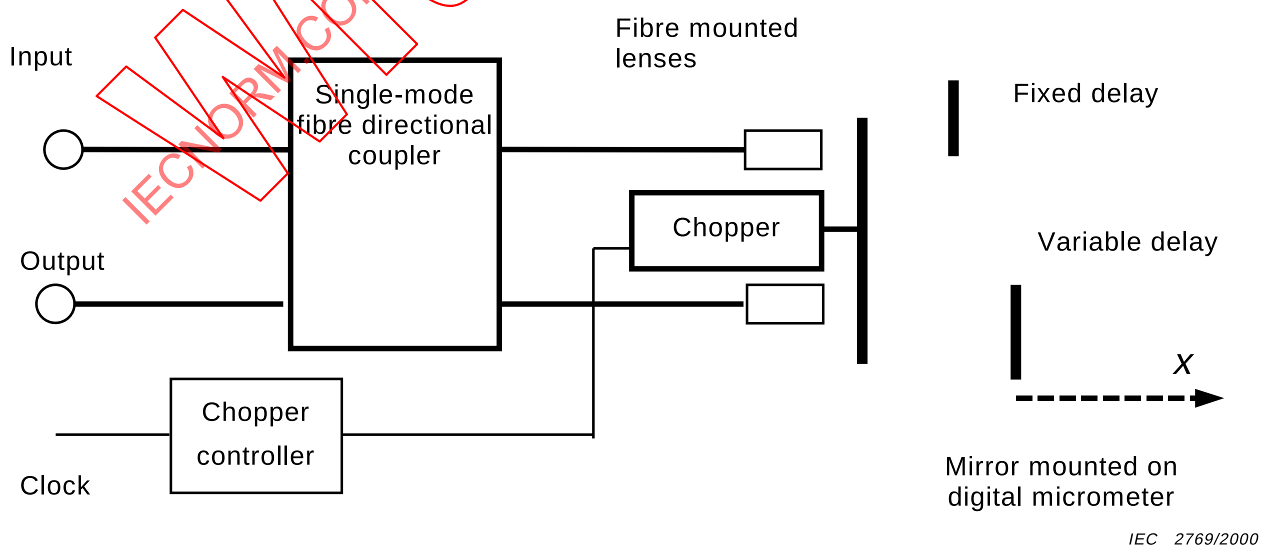


Figure 3 – Typical differential delay [dispersion] simulator for CD test set calibration

6.3 Calibration procedure

The calibration procedure below should be performed at several optical power levels, obtained using an optical attenuator, to ensure that signal level dependent effects are taken into account. This ensures that variations of fibre loss or coupling efficiency are represented.

The calibration is common to all types of CD test set and is carried out as follows:

a) establish that the test equipment requirements have been met (see 4.2.3);

b) establish that the test environmental conditions have been met (see 4.2.2);

c) set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2);

d) refer to annex B to consider the effects and technical origins of uncertainty sources – care shall be taken to allow for all uncertainties (including for example, temperature, ageing, etc.) associated with the delay [dispersion] artefacts;

e) select a specific operating wavelength for the calibration (for example, 1 310 nm);

f) set the delay line (see figures 2 or 3) with the mirror/prism at one end (for example, the origin) and configure the CD test set to measure the total optical delay, phase shift, interference fringe shift or differential phase shift for this optical system;

g) move the mirror/prism along in evenly spaced steps and measure the delay, phase shift, interference fringe shift or differential phase shift at each step. In order to reduce the effect of noise, these measurements shall be performed with sufficient data averaging. A sufficient number of delay line steps shall be used. Successive mirror positions x give rise to a delay equal to $2x/c$, and an equivalent phase shift or differential phase shift change. If applicable, convert the phase shift into delay [differential phase shift into differential delay]. The completed set of measurements should lie on a straight line of delay [differential delay], phase shift, interference fringe shift or differential phase shift versus mirror position x with a slope of $2/c$;

h) use a least-squares linear regression to obtain the best fitted line;

i) the slope, sl and intercept [correction offset, CO] of the fit should be evaluated using normal data fitting methods and these values recorded. The scaling factor SF_{del} for delay [differential delay] is defined as

$$SF_{\text{del}} = [sl \times c / 2] \qquad (5)$$

Any visible non-linearity (or excessively large data fit residuals) and noise represent potential sources of uncertainty. The delay [differential delay] scaling factor SF_{del} may be used to make adjustments to the CD test set. The above procedure may be repeated several times to establish a more precise (average) scale uncertainty value. Estimation of the average delay [differential delay] scaling factor SF_{del}, zero offset and other uncertainties shall be carried out (see clause 8 and annex A).

6.4 Uncertainties and reporting

Refer to annexes A and B for discussion on handling uncertainties and sources of uncertainty pertaining to delay [dispersion] calibration, respectively.

Refer to clause 8 for details of calibration results reporting.

7 Calibration checking procedure

7.1 General

This clause describes the detailed procedure of checking calibration of any CD test set using a reference fibre. The selection criteria for the reference fibre are given in 7.2, 7.3 and figure 4 describe the calibration process of comparing CD test sets using a reference fibre.

Subclause 8.5 deals with the generation of new reference fibres to provide new transferable calibration checking artefacts. Figure 5 shows the process of generating a new reference fibre.

7.2 Equipment and preparation

The choice of fibre as a potential reference fibre is not critical but generally the fibre

a) should be a standard calibrated fibre calibrated by a national standards laboratory, or a standard fibre generated on a CD test set known to be correctly calibrated;

b) shall have low or moderate attenuation levels;

c) shall have good longitudinal homogeneity and 'typical' properties for the fibre type (see annex C) such as mode field diameter, dispersion etc.;

d) should ideally be taken from the same production unit that the CD test set will be attached to, at least for QA applications;

e) should be longer than the minimum measurable length for the CD test set, i.e. >1 km but significantly less than the maximum length, for example <25 km, in order that dispersion measurement repeatability is nearly optimum. In the case of interferometric methods, the fibre length should be that required by the unit (several metres);

f) should be adequately protected from environmental factors such as dust, winding tension variations, air currents and physical damage and may optionally be placed within an environmentally controlled enclosure.

NOTE More than one fibre of a given type or more than one type of fibre may be used.

7.3 Procedure

Perform calibration checking using the following procedure (refer to figure 4):

a) Establish that the test equipment requirements have been met (see 4.2.3).

b) Establish that the test environmental conditions have been met (see 4.2.2).

c) Set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2).

d) Refer to annex B to consider the effects and technical origins of uncertainty sources.

e) Present the reference (standard) fibre to the CD test set under consideration. Use the reference fibre standard length value and any length corrections for removal of fibre during preparation.

f) Determine zero dispersion wavelength λ_0 and slope S_0 of the fibre using the appropriate data fit and wavelength range. If necessary, repeat the measurement several times to average out uncertainties type A.

g) Compare the average zero dispersion wavelength and slope obtained with the reference values. These biases should be specified in the calibration results. Compare also the dispersion values and the residuals of the data fit (if used) for any abnormality. It is necessary to evaluate the uncertainty of the reference fibre values and then to evaluate the successive (cumulative) transfer uncertainty (see figure 4). If the uncertainty limits are not exceeded, then the calibration period may be extended and a new certificate issued (see 7.4 and clause 8). If the resultant uncertainty of the CD test set falls outside the specified limits of its existing calibration certificate (see clause 8), then full calibration is required.

h) Investigate abnormalities, if necessary perform a full calibration to correct the situation.

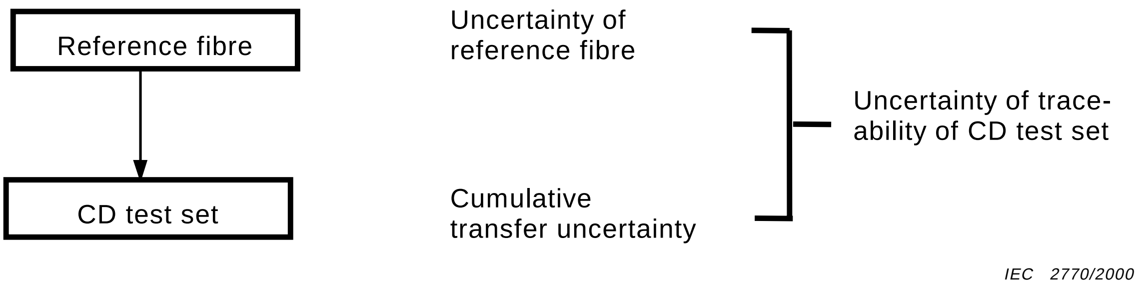


Figure 4 – Reference fibre comparison

7.4 Uncertainties and reporting

Refer to annexes A and B for discussion on handling uncertainties and sources of uncertainty pertaining to calibration checking respectively.

Refer to clause 8 for details of calibration checking results reporting.

7.5 Generation of infant reference fibre

It is vital to record the exact measurement conditions and several rules shall be applied when creating an infant reference fibre (see figure 5).

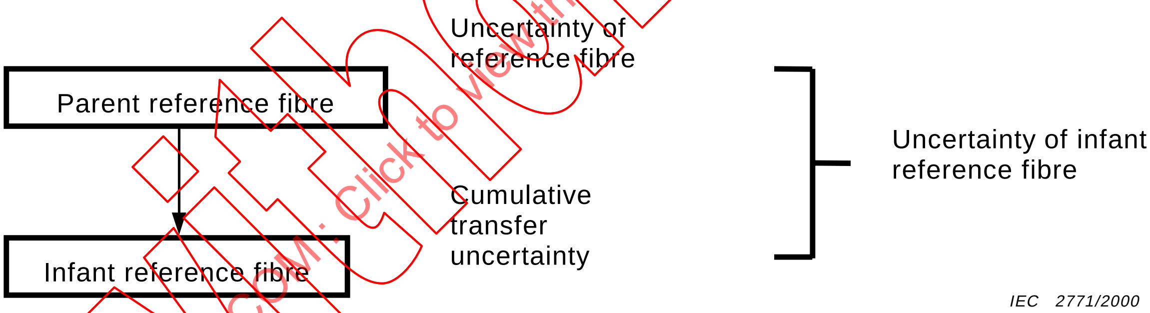


Figure 5 – Generation of a reference fibre

a) The parent fibre shall be measured over a sufficiently narrow wavelength measurement range such that a known delay [dispersion] data fit can be accurately applied. Refer to annex C.

b) The infant fibre shall be similar in characteristics to the parent fibre, for example same class/type, similar length (see 8.2). The agreed standard length and group index value for the fibre shall be recorded.

c) The wavelength range and exact wavelength values used for the parent fibre characterization shall be retained for all reference fibres generated from the parent. This is to ensure that the data fit is identically weighted in all measurements to remove fit model bias.

d) The data fit equation shall be the same for the parent and all infant fibres being compared.

e) If necessary, the effect of differing optical power levels between the infant and parent fibre shall be corrected for, or a similar power level employed for each measurement, by using appropriate optical attenuators.

The generation of the infant reference fibre is performed using (ideally, calibrated) a CD test set as a temporary transfer standard as follows:

a) establish that the test equipment requirements have been met (see 4.2.3);

b) establish that the test environmental conditions have been met (see 4.2.2);

c) set up the CD test set instrument state to the appropriate settings for calibration procedures (see 4.2.2);

d) refer to annex B to consider the effects and technical origins of uncertainty sources;

e) use the agreed standard length of the parent reference fibre and any corrections for fibre removed during cleaving, etc.;

f) present the parent fibre and determine zero dispersion wavelength and slope;

g) repeat the measurement as necessary to improve measurement uncertainty;

h) ensure the biases for the parent fibre are within acceptable uncertainty limits on the CD test set used for the transfer (see figure 5);

i) use the agreed standard length of the new fibre and any corrections for fibre removed during cleaving, etc.;

j) present the infant fibre (selected in accordance with the above rules) and determine zero dispersion wavelength and slope using the same measurement set up as for the parent fibre measurement;

k) repeat the measurement as necessary to improve measurement uncertainty;

l) on any new standard fibre calibration certificate, record (see clause 8):
   - the zero dispersion wavelength value(s);
   - the fibre length and group index value;
   - the wavelength points and data fit used;
   - the slope(s) at the zero dispersion wavelength(s);
   - the value(s) of dispersion at measurement wavelength(s) and other specified wavelength(s) as required;
   - the calibration uncertainties arising from the uncertainty of the parent fibre and the cumulative transfer uncertainty of the transfer process;
   - other pertinent environmental factors (for example, temperature of the fibre).

8 Documentation

All CD test sets referring to this standard shall have their calibration reported as outlined below. All uncertainty statements shall be made on the mathematical basis of annex A.

8.1 Specifications, measurement data and uncertainties

Following a successful completion of a calibration of the CD test set, a verification of the adjustment shall be performed by repeating the appropriate procedures (see clauses 5 and 6), to check that the CD test set is indeed correctly calibrated. Alternatively, a calibration check using a reference fibre (see clause 9) can be substituted.

The uncertainties of a single CD test set shall be documented in a calibration certificate in order to claim compliance with this standard. The uncertainties shall be stated in the form of expanded uncertainties, i.e. by multiplying the relevant standard uncertainty by the coverage factor, k.

A manufacturer of CD test sets may use the uncertainty of a series of identical CD test sets of his own manufacture to evaluate the technical specification values of uncertainty of this model of CD test set. The uncertainties of a series of CD test sets may be used or specified in appropriate data sheets by the manufacturer of the CD test set.

The certificates/specifications should include the following:

a) all transfer environmental conditions (see clause 4) of the CD test set under test;

b) if no adjustments were applied during the transfer(s), with the intention that these be applied manually to subsequent fibre measurements, the calibration offset(s) and scaling factor(s) shall be reported. Report where applicable, the applicable calibration offsets and scaling factors for fibre lambda zero, slope and dispersion/delay and applicable wavelength ranges.

   If internal adjustment has been applied, for example by hardware or software changes, state that this has in fact been performed on the certificate (it is not necessary to record the actual *CO* and *SF* values);

   NOTE For calibration checking, record the bias between reference fibre parameters (see 7.3) and the measurement result of CD test set. When an infant reference fibre is generated (see 7.5) record the fibre parameters as listed in 7.5.

c) the instrument state of the CD test set during the calibration procedure, the most important parameters being calibration date, CD test set serial number or other identification, test wavelength(s) used, fibre type(s), instrument settings, averaging time/speed, data fitting model, test set mode of operation and serial numbers of any artefacts used;

d) the calibration period, and the new calibration due-date;

e) the following statement:

   “Information on the CD test set traceability is available on request”;

f) signature of a qualified person assigned and authorized to supervise calibration activities;

g) statement of procedure and detail of all significant equipment or artefacts used (for example, type of artefact, identification, operating principle, etc.).

8.2 Traceability information

An example of a traceability chain is illustrated in figure 1. The traceability information indicated in 8.1 e) is to be made available upon request and shall contain the following:

a) the name of the national standards laboratory and, if applicable, of the accredited calibration laboratory which forms the top of the calibration chain;

b) a description of all wavelength standards, delay [dispersion] standards and related instruments (with re-calibration periods, etc.) in the calibration chain, from either the calibration laboratory or the accredited calibration laboratory to the CD test set;

c) all actual sets of transfer environmental conditions (nominal values only) in the calibration chain;

d) the uncertainties of all artefacts and standards in the calibration chain in the form of expanded uncertainties;

e) the transfer uncertainties of all transfer processes in the calibration chain, in the form of expanded uncertainties.

Annex A
(normative)

Mathematical basis

A major part of the effort in calibration goes into evaluating uncertainties. This annex suggests a standard format for reporting and accumulating uncertainties.

The following is based on the *Guide to the Expression of Uncertainty in Measurement*. This annex distinguishes three types of deviations (see A.1) between an actual measurement and the "true" value of the measured quantity: known deviations, which can be corrected, uncertainties type A, which are obtained from a series of measurements on the same measurand and uncertainties type B which are obtained from other knowledge. Each of these may be caused by a number of influencing quantities. This annex indicates a standardized form of evaluating, accumulating and reporting these contributions.

A.1 Deviations

A deviation characterizes a known error of a measurement result. It should be noted that the term "error" is equivalent to "deviation".

It is useful to distinguish between measurement results in linear form, for example wavelength or per cent, and measurement results in logarithmic form, for example optical power in dBm. In both cases, the deviation or error Δy quantifies the difference between an actual measurement result y_{actual} and the "true" value of the measured quantity y_{ref}.

$$\Delta y = y_{\text{actual}} - y_{\text{ref}} \tag{A.1}$$

A correction is possible by subtracting the deviation from the measurement result.

A.2 Uncertainties type A

Randomly changing measurement results should be characterized by an uncertainty type A. A normal (Gaussian) distribution of measurement samples is usually assumed. It is recommended to keep these uncertainties as small as possible by averaging a number of measurement samples. In order to save time in the calibration of an individual test set from a series of identical test sets, it is suggested that each random (type A) uncertainty be evaluated in two steps:

A.2.1 As the first step, determine the experimental standard deviation $s_{\text{type A}}$ of a typical measurement situation from a large number of measurements, m. The centre of the distribution is assumed to coincide with zero, i.e. the reference standard value. Note that all random (type A) uncertainties shall be reported as relative uncertainties of the CD test set response.

The experimental standard deviation, characterizing an uncertainty type A, is approximately:

$$s_{\text{type A}} = \left[\frac{1}{m-1} \cdot \sum_{m} (y_{\text{i}} - y_{\text{mean}})^2 \right]^{\frac{1}{2}} \tag{A.2}$$

where

y_{i} is the measurement sample of a series of measurements of the dispersion;

y_{mean} is the mean value of the data dispersion;

m is the number of characterizing measurements in determining the standard deviation with m assumed to be large, for example >30.

A.2.2 As the second step, determine the standard uncertainty of the individual case $\sigma_{type\ A}$ from a smaller number of measurements n. Often n = 1 in order to save measurement time. The result is the standard uncertainty type A:

$$\sigma_{type\ A} = s_{type\ A} / \sqrt{n} \tag{A.3}$$

where $\sigma_{type\ A}$ expresses the uncertainty of the mean, which assumes averaging of the n measurement samples. Note that the two steps may be gathered into a single step, by making $m = n$. Additional statistical techniques, for example t-statistics may be required.

A.3 Uncertainties type B

An uncertainty type B usually quantifies an unknown fixed offset between a measurement result and the “true” value of a measured quantity. These uncertainties can be described by the width of an uncertainty band, as illustrated in figure A.1. A uniform (rectangular) distribution of measurement results is assumed.

This standard suggests specifying the half-width $U_{type\ B}$ of the band of relative uncertainties. The uncertainty band can be calculated by multiplying the tolerance band of the influencing condition, for example of the temperature, with the test set’s worst case dependence on this condition. These calculations should be based on known physical relations, manufacturer’s specifications, data provided in calibration certificates or on a sufficiently large number of characterizing measurements of the same type of test set. Uncertainties type A in these measurements shall be kept as small as possible, for example by averaging.

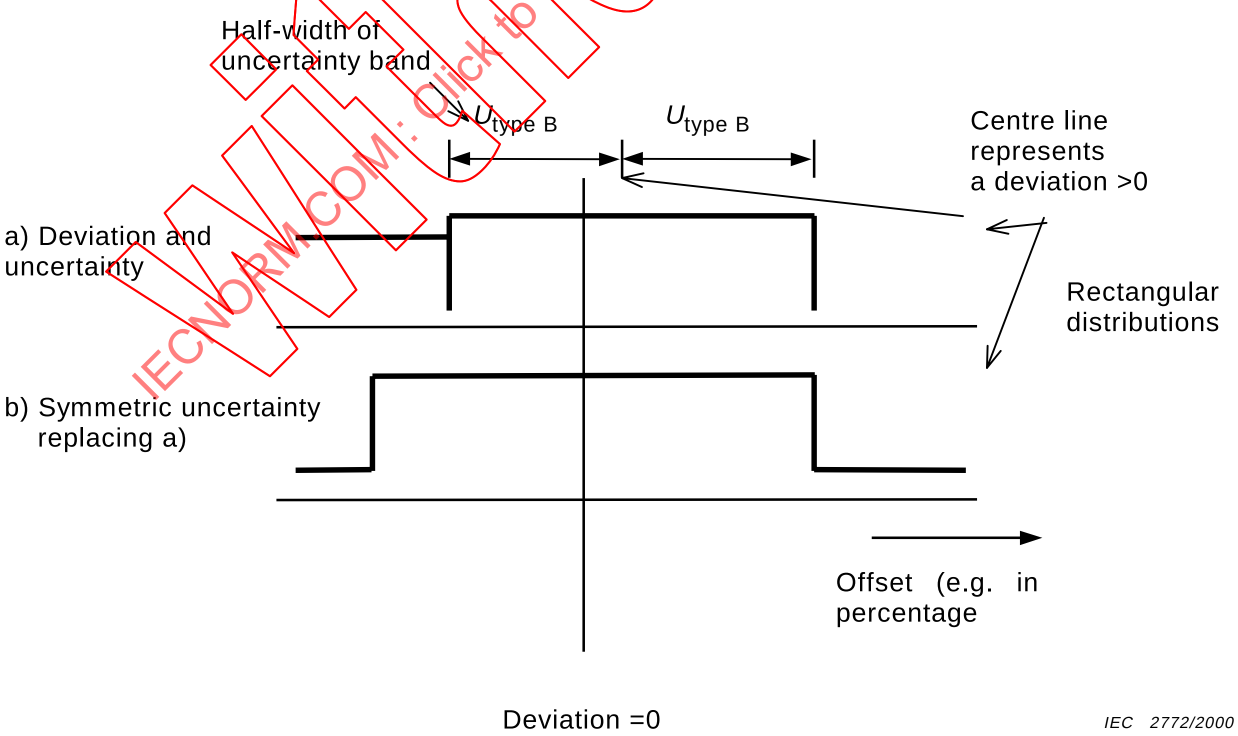


Figure A.1 – Deviation and uncertainty type B, and how to replace both by an appropriately larger uncertainty

As illustrated in figure A.1, it is possible to omit the deviation by specifying a wider and symmetrical uncertainty band.

The expanded uncertainty can alternatively be expressed by an equivalent standard uncertainty $\sigma_{\text{type B}}$:

Uncertainty type B (half-width):

$$U_{\text{type B}} = \{\text{half-width of parameter's tolerance band} \times \text{CD test set's sensitivity}\} \quad \text{(A.4)}$$

Standard uncertainty type B (calculated):

$$\sigma_{\text{type B}} = U_{\text{type B}} / \sqrt{3} \quad \text{(A.5)}$$

A.4 Accumulation of uncertainties

The "combined standard uncertainty" is used to collect a number, i, of individual uncertainties into a single number. The combined standard uncertainty is based on statistical independence of the individual uncertainties; this leads to a root-sum-square of their standard deviations. In compliance with the *Guide to the Expression of Uncertainty in Measurement*, the following formulae shall determine the cumulative deviation, combined standard uncertainty and combined expanded uncertainty.

Cumulative deviation (error):

$$\Delta Y = \sum \Delta y_i \quad \text{(A.6)}$$

Combined standard uncertainty:

$$u_c = \left[\sum_i \left(\sigma_{\text{typeB,i}}\right)^2 + \sum_j \left(\sigma_{\text{typeA,j}}\right)^2 \right]^{\frac{1}{2}} \quad \text{(A.7)}$$

where

$\sigma_{\text{typeB,i}}$ is the (calculated) standard uncertainty representing systematic (type B) uncertainty, one of i;

$\sigma_{\text{typeA,j}}$ is the standard uncertainty characterizing a random (type A) uncertainty, one of j;

i is the number of uncertainties type B;

j is the number of uncertainties type A.

NOTE The first part of equation (A.7) collects all uncertainties type B, and the second part collects all uncertainties type A. It is acceptable to neglect uncertainty contributions to this equation which are smaller than 1/10 of the largest contribution, because squaring them will reduce their significance to 1/100 of the largest contribution.

Combined expanded uncertainty:

$$U = \pm\, u_c \times k \quad \text{(A.8)}$$

where *k* is the coverage factor. Refer to 3.14 and 3.15.

In the majority of measurements, it is possible to evaluate type B uncertainties with high reliability. Further, if the procedure followed for making the measurements is well established and the type A evaluations are obtained from a sufficient number of observations, then the use of a coverage factor $k = 2$ will mean that the combined expanded uncertainty, U, will provide an interval with a level of confidence of 95,5 %; for $k = 3$ this would be 99,7 %.

However, in some cases, it may not be practical to base the type A evaluation on a large number of readings, which could result in the level of confidence being significantly less than 95 % if a coverage factor of $k = 2$ is used. In these situations, the value of k, or more strictly k_p where p is the confidence probability in percentage terms, for example 95, should be based on a t-distribution rather than a normal distribution. Generally, if an uncertainty assessment involves only one type A evaluation and the number of readings, n, is greater than 2 and the type A uncertainty is less than half the combined standard uncertainty, u_c, then the coverage factors corresponding to a large distribution can be used. If this is not the case, then in order to correctly obtain the required value for k, it is necessary to obtain an estimate of the effective degrees of freedom v_{eff} of the combined standard uncertainty u_c. The Welch-Satterwaite equation is used to calculate a value of v_{eff} based on the degrees of freedom v_i, v_j, of the individual uncertainty contributions σ_i, σ_j; therefore:

$$v_{eff} = \frac{(u_c)^4}{\sum_i \frac{(\sigma_{typeB,i})^4}{v_i} + \sum_j \frac{(\sigma_{typeA,j})^4}{v_j}} \tag{A.9}$$

The degrees of freedom v_j, for contributions obtained from type A evaluations is j-1. For type B contributions the degrees of freedom will need to be estimated from available information or knowledge of the reliability of the estimation of the standard uncertainty. The degrees of freedom for each type B contribution are obtained from the relative uncertainty $\Delta\sigma_i/\sigma_i$. A value for the relative uncertainty is obtained, subjectively, from scientific judgement based on the pool of available information. Therefore for type B contributions:

$$v_i = \frac{1}{2}\left(\frac{\Delta\sigma_i}{\sigma_i}\right)^{-2} \tag{A.10}$$

It is often possible to take the number of degrees of freedom v_i of a type B contribution as infinite. In these cases, the effective degree of freedom of σ_i will depend on the degrees of freedom of type A contributions and their magnitude in relation to the type B contributions.

Having obtained a value for v_{eff}, a standard t-distribution table is used to find a value of t corresponding to a confidence level of 95 %. This is the value of k required to calculate the combined expanded uncertainty U in equation (A.8).

A.5 Reporting

In calibration reports and technical data sheets, combined standard uncertainties in the CD test set output shall be reported in the form of expanded uncertainties, together with the applicable confidence level. The default confidence level is 95,5 %.

Annex B
(normative)

Assessment of operational uncertainties

This annex describes potential uncertainty sources, and tests for individual uncertainties. The purpose of these tests is to evaluate/calculate the absolute uncertainties of all standards in the calibration chain for the CD test set as outlined in clause 5. The compilation of uncertainty sources is by no means exhaustive.

Naturally, operating conditions for a calibrated CD test set will differ significantly from those pertaining at the time of calibration. The operational uncertainty is the additional uncertainty induced by operating the CD test set to the extremities of its intended operating range (temperature, loss, etc.). The operating range may be set by the CD test set manufacturer or by the calibration laboratory in charge of calibration for operating conditions. To calculate the operational uncertainty, use the mathematical basis of annex A.

Each individual operational uncertainty may be evaluated for those uncertainty sources in the actual transfer process. All uncertainties should be reported using the mathematical basis of annex A in the form of an expanded uncertainty type B.

An operational uncertainty is defined as the span of relative changes of the response of the CD test set, when changing one of the operating parameters within the specified operating range. The zero point is defined by the response at the transfer condition. The span is defined by the maximum positive and negative changes of the response; an asymmetric distribution of uncertainties about the zero point is the usual result.

An operational uncertainty may be assumed to be zero if the operating band of that parameter coincides with the tolerance band of the parameter during transfer. Generally, the operational uncertainty will increase with the width of the operating range.

B.1 Wavelength calibration uncertainties

B.1.1 Wavelength offsets

- *Discrete light sources (lasers):*

A major source of uncertainty arises from the calibration of the optical spectrum analyzer (or similar instrument) used to calibrate the system. The instrument shall be calibrated to a known accuracy with respect to a recognized standard; this uncertainty will convert to systematic uncertainty, dependent on the fibre dispersion. The effects of laser spectral distribution and central wavelength stability/shift shall also be considered.

- *Tunable (programmable) light sources*

Uncertainty arises from the individual wavelength accuracy of each filter or laser (or source) used to calibrate the monochromator. Typically, the calibration law for the monochromator is obtained by appropriate data fitting, which will smooth the individual uncertainties.

Other uncertainties arise from

a) the quantization of the (usually) digital monochromator drive;

b) long term drift of the monochromator and standards filters/lasers;

c) thermal drift of the monochromator;

d) the monochromator repeatability (mechanical/electrical);

e) the monochromator mechanical alignment.

B.1.2 Source spectral width and shape

The finite spectral width of the light source used in a CD test set affects the accuracy of the dispersion measurements since dispersion varies with wavelength.

To reduce uncertainties, the central wavelengths of the source shall be evaluated using equation (1), and not just taking the maximum power wavelength or the centre wavelength of the monochromator window. This is particularly true when using broadband sources (for example LEDs) which have a near Gaussian spectral shape with a monochromator. In this case, the light spectrum after the monochromator generally has an asymmetrical spectral shape, leading to a central wavelength of the light not at the centre of the monochromator window.

In practice, when measuring ordinary fibres the effect of referring just to the monochromator central wavelength is almost negligible for spectral widths below 5 nm, with LEDs having at least 50 nm FWHM spectral width (the induced error in the measured fibre zero dispersion wavelength and zero dispersion slope is below 1 nm and 1 %, respectively in this case). Beyond these limits, a correct evaluation of the central wavelength of the source used is required (this can typically be obtained, using method C (5.3.3) for the CD test set wavelength calibration).

The residual effects of the source finite spectral width depend on the delay detection system and should be evaluated for the CD test type in use. When using method A (5.3.1) and method B (5.3.2) for wavelength calibration, it is desirable to maintain spectral reference source spectral width at less than 5 nm. In any case, it is essential to ensure that no significant spectral lobes or stray light occur.

B.2 Fibre length uncertainty

Since dispersion is always normalized to unit length, it is necessary to determine the length of fibre under test. This may be done, for example, using the CD test set or an OTDR, each respectively using an appropriate fibre group index value. The group index value should be obtained from standard measurement methods, for example the 'cut back' method, mechanical length comparisons, manufacturer's data, etc. The length measurement apparatus shall be calibrated to known standards. The uncertainties in group index and length measurement shall be taken into account.

Where standard fibres are in use, approximately the same length of fibre may be used in both parent and infant CD test sets. Care shall be taken to ensure negligible amounts of fibre are trimmed off during fibre splicing, etc. Connectorized fibres are acceptable (see B.6.4).

B.3 Optical delay variation

The chromatic dispersion effect is a relatively minute change in delay compared to the total optical propagation delay. Therefore, it is essential to maintain a constant fibre delay at least during dispersion measurement periods. The relative ease by which this situation can be approached in practice depends on the measurement time and the dispersion measurement technique used. The main sources of total delay variation are fibre strain and temperature changes which occur over the measurement time.

B.3.1 Axial fibre strain

Axial strain in a fibre (for example wound tightly on a drum) may cause significant delay changes, perhaps as a result of thermal expansion of the drum or fibre lay duct. The strain results in a physical length change ΔL and group index change Δn. To first order $dn/d\lambda$ (the dispersion) is unaffected. However, if the strain were to vary during measurements, for example drum temperature changes or drift, significant delay uncertainty can be obtained because delay points are obtained sequentially. It is therefore necessary to minimize changes in the fibre temperature or fibre strain for the duration of the delay measurements and for all calibration work and for all actual test work if CD test set calibration is to be guaranteed. The levels of strain change tolerable depend on the measurement method used. Also, depending on the measurement duration and type of measurement method, it may be necessary to adopt special measures to stabilize fibre temperature and other environmental conditions beyond that stipulated in 4.2.2.

B.3.2 Fibre temperature

In the case of fibre temperature, several effects apply:

a) The natural thermal expansion of fibre will result in optical delay variation, both as a physical length change and group index change. It is therefore necessary to minimize change in the fibre temperature as described above. A typical value of 0,1 °C change over the measurement period would result in 0,1 ps $\times$ nm^{-1} $\times$ km^{-1} uncertainty. Again, depending on measurement time and method, special measures as described in B.3.1 may be required to stabilize the fibre environment.

b) Uncertainty due to the physical length changes resulting from strain and temperature will arise if the fibre length is determined at a different strain level and/or temperature. It is therefore advisable to reduce this uncertainty to a negligible magnitude by measuring the fibre length as soon as possible prior to or following the dispersion measurements, and to use that value in dispersion results generation.

c) Temperature has an additional effect of physically altering $dn/d\lambda$ to first order (a form of thermo-optic effect), amounting to a zero dispersion wavelength shift of ~+0,03 nm/°C. The temperature sensitivity of the slope is typically negligible. A reasonable level of thermal drift during the measurement time would be 1 °C. This applies to all measurement techniques since it is a 'real' physical effect on the fibre under test. It is also advisable that comparison measurements using reference fibres are made at similar temperatures (i.e. 23 °C ± 2 °C) to render negligible the uncertainty arising from the thermo-optic effect.

B.4 Instrumentation uncertainties

Many sources of potential uncertainty in CD test sets can arise within the electronic systems for determining pulse delay or phase shift. These are dealt with in turn. Numerous papers in the literature treat these effects in detail.

B.4.1 Pulse delay determination

In many pulse delay CD test sets the delay is determined by electronically or visually aligning the received optical pulse to a digitally delayed version of the input optical pulse on a waveform processor or oscilloscope. Uncertainties here are as follows:

a) digital delay generator uncertainty – shall be calibrated to known standards;

b) timebase linearity/uncertainty in processor/scope – shall be calibrated to known standards;

c) waveform position determination – this is usually performed by waveform analysis of the pulses. This is subject to some digital quantization effects and to bias caused by optical pulse broadening (particularly in long fibres). Visually aligned systems are subject to operator uncertainty, (for example oscilloscope parallax);

d) time delay jitter in digital delay generator/scope will result in random (type A) uncertainty;

e) receiver noise will result in random (type A) uncertainty, increasing in magnitude for long fibre.

B.4.2 Phase shift determination

In the case of phase shift systems, a high frequency signal is used to obtain a phase shift due to the group delay in the fibre. This results in a large number of complete 2π cycles of total phase shift in the fibre. Thus whilst the phase meter gives an output reflecting only the final incomplete cycle of phase, the actual phase being detected is that induced by the total fibre length. Therefore, a small shift in frequency will produce a proportionately much larger measured phase shift (i.e. phase meter indication).

Phase detection uncertainties arise from the following sources:

a) master oscillator frequency drift: drift may produce phase shift or even cycle slippage due to the large total delay in the fibre (phase shift is proportional to total delay and frequency). Frequency drift away from the nominal value which may be a result of thermal drift shall be minimized during the measurement time;

b) oscillator frequency nominal (central) value: a given percentage uncertainty, for example due to ageing, in the nominal master oscillator value will result in similar percentage uncertainty in the total phase shift and hence the measured dispersion. It is necessary to calibrate the master oscillator to known standards;

c) phase meter non-linearity: the phase meter shall respond in a linear (or mathematically corrected non-linear) fashion to the input signal and reference phase difference, usually an inherent characteristic of the electronic systems;

d) phase noise in master oscillator and phase meter: these both contribute noise which will become the dominant noise source at high received optical powers (short test fibres); a random (type A) uncertainty;

e) optical detector/receiver noise: this becomes significant for long fibres where received optical power is low; a random (type A) uncertainty;

f) any phase shift within the receiver that is sensitive to frequency of operation shall be accounted for.

B.4.3 Differential phase shift determination

For differential phase shift systems, only differences in phase are measured between wavelengths. It is assumed that the phase metering systems, optical receiver, etc. are insensitive to the number of complete 2π phase cycles delay between the received optical signal and the oscillator input.

The differential phase detection uncertainties arise from the following sources:

a) master oscillator frequency drift: drift may produce phase shift or even cycle slippage due to the large total delay in the fibre (phase shift is proportional to total delay and frequency). However, the differential phase shift will not reflect this. Instead, the percentage change in oscillator frequency will yield precisely this percentage differential phase shift. Frequency drift away from the nominal value which may be a result of thermal drift, etc. shall be minimized during the measurement time;

b) oscillator frequency nominal (central) value: a given percentage uncertainty, for example due to ageing, in the nominal master oscillator value will result in similar percentage uncertainty in phase shift and dispersion. It is necessary to calibrate the master oscillator to known standards;

c) phase meter non-linearity: the phase meter shall respond in a linear (or mathematically corrected non-linear) fashion to the input signal and reference phase difference, usually a characteristic of the electronic systems;

d) phase noise in master oscillator/phase meter at the relevant electronic frequency band (for example d.c. or at wavelength modulation frequency): these will contribute noise, i.e. type A uncertainty to the system which will be particularly evident for high received powers, namely shorter fibres; a type A uncertainty;

e) optical detector/receiver noise: this becomes significant for long fibres where received optical power is low; a type A uncertainty.

B.4.4 Interference fringe position determination

In the case of the interference methods, the interference fringe envelope peak position determines the optical delay and is measured directly by scanning the variable optical delay line. Uncertainties are known to stem from the following:

a) delay line mirror position uncertainty: this is essentially uncertainty in the mirror translation stage movement, which shall be calibrated to known standards using a mechanical scaling system during translation stage manufacture, or a calibrated position sensor (for example optical encoder) shall be used;

b) receiver noise will result in random (type A) uncertainty of power during the scan, so that peak position fitting algorithms may be influenced. This effect can be minimized by maintaining a low optical loss in the system, including fibre coupling and during calibration using artefacts.

B.4.5 Electronic scale factor uncertainty

A fundamental part of any CD instrument is the conversion of the delay dispersion signal to an electronic one. All post-processing in the electronic domain will be subject to scale/gain uncertainty, thermal drift, ageing, etc. These effects can be optimized by careful design. However, it is necessary to calibrate the total delay or dispersion scale factor as in 3.3 to correct for these effects.

B.4.6 Time delay and phase shift range uncertainty

It is normal to expect CD test sets to perform on fibres from 1 km to in excess of 100 km.

In the case of pulse delay measurement systems, this simply means the delay generator shall operate up to a sufficiently large delay value, possibly from near zero delay with sufficient step size/resolution and linearity. Uncertainty due to these sources shall be evaluated. In practice, digital delay techniques render all these sources of uncertainty negligible.

In the case of phase shift and differential phase shift systems, at no point should the phase shift system cause uncertainty due to cycle slippage, signal overload, or underload over the entire range of fibre lengths to be encountered. In practice, it may be necessary to select the source modulation frequency or in the case of differential phase shift systems also the value of wavelength step $\Delta\lambda$ to avoid these problems (see C.3.3). Each frequency or $\Delta\lambda$ value selected shall have its associated uncertainties identified and applied at the appropriate times in the course of CD measurements and calibration.

B.4.7 Computational uncertainties

Many CD test sets use microcomputers to process raw data. Sufficient numerical accuracy shall be provided to ensure that computational uncertainties, rounding, etc. are negligible. This is particularly relevant when least squares delay or dispersion data fitting is applied.

B.5 Effect of dispersion modelling

The use of an accurate data fit is paramount and is a potential source of error. For the pulse delay and phase shift methods λ_0, S_0 and estimated dispersion are obtained from the derivative of a functional fit to the group delay measurement data. Many empirical models exist, for example 3-term Sellmeier, 5-term polynomial. For the differential phase shift method, dispersion measurements at the measurement wavelengths may be obtained directly without recourse to these fitting functions. However, in order to obtain λ_0, S_0 and the dispersion at wavelengths of interest other than those used for measurements, the measured dispersion values shall be fitted to the derivative of the corresponding mathematical function that would be used for the pulse delay and phase shift methods.

Several rules shall be applied when using data fits:

a) the data fit/model should be appropriate for the fibre under test (see C.4), for example 3-term Sellmeier suits unshifted fibre;

b) the data fit should be used over a sufficiently narrow wavelength range such that the data fit selected is known to be accurate. This may be determined by standard 'goodness of fit' tests on the data fitting results;

c) the wavelength range selected, and number and position of points have a bearing on the final data fit results. It is therefore paramount to perform the dispersion comparison (check calibration procedure, clause 7) on reference fibre(s) using identical parameters on the CD test sets involved.

In the differential phase shift method, the linear approximation used causes an additional uncertainty, however in practice, at sufficiently small values of $\Delta\lambda$ (see C.3.3), the uncertainty is to all intents and purposes negligible but nevertheless may be mathematically corrected to zero for all fibre types whenever a dispersion data fit is used.

B.6 Fibre related uncertainties

B.6.1 Second order modes

Dispersion measurements are normally confined to wavelengths above the usual cut-off in telecommunication-grade fibres, i.e. 1 270 nm. However, the presence of higher order modes in the fibre will cause dispersion measurement uncertainty and so it is essential for calibration to be guaranteed to operate only in the region above the fibre cut-off. This rule applies to all fibres under test as well as to any fibre optic parts of the CD test set. Alternatively, a suitable fibre mode filter to remove the higher order modes shall be used, if dispersion measurements are made near to or below the expected fibre cut-off wavelengths.

B.6.2 OH^- absorption

The hydroxyl (OH^-) absorption peaks at 1 240 nm and 1 380 nm are normally almost absent in modern high-quality fibre. However, in the presence of a large (for example 4 dB km^{-1}) OH^- peak and in the vicinity of this peak, some dispersion modification may occur. This will affect dispersion calibration accuracy. Care shall be taken to a) avoid the 1 240 nm and 1 380 nm regions and/or b) to provide calibrated measurements only on low OH^- fibres.

B.6.3 Total fibre loss

To establish the effects of the equipment, optical and electrical attenuator uncertainties, it is necessary to characterize dispersion measurements on fibre with a variable loss added in the series. The dispersion variation with added loss up to the CD test set dynamic range limit should be established to determine the possible uncertainty when operating over all loss ranges.

Ultimately, the dynamic range of the test set will be related to the combined effects of the total loss and the total dispersion of the fibre under test. For this reason this series attenuator approach should not be treated as a complete or accurate indicator of the uncertainties caused by fibre loss.

B.6.4 Optical reflections

Reflections at interfaces within the CD test set optics and fibre will result in retrograde delay paths between the source and detector. This will result in pulse distortion or phase offset at the detector, which will bias the dispersion results. It is essential to maintain reflections as low as possible by suitable optical design, connectors of low reflectivity, index matched fibre splicing methods, etc. To maintain accuracy below 0,01 ps $\times$ nm^{-1} $\times$ km^{-1}, it is usually necessary to maintain no more than –30 dB at each reflection point (for example connectors) and to limit the number of reflection points to a bare minimum.

B.7 System dispersion uncertainties

All CD test sets contribute their own chromatic dispersion to a fibre measurement. This may be due to

a) pulse delay or phase mismatch between discrete sources which are not properly compensated; or

b) internal chromatic delay within LED sources.

In either case a "system" measurement shall be taken with a short test fibre (~ 1 m to 5 m long) and this measurement used to compensate actual fibre results for the effects described. The measurement on the short fibre may require that an optical attenuator be used to minimize the effect of level dependent phase shifts.

The "system reference measurement" shall be repeated and the compensation updated at regular intervals (dependent on the measurement accuracy targeted and the internal delay stability of the light sources over time and temperature). The system reference measurement shall be subject to its own measurement uncertainties which will compound with the test measurement uncertainties.

Annex C
(informative)

Chromatic dispersion

C.1 Chromatic dispersion in fibres

Chromatic dispersion is the variation with wavelength of the group delay of light propagating along a single mode optical fibre. It is defined in terms of the delay change per unit change in wavelength and is normalized to fibre length.

The chromatic dispersion coefficient is measured in units of $ps \times nm^{-1} \times km^{-1}$, i.e. picoseconds delay change per nanometre of source spectral width change per kilometre of fibre length.

The measured value and effect of chromatic dispersion is not dependent on the direction of propagation of light in the fibre and is only weakly dependent on fibre curvature and fibre temperature (see B.3.2).

Chromatic dispersion arises from

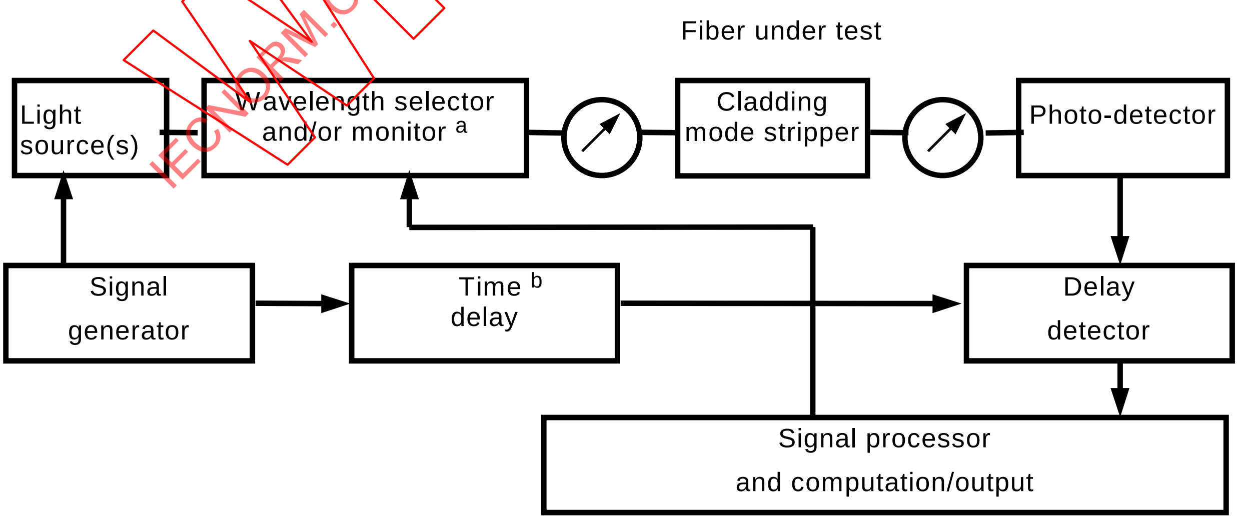
a) material dispersion in the fibre;

b) profile and waveguide dispersion effects associated with the actual waveguide structure and the refractive index profile.

The total dispersion variation with wavelength is of interest particularly in the wavelength region(s) where dispersion falls to zero (i.e. where the fibre information carrying capacity is maximized). This (these) point(s) are usually in the 1 270 nm to 1 700 nm spectral range.

C.2 Description of chromatic dispersion test sets

A chromatic dispersion (CD) test set is an instrument which can measure the chromatic dispersion of single mode optical fibres as a function of wavelength (see figure C.1).



IEC 2773/2000

[a] When needed (this device is sometimes located between the fibre under test and the photodetector).

[b] When needed.

Figure C.1 – Schematic diagram of a CD test set