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Edition 3.0 2014-05

INTERNATIONAL STANDARD

colour inside

Fibre optic interconnecting devices and passive components – Fibre optic passive chromatic dispersion compensators – Part 1: Generic specification

IEC 61978-1:2014-05(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – FIBRE OPTIC PASSIVE CHROMATIC DISPERSION COMPENSATORS –

Part 1: Generic specification

FOREWORD

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International Standard IEC 61978-1 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition, published in 2009, and constitutes a technical revision.

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

a) introduction of new terms and definitions;
b) revision of classifications;
c) addition of Annex E.

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

CDV	Report on voting
86B/3639/CDV	86B/3710/RVC

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 2.

A list of all parts in the IEC 61978 series, published under the general title *Fibre optic interconnecting devices and passive components – Fibre optic passive chromatic dispersion compensators,* can be found on the IEC website.

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

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – FIBRE OPTIC PASSIVE CHROMATIC DISPERSION COMPENSATORS –

Part 1: Generic specification

1 Scope

This part of IEC 61978 applies to fibre optic passive chromatic dispersion compensators, all exhibiting the following features:

- they are optically passive;
- they have an optical input and an optical output for transmitting optical power;
- the ports are optical fibres or optical fibre connectors;
- they are wavelength sensitive;
- they may be polarization sensitive.

This standard establishes uniform requirements for the passive chromatic dispersion compensator.

2 Normative references

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

IEC 60027 (all parts), *Letter symbols to be used in electrical technology*

IEC 60050-731, *International Electrotechnical Vocabulary – Chapter 731: Optical fibre communication*

IEC 60617 (all parts), *Graphical symbols for diagrams*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

IEC 60793-2-50:2012, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60825 (all parts), *Safety of laser products*

IEC 61300 (all parts), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures*

IEC 61300-3-38, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-38: Examinations and measurements – Group delay, chromatic dispersion and phase ripple*

IEC TR 61930, *Fibre optic graphical symbology*

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IEC Guide 102, *Electronic components – Specification structures for quality assessment (Qualification approval and capability approval)*

ISO 129-1, *Technical drawings – Indication of dimensions and tolerances – Part 1: General principles*

ISO 286-1, *Geometrical product specifications (GPS) – ISO coding system for tolerances of linear sizes – Part 1: Bases of tolerances and fits*

ISO 1101, *Geometrical Product Specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run-out*

ISO 8601, *Data elements and interchange formats – Information interchange – Representation of dates and times*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-731, as well as the following definitions apply.

3.1 Basic terms

3.1.1
port
optical fibre or optical fibre connector attached to a passive component for the entry and/or exit of optical power (input and/or output port)

3.2 Component terms

3.2.1
passive chromatic dispersion compensator
PCDC
two-port in-line passive device used to perform chromatic dispersion compensation

Note 1 to entry: PCDCs are commonly used to compensate the chromatic dispersion of an optical path by adding the opposite sign chromatic dispersion.

Note 2 to entry: The typical optical paths comprise single-mode fibre, dispersion shifted fibre and/or non-zero dispersion shifted fibre. PCDCs have either negative or positive chromatic dispersion values depending on the chromatic dispersion sign of the optical path.

3.2.2
dispersion compensating fibre
DCF
speciality fibre to compensate for the chromatic dispersion of an optical path

3.2.3
passive DCF based dispersion compensator
PCDC which constitutes DCF; realised by having chromatic dispersion characteristics of opposite sign to that of the optical path which are controlled the refractive index profile of the fibre

3.2.4
fibre Bragg grating
FBG
fibre type optical device which has modulated refractive index profile in the core

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3.2.5
passive FBG based dispersion compensator
PCDC which constitutes a FBG; PCDC is realised by a chirped FBG which has gradually changing refractive index along the fibre axis

3.2.6
virtually imaged phased array
VIPA
optical device having a glass plate with a highly reflective mirror

Note 1 to entry: A VIPA has the same functions as a grating.

3.2.7
passive VIPA based dispersion compensator
PCDC which consisting of a VIPA, focusing lens and 3-dimensional mirror

Note 1 to entry: PCDC produces both positive and negative chromatic dispersion by the movement of the 3-dimensional mirror to compensate for the chromatic dispersion of an optical path.

3.2.8
etalon
optical cavity which consists of a pair of parallel reflective mirrors

3.2.9
Gires-Tournois etalon
GT etalon
etalon having a highly reflective mirror and a half mirror

Note 1 to entry: The GT etalon is sometimes called a GT interferometer.

3.2.10
passive GT etalon based dispersion compensator
PCDC which comprises a GT etalon

3.3 Performance parameter

3.3.1
chromatic dispersion compensation
process by which a specific amount of chromatic dispersion is removed in order to mitigate the system impairment caused by unwanted dispersion

3.3.2
group delay
time by which a pulse is delayed by an optical device

Note 1 to entry: The group delay generally varies with the operating wavelength.

3.3.3
chromatic dispersion
derivative of group delay with respect to wavelength or frequency

Note 1 to entry: A typical unit is ps/nm or ps/GHz. The chromatic dispersion generally varies with the operating wavelength.

Note 2 to entry: The units of ps/GHz are not commonly used; however, it is suitable for the evaluation of transmission system influence.

3.3.4
dispersion slope
derivative of chromatic dispersion with respect to wavelength or frequency

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Note 1 to entry: A typical unit is ps/nm2 or ps/GHz2.The unit of ps/GHz2 is not commonly used; however, it is suitable for the evaluation of transmission system influence.

Note 2 to entry: The dispersion slope generally varies with the operating wavelength

3.3.5
operating wavelength
nominal wavelength λ at which a passive device operates with the specified performance

Note 1 to entry: Operating wavelength includes the wavelength to be nominally transmitted, attenuated and isolated.

3.3.6
operating wavelength range
specified range of wavelengths including all operating wavelengths

Note 1 to entry: Operating wavelength range shall include all passbands when two or more the passbands are exist.

3.3.7
figure of merit
FoM
ratio of the dispersion to the insertion loss of a PCDC at a particular operating wavelength

3.3.8
passband
wavelength range within which a passive optical component is required to operate with optical attenuation less than or equal to a specified optical attenuation value

Note 1 to entry: There may be one or more passbands for a PCDC.

3.3.9
passband ripple
maximum peak-to-peak variation of insertion loss in the passband

Note 1 to entry: The passband ripple of a PCDC is defined as the maximum passband ripple for all passbands.

3.3.10
group delay ripple
GDR
maximum peak-to-peak variation of the group delay approximated by a desired function of wavelength (or frequency), typically a linear fit, within a channel wavelength (or frequency) range

3.3.11
phase ripple
maximum peak-to-peak variation in measured phase spectrum when compared to a quadratic fit within a channel wavelength (or frequency) range

Note 1 to entry: Phase ripple (unit: radian) is calculated as the product of a peak-to-peak group delay ripple (unit: s) and a period of group delay ripple (unit: Hz). Refer to IEC 61300-3-38.

3.3.12
insertion loss
reduction in optical power between an input and output port of a passive component expressed in decibels. It is defined as follows:

$$a = -10\log\frac{P_a}{P_0}$$

where

P_0 is the optical power launched into the input port;

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P_a is the optical power received from the output port.

3.3.13
return loss
fraction of input power that is returned from a port of a passive component expressed in decibels. It is defined as follows:

$$RL = -10\log\frac{P_r}{P_0}$$

where

P_0 is the optical power launched into a port;

P_r is the optical power received back from the same port.

3.3.14
reflectance
ratio of the optical power returning back from a port to input power expressed in %

3.3.15
polarization dependent loss
PDL
maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all the SOPs

3.3.16
wavelength dependent loss
WDL
maximum variation of the insertion loss over operating wavelength range

3.3.17
polarization mode dispersion
PMD
average delay of the travelling time between the two principal states of polarization (PSP), when an optical signal passes through an passive optical component

4 Requirements

4.1 General

The requirements for PCDCs covered by this clause are intended to aid in classifying this device in a relevant specification. Additional or more severe requirements may be imposed by the relevant blank detail specification and by the detail specification.

4.2 Classification

4.2.1 General

PCDCs shall be classified as follows:

– type;
– style;
– variant;
– normative reference extensions.

4.2.2 Type

PCDCs can be categorized into different types, as follows:

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– by operating technologies (DCF, FBG, VIPA, GT etalon and so on);
– by dispersion compensating performance (for example, wavelength dispersion compensating, dispersion slope compensating);
– by operating wavelength range (for example, O-band, C-band, L-band);
– by categories of transmission fibre which PCDCs are applied (for example, IEC 60793-2-50:2012, B1, B2, B4).

The application of PCDCs and the suitable operating mechanisms are summarized in Table 1.

Table 1 – Types of passive chromatic dispersion compensators

Applications	Channel number	Passbands	Technologies
TDM (Time division multiplexing)	Single channel	Narrow	Dispersion compensating fibre (DCF) Fibre Bragg grating (FBG) GT etalon
WDM (Wavelength division multiplexing)	Single channel	Narrow	FBG
	Multi-channel [a]	Narrow	FBG GT etalon Virtually imaged phased array (VIPA)
		Wide	DCF
[a] Multi-channel PCDCs can be used for a single channel use.			

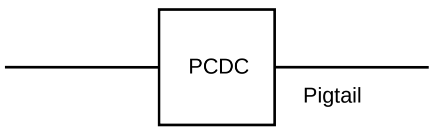
4.2.3 Style

4.2.3.1 General

PCDC may be classified into styles based on the fibre type(s), the connector type(s), cable type(s), housing shape, temperature control and the configuration. Style is not intended to define material or design. The configurations of PCDC ports are classified as follows.

4.2.3.2 Configuration A

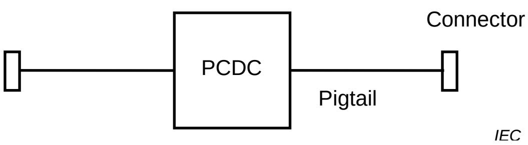
A device containing integral fibre optic pigtails, without connectors.



IEC 1687/2000

4.2.3.3 Configuration B

A device containing integral fibre optic pigtails, with a connector on each pigtail.



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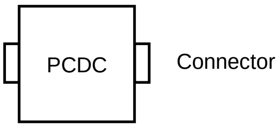
4.2.3.4 Configuration C

A device containing fibre optic connectors as an integral part of the device housing.



IEC 1689/2000

4.2.3.5 Configuration D

A device containing some combination of the interfacing features of the preceding configurations.

4.2.4 Variant

The PCDC variant identifies those common features which encompass structurally similar components.

Examples of features which define a variant include, but are not limited to, the following:

– fibre type;

– connector type.

4.2.5 Normative reference extensions

Normative reference extensions are used to identify integrated independent standards, specifications or other reference documents into blank detail specifications.

Unless a specified exception is noted, additional requirements imposed by an extension are mandatory. Usage is primarily intended to merge associated components to form hybrid devices, or integrated functional application requirements that are dependent on technical expertise other than fibre optics.

Published reference documents produced by ITU consistent with the scope statements of the relevant IEC specification series may be used as an extension. Published documents produced by other regional standardization bodies such as TIA, ETSI, JIS, etc., may be referenced in a bibliography attached to the generic specification.

Some optical fibre splice configurations require special qualification provisions that shall not be imposed universally. This accommodates individual component design configurations, specialized field tooling, or specific application processes. In this case, requirements are necessary to assure repeatable performance or adequate safety, and provide additional guidance for complete product specification. These extensions are mandatory whenever used to prepare, assemble or install an optical fibre splice either for field application usage or preparation of qualification test specimens. The relevant specification shall clarify all stipulations. However, design- and style-dependent extensions shall not be imposed universally.

In the event of conflicting requirements, precedence shall be given, in descending order, as follows: generic over mandatory extension, over blank detail, over detail, over application specific extension.

Examples of requirements for normative extensions are as follows:

a) some commercial or residential building applications may require direct reference to specific safety codes and regulations or incorporate other specific material flammability or toxicity requirements for specialized locations;

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b) specialized field tooling may require an extension to implement specific ocular safety, electrical shock or burn hazard avoidance requirements, or require isolation procedures to prevent potential ignition of combustible gases.

4.3 Documentation

4.3.1 Symbols

Graphical and letter symbols shall, whenever possible, be taken from the IEC 60027 series, IEC 60617 and IEC/TR 61930.

4.3.2 Specification system

4.3.2.1 General

This specification is part of a three-level IEC specification system. Subsidiary specifications shall consist of blank detail specifications and detail specifications. This system is shown in Table 2. There are no sectional specifications for passive dispersion compensators.

Table 2 – Three-level IEC specification structure

Specification level	Examples of information to be included	Applicable to
Basic	Inspection rules Optical measuring methods Environmental test methods Sampling plans Identification rule Marking standards Dimensional standards Terminology standards Symbol standards Preferred number series SI units	Two or more component families or subfamilies
Generic	Specific terminology Specific symbols Specific units Preferred values Marking Selection of tests	Component family
Blank detail	Quality conformance test schedule Inspection requirements Information common to a number of types	Groups of types having a common test schedule
Detail	Individual values Specific information Completed quality conformance test schedules	Individual type

4.3.2.2 Blank detail specifications

The blank detail specification lists all of the parameters and features applicable to a PCDC, including the type, operating characteristics, housing configurations, test methods, and performance requirements. The blank detail specification is applicable to any PCDC design and quality assessment requirement. The blank detail specification contains the preferred format for stating the required information in the detail specification.

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Blank detail specifications are not, by themselves, a specification level. They are associated with the generic specification.

Each blank detail specification shall be limited to one environmental category.

Each blank detail specification shall contain

– the minimum mandatory test schedules and performance requirements,
– one or more assessment levels,
– the preferred format for stating the required information in the detail specification,
– in case of hybrid components, including connectors, addition of appropriate entry fields to show the reference normative document, document title and issue date.

4.3.2.3 Detail specifications

A specific PCDC is described by a corresponding detail specification, which is prepared by filling in the blanks of the blank detail specification. Within the constraints imposed by this generic specification, the blank detail specification may be filled in by any national committee of the IEC, thereby defining a particular PCDC as an IEC standard.

Detail specifications shall specify the following, as applicable:

– type (see 4.2.2);
– style (see 4.2.3);
– variant(s) (see 4.2.4);
– part identification number for each variant (see 4.7.1);
– drawings, dimensions required (see 4.3.3);
– performance requirements (see 4.6).

4.3.3 Drawings

4.3.3.1 General

The drawings and dimensions given in detail specifications shall not restrict themselves to details of construction, nor shall they be used as manufacturing drawings.

4.3.3.2 Projection system

Either first angle or third angle projection shall be used for the drawings in documents covered by this specification. All drawings within a document shall use the same projection system and the drawings shall state which system is used.

4.3.3.3 Dimensional system

All dimensions shall be given in accordance with ISO 129-1, ISO 286-1 and ISO 1101.

The metric system shall be used in all specifications.

Dimensions shall not contain more than five significant digits.

When units are converted, a note shall be added in each relevant specification and the conversion between systems of units shall use a factor of 25,4 mm to 1 inch.

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4.3.4 Tests and measurements

4.3.4.1 Test and measurement procedures

The test and measurement procedures for optical, mechanical, climatic and environmental characteristics of passive dispersion compensators to be used shall be defined and selected preferentially from the IEC 61300 series.

The size measurement method to be used shall be specified in the detail specification for dimensions, which are specified within a total tolerance of 0,01 mm or less.

4.3.4.2 Reference components

Reference components for measurement purposes, if required, shall be specified in the relevant specification.

4.3.4.3 Gauges

Gauges, if required, shall be specified in the relevant specification.

4.3.5 Test data sheets

Test data sheets shall be prepared for each test conducted as required by a relevant specification. The data sheets shall be included in the qualification report and in the periodic inspection report.

Data sheets shall contain the following information as a minimum:

- title of test and date;
- specimen description including the type of fibre, connector or other coupling device. The description shall also include the variant identification number (see 4.7.2);
- test equipment used and date of latest calibration;
- all applicable test details;
- all measurement values and observations;
- sufficiently detailed documentation to provide traceable information for failure analysis.

4.3.6 Instructions for use

Instructions for use, when required, shall be given by the manufacturer and shall include

- assembly and connection instructions;
- cleaning method;
- safety aspects;
- additional information as necessary.

4.4 Standardization system

4.4.1 Performance standards

Performance standards contain a series of tests and measurements (which may or may not be grouped into a specified schedule depending on the requirements of that standard) with clearly defined conditions, severities, and “pass/fail” criteria. The tests are intended to be run on a “once-off” basis to prove any product’s ability to satisfy the “performance standards” requirement. Each performance standard has a different set of tests, and/or severities (and/or groupings) and represents the requirements of a market sector, user group or system location.

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A product that has been shown to meet all the requirements of a performance standard can be declared as complying with a performance standard but should then be controlled by a quality assurance/quality conformance programme.

It is possible to define a key point of the test and measurements standards when these are applied (particularly with regard to insertion loss and return loss) in conjunction with the interface standards of inter product compatibility. This ensures conformance of each individual product to this standard,

4.4.2 Reliability standards

Reliability standards are intended to ensure that a component can meet performance specifications under stated conditions for a stated time period.

For each type of component, the following shall be identified (and appear in the standard):

- failure modes (ways in which a component can fail);
- failure mechanisms (causes of failure, which may be common to several components);
- failure effects (observable, general, mechanical or optical effects of failure).

These are all related to environmental and material aspects.

Initially, just after component manufacture, there is an “infant mortality phase” during which many components would fail if they were deployed in the field. To avoid early field failure, all components may be subjected to a screening process in the factory involving environmental stresses that may be mechanical, thermal or humidity-related. This is to induce known failure mechanisms in a controlled environmental situation to occur earlier than would normally be seen in the unscreened population. For those components that survive (and are then sold), there is a reduced failure rate, since these mechanisms have been eliminated.

Screening is an optional part of the manufacturing process, rather than a test method. It will not affect the “useful life” of a component defined as the period during which it performs according to specifications. Eventually other failure mechanisms appear, and the failure rate increases beyond the defined threshold. At this point the useful life ends and the “wear-out region” begins, and the component shall be replaced.

At the beginning of useful life, performance testing on a sampled population of components may be applied by the supplier, by the manufacturer or by a third party. This is to ensure that the component meets performance specifications over the range of intended environments at this initial time. Reliability testing, on the other hand, is applied to ensure that the component meets performance specifications for at least a specified minimum useful lifetime or specified maximum failure rate. These tests are usually carried out by utilizing the performance testing, but increasing duration and severity to accelerate the failure mechanisms.

A reliability theory relates component reliability testing to component parameters and to lifetime or failure rate under testing. The theory then extrapolates these to lifetime or failure rate under less stressful service conditions. The reliability specifications include values of the component parameters needed to ensure the specified minimum lifetime or maximum failure rate in service.

4.4.3 Interlinking

Standards currently under preparation are given in Figure 1. A large number of the test and measurements standards already exist, and quality assurance qualification approval already exists and has done so for many years. As previously mentioned, alternative methods of quality assurance/quality conformance are being developed under the headings of capability approval and technology approval which are covered in IEC Guide 102.

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With regard to interface, performance and reliability standards, once all three of these standards are in place, the matrix given in Table 3 demonstrates some of the other options available for product standardization.

Product A is fully IEC standardized, having a standard interface and meeting defined performance and reliability standards.

Product B is a product with a proprietary interface but which meets a defined IEC performance and reliability standard.

Product C is a product that complies with an IEC standard interface but does not meet the requirements of either an IEC performance or reliability standard.

Product D is a product that complies with both an IEC standard interface and a performance standard but does not meet any reliability requirements.

Obviously, the matrix is more complex than shown since there will be a number of interface, performance and reliability standards which may cross-refer. In addition, the products may all be subject to a quality assurance programme that could be under IEC qualification approval, capability approval, technology approval (as Table 4 attempts to demonstrate), or even a national or company quality assurance system.

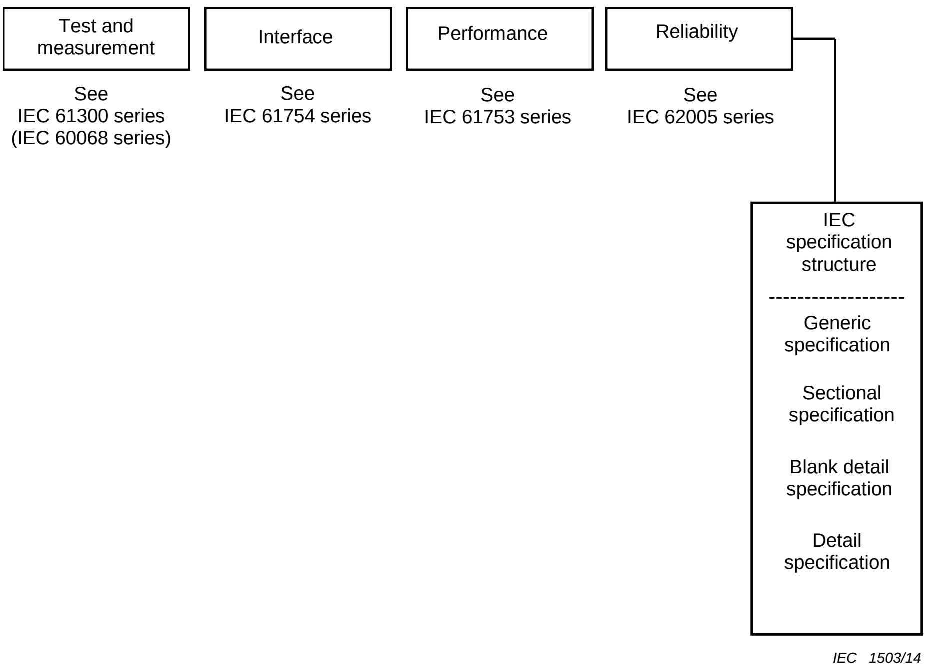

Figure 1 – Standards currently under preparation

Table 3 – Standards interlink matrix

Product group	Interface standard	Performance standard	Reliability standard
Product A	Yes	Yes	Yes
Product B	No	Yes	Yes
Product C	Yes	No	No
Product D	Yes	Yes	No

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Table 4 – Quality assurance options

Product group	Company A			Company B			Company C		
	QA	CA	TA	QA	CA	TA	QA	CA	TA
Product A	X			X					X
Product B	X				X				X
Product C	X				X				X
Product D	X					X			X

4.5 Design and construction

4.5.1 Materials

4.5.1.1 General

The devices shall be manufactured with materials which meet the requirements of the detail specification. When non-flammable materials are required, the requirement shall be specified in the relevant specification, and the test of IEC 60695-11-5 shall be cited as reference.

4.5.1.2 Corrosion resistance

All materials used in the construction of compensator sets shall be corrosion resistant or suitably finished to meet the requirements of the relevant specification.

4.5.1.3 Non-flammable materials

When non-flammable materials are required, the requirement shall be specified in the specification and IEC 60695-11-5 shall be referenced.

4.5.2 Workmanship

Components and associated hardware shall be manufactured to a uniform quality and shall be free of sharp edges, burrs or other defects that will affect life, serviceability or appearance. Particular attention shall be given to neatness and thoroughness of marking, plating, soldering, bonding, etc.

4.6 Performance

PCDCs shall meet the performance requirements specified in the relevant specification.

4.7 Identification and marking

4.7.1 General

Components, associated hardware and packages shall be permanently and legibly identified and marked when this is required by the relevant specification.

4.7.2 Variant identification number

Each variant in a detail specification shall be assigned a variant identification number. The number shall consist of the number assigned to the detail specification followed by a four-digit dash number and a letter designating the assessment level. The first digit of the dash number shall be sequentially assigned to each component type covered by the detail specification. The last three digits shall be sequentially assigned to each variant of the component.

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EXAMPLE: **QC940000/US0001 -1** **001** **A**

Detail specification number

Component type

Variant number

Assessment level

4.7.3 Component marking

Component marking, if required, shall be specified in the detail specification. The preferred order of marking is as follows:

a) port identification;

b) manufacturer's part number (including serial number, if applicable);

c) manufacturer's identification mark or logo;

d) manufacturing date;

e) variant identification number;

f) any additional marking required by the detail specification.

If space does not allow for all the required marking on the component, each unit shall be individually packaged with a data sheet containing all of the required information which is not marked.

4.7.4 Package marking

Several PCDCs may be packed together for shipment.

Package marking, if required, shall be specified in the detail specification. The preferred order of marking is as follows:

a) manufacturer's identification mark or logo;

b) manufacturer's part number;

c) manufacturing date code (year/week, see ISO 8601);

d) variant identification number(s) (see 4.7.1);

e) the type designation (see 4.2.2);

f) the assessment level;

g) any additional marking required by the detail specification.

When applicable, individual unit packages (within the sealed package) shall be marked with the reference number of the certified record of released lots, the manufacturer's factory identity code and the component identification.

4.8 Packaging

Packages shall include instructions for use when required by the specification (see 4.3.6).

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4.9 Storage conditions

Where short-term degradable materials, such as adhesives, are supplied with the package of connector parts, the manufacturer shall mark these with the expiry date (year and week numbers, see ISO 8601) together with any requirements or precautions concerning safety hazards or environmental conditions for storage.

4.10 Safety

PCDCs, when used on an optical fibre transmission system and/or equipment, may emit potentially hazardous radiation from an uncapped or unterminated output port or fibre end.

The PCDC manufacturers shall make available sufficient information to alert system designers and users about the potential hazard and shall indicate the required precautions and working practices.

In addition, each detail specification shall include the following:

WARNING

Care should be taken when handling small diameter fibre to prevent puncturing the skin, especially in the eye area. Direct viewing of the end of an optical fibre or an optical fibre connector when it is propagating energy is not recommended, unless prior assurance has been obtained as to the safety energy output level.

Reference shall be made to the IEC 60825 series, the relevant standard on safety.

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Annex A
(informative)

Example of dispersion compensating fibre (DCF) technologies

Chromatic dispersion in optical fibre is expressed as the sum of material dispersion caused by wavelength dependence of the refractive index of the glass materials and waveguide dispersion caused by index profile of optical fibre (Figure A.1). Silica glass optical fibre material dispersion does not vary greatly. Waveguide dispersion can be controlled by changing the index profile of the optical fibre. DCFs are designed to control waveguide dispersion to achieve the desired dispersion characteristics.

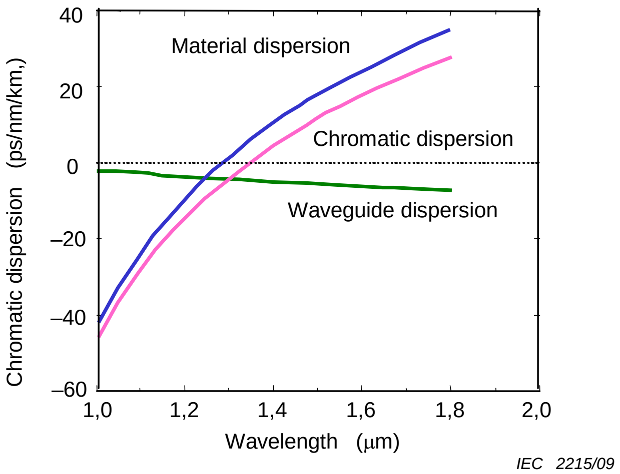

Figure A.1 – Chromatic dispersion in a standard single-mode optical fibre (SMF)

Figure A.2 shows the contour for different dispersions at a wavelength of 1,55 μm as a function of the relative refractive index difference, Δ, from a pure silica cladding index value level and core diameter in a step-index profile with the germanium-doped silica core. From this figure, a DCF with a large negative chromatic dispersion can be obtained by increasing *Δ* and decreasing the diameter of the core.

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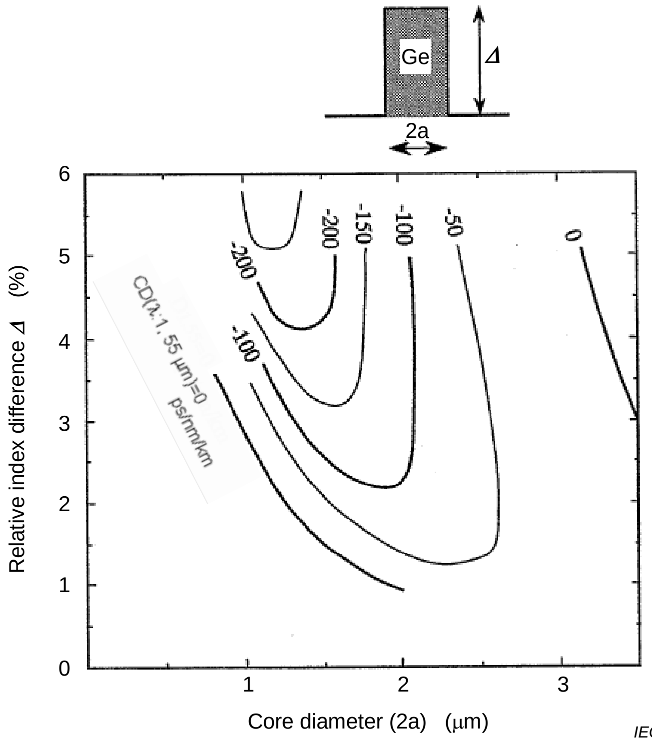
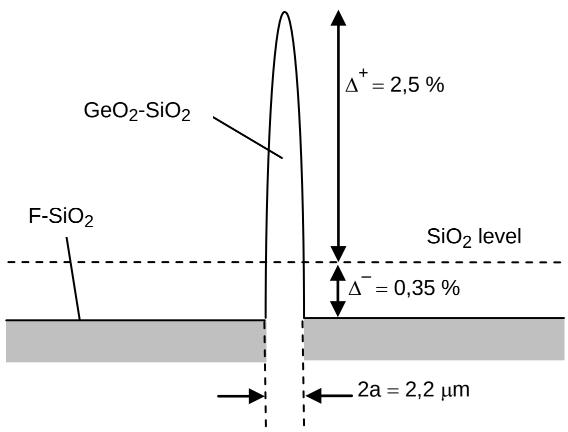


IEC 1504/14

Figure A.2 – Calculated contour for different dispersion at the wavelength of 1,55 µm (CD(λ:1,55 µm)) for a step index core fibre

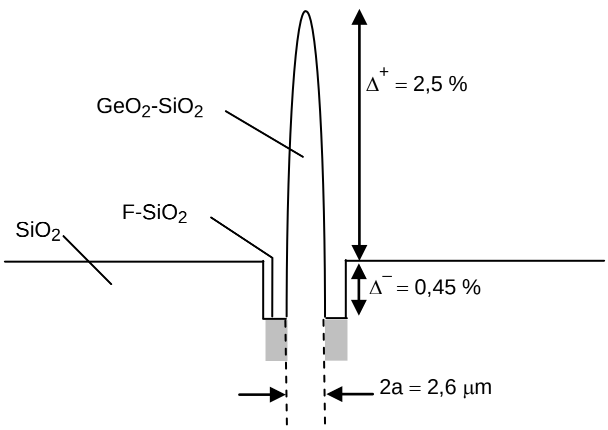
Figure A.3 shows two examples of refractive index profiles of DCFs. The relative refractive index difference between the core and the cladding is larger and the core diameter is smaller than those of standard single-mode fibres. These design differences result in larger waveguide dispersion. As for the double-cladding type DCF, much larger waveguide dispersion can be obtained than in the case of the matched cladding type DCF.

Double cladding type DCF can give negative dispersion slope in C-band and/or L-band. Because of this, the positive dispersion slope of SMFs (IEC 60793-2-50:2012, B1 fibres) can be compensated by using this type of DCF. Dispersion slope compensation is important to achieve a uniform dispersion value over the wavelength range of a WDM transmission system.



IEC 2217/09

Figure A.3a – Matched cladding type



IEC 2218/09

Figure A.3b – Double cladding type

Figure A.3 – Examples of refractive index profile used in DCF

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Annex B
(informative)

Example of fibre Bragg grating (FBG) technologies

Fibre Bragg grating (FBG) is a fibre type optical device that has a modulated refractive index profile in the core along the longitudinal axis. A FBG functions as a reflective filter where reflection wavelength is defined in Equation (B.1). Generally, refractive index modulation is generated by using UV radiation induced refractive index change.

$$\lambda_B = 2 \times \Lambda \times n_{eff} \qquad \text{(B.1)}$$

where

λ_B is the reflection wavelength (Bragg wavelength);

Λ is the refractive index modulation period;

n_{eff} is the effective refractive index.

The basic principle of dispersion compensation using a chirped FBG is shown in Figure B.1. In chirped FBG, grating period and/or effective refractive index are gradually changed and reflection wavelength changes along the fibre axis. After travelling through the transport fibre, the signal experiences a positive chromatic dispersion so that its longer part arrives before its shorter part. The chirped FBG provides more group delay for the longer part of the signal thus compensating for the effect of the chromatic dispersion. The slope of the group delay spectrum corresponds to the dispersion the FBG provides. To conveniently access the output signal, an optical circulator is used.

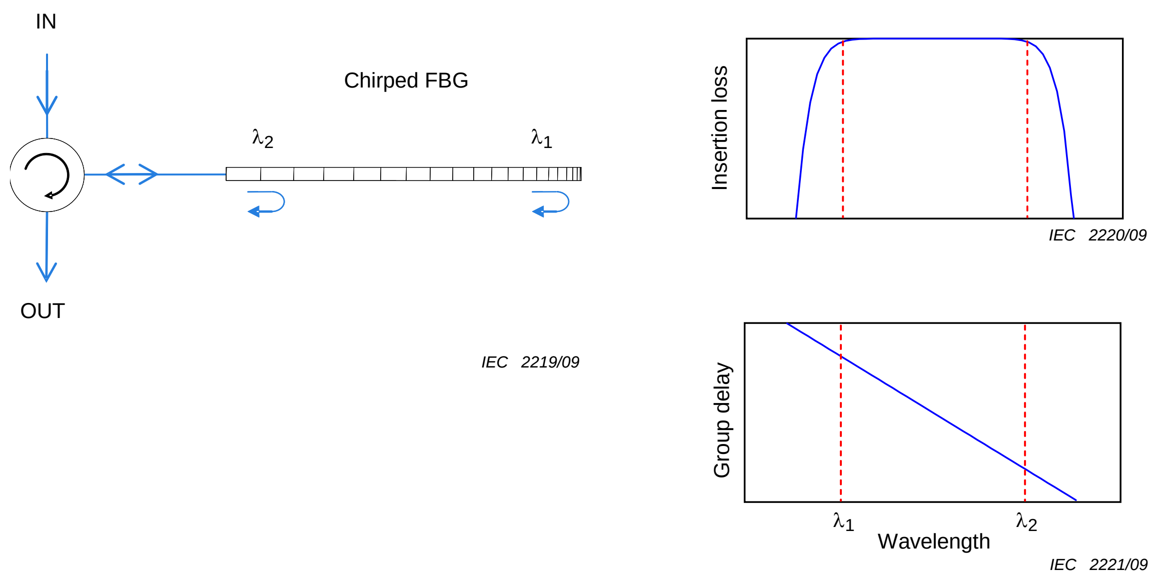

Figure B.1 – Illustration of the use of a chirped fibre Bragg grating for chromatic dispersion compensation

The FBG can be made multi-channel, allowing for a simultaneous compensation of the chromatic dispersion accumulated in all channels of a WDM system. The multi-channel character of the FBG is typically obtained through a sampling approach, that is, a spatial modulation of its physical properties. As an example, Figure B.2 shows an expanded view over 10 nm of the spectral characteristics of a multi-channels FBG tailored for compensating the chromatic dispersion accumulated over 100 km of single-mode fibre specified in IEC 60793-2-50:2012, category B1.

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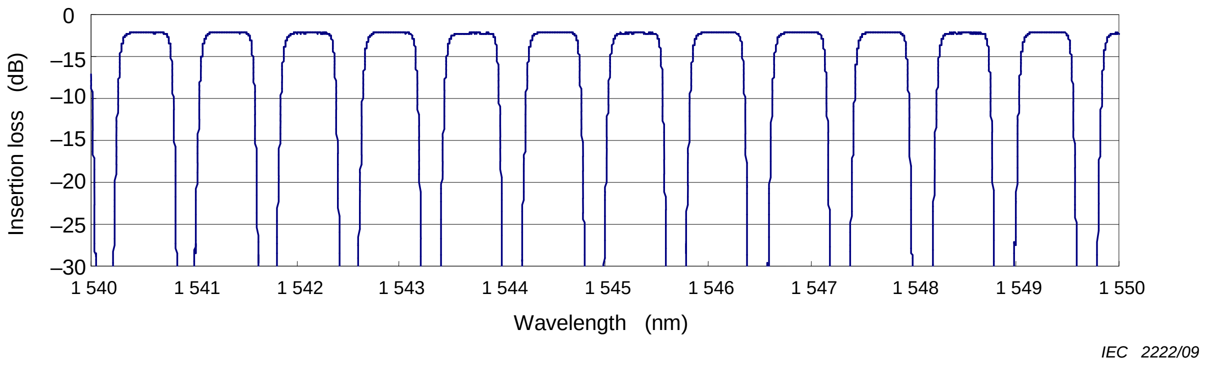

Figure B.2a – Insertion loss including the optical circulator

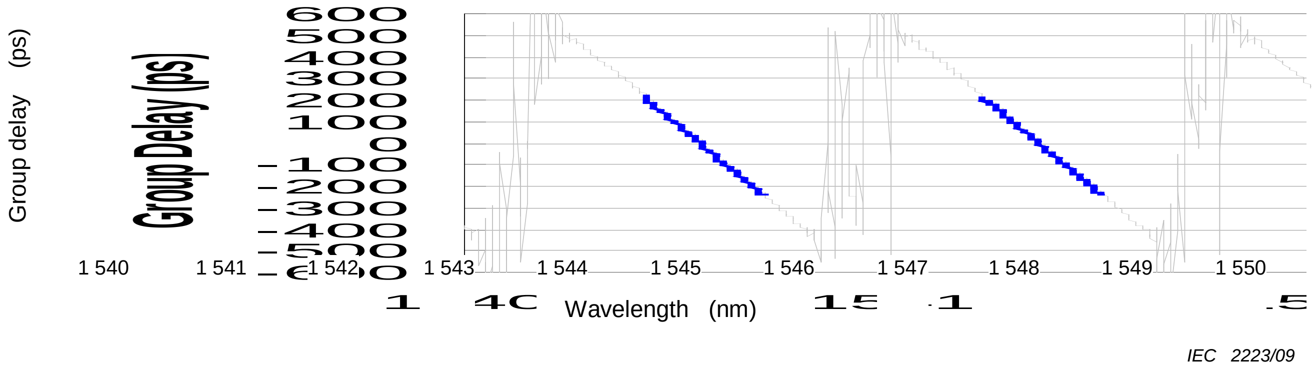

Figure B.2b – Group delay spectrum

Figure B.2 – Expanded view over 10 nm of the insertion loss spectrum of a multi-channel FBG

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Annex C
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Example of virtually imaged phased array (VIPA) technologies

Figure C.1 shows the structure of a virtually imaged phased array (VIPA). The input light from a single-mode fibre is line-focused into a glass plate. The glass plate is coated on both surfaces and collimated light is emitted from the reverse side of the glass plate after multiple reflections between the coated surfaces. The light from the glass plate is then focused onto a curved mirror. The reflected light travels back to the glass plate and is finally coupled back into the fibre.

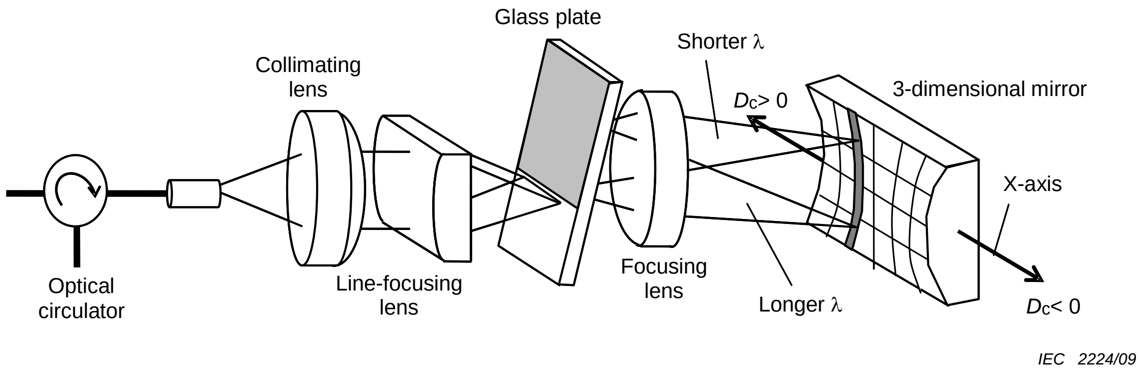

Figure C.1 – Structure of virtually imaged phased array (VIPA)

Figure C.2 shows the detailed light path. Each time that the light is reflected at the right-angle surface of the glass plate, a small percentage of the power passes through the partially reflecting coating. This creates multiple beams that diverge from the corresponding beam waist in the virtual image. The interference of these diverging beams generates collimated light. This collimated light travels at an angle from the optical axis which varies with the wavelength. Chromatic dispersion, i.e. the wavelength dependence of distance travelled, is determined by the wavelength dependence of the pointing angle of collimated light from the glass plate and the surface profile of the reflection mirror. The convex portion of the mirror produces negative chromatic dispersion and the concave portion of the mirror produces positive chromatic dispersion. Figure C.1 shows that the collimated light (gray line area on the surface of the 3-D mirror) reflects along the concave mirror surface which produces positive chromatic dispersion. By shifting the position of the 3-D mirror along the X-axis, the collimated light can also reflect off the convex mirror surface, which produces negative chromatic dispersion. If the surface profile of the 3-D mirror is designed such that the curvature of the mirror's surface is gradually changed along the X-axis, the chromatic dispersion can be readily changed by shifting the 3-D mirror's position along the X-axis.

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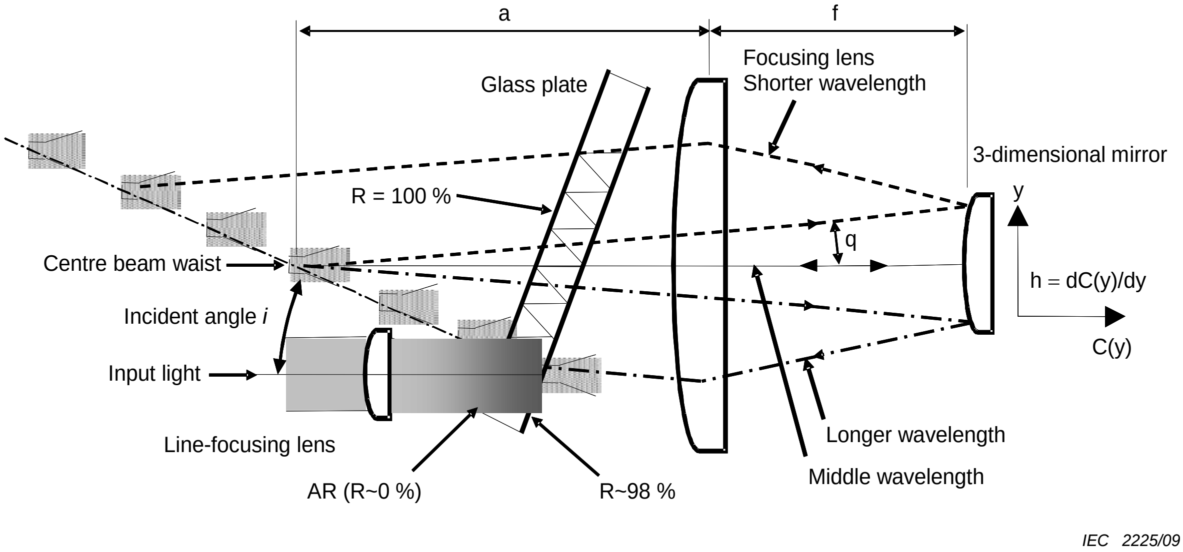

Figure C.2 – Detailed light path and mechanism of generating chromatic dispersion

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Annex D
(informative)

Example of GT etalon technologies

An etalon is an optical cavity which consists of a pair of parallel reflective mirrors. Multiple reflection interference between two filters gives cyclic spectrum and dispersion characteristics. The period of cyclic spectrum is called free spectral range (FSR). Operating wavelength and FSR can be adjusted by changing optical distance between the two mirrors.

There are mainly two types of etalons: Fabry-Perot (FP) etalon and Gires-Tournois (GT) etalon. The GT etalon (Figure D.1) is suitable for dispersion compensation. The GT etalon is an optical cavity that consists of mirrors having different reflectivity. Generally, the front mirror has low reflectivity and rear mirror has high reflectivity. In this case, the reflection power spectrum is relatively smooth, although the phase of the reflected light depends strongly on the wavelength. Using a multiple cavity etalon with optimized design, higher order dispersion can be compensated. Sometimes a GT etalon is called a GT interferometer.

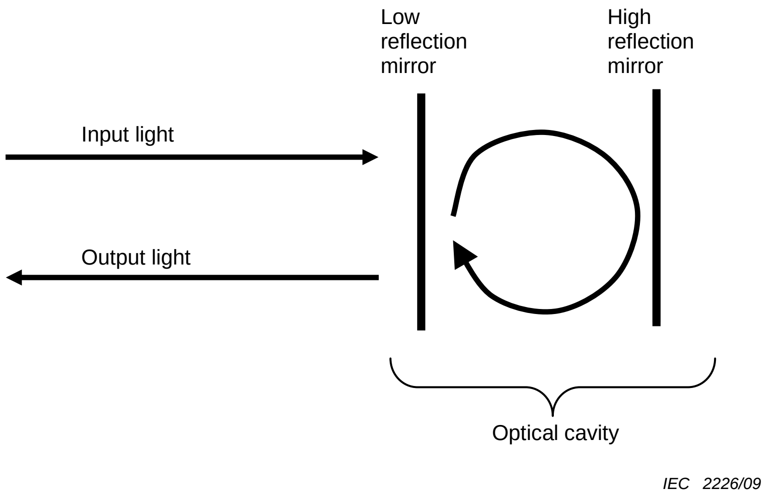

Figure D.1 – Gires-Tournois etalon

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Annex E
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Technology dependent characteristics of PCDCs

As described in Annexes A to D, mainly four technologies are used for PCDCs. Table E.1 shows the summary of technology-dependent characteristics of PCDCs.

Table E.1 – Summary of technology dependent characteristics of PCDCs

	DCF	**FBG**	**VIPA**	**Etalon**
Passband	Wide	Relatively narrow	Narrow/periodical	Narrow/periodical or wide
GDR period	No GDR	Typically approx. 10 pm	Typically approx. 2 pm	Typically approx. 30 pm
Loss dependency on dispersion	Yes	No	No	No
Non linearity	Yes	No	No	No
Tuneable function	No	Yes	Yes	Yes

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