BS EN 62074-1:2014

BSI Standards Publication

Fibre optic interconnecting devices and passive components — Fibre optic WDM devices

Part 1: Generic specification

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National foreword

This British Standard is the UK implementation of EN 62074-1:2014. It is identical to IEC 62074-1:2014. It supersedes BS EN 62074-1:2009 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/2, Fibre optic interconnecting devices and passive components.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Fibre optic interconnecting devices and passive components - Fibre optic WDM devices - Part 1: Generic specification
(IEC 62074-1:2014)

Dispositifs d'interconnexion et dispositifs passifs à fibres optiques - Dispositifs WDM à fibres optiques - Partie 1: Spécification générique
(CEI 62074-1:2014)

Lichtwellenleiter - Verbindungselemente und passive Bauteile - Lichtwellenleiter-WDM-Bauteile - Teil 1: Fachgrundspezifikation
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Foreword

The text of document 86B/3700/FDIS, future edition 2 of IEC 62074-1, prepared by SC 86B "Fibre optic interconnecting devices and passive components" of IEC/TC 86 "Fibre optics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62074-1:2014.

The following dates are fixed:

– latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2014-12-13
– latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-03-13

This document supersedes EN 62074-1:2009.

EN 62074-1:2014 includes the following significant technical changes with respect to EN 62074-1:2009:

- substantial updating to the definitions;
- the addition of informative Annexes C to G, giving examples of technical information concerning WDM devices.

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The text of the International Standard IEC 62074-1:2014 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60027	series	Letter symbols to be used in electrical technology	EN 60027	series
IEC 60050-731	-	International Electrotechnical Vocabulary (IEV) Chapter 731: Optical fibre communication	-	-
IEC 60695-11-5	-	Fire hazard testing Part 11-5: Test flames - Needle-flame test method - Apparatus, confirmatory test arrangement and guidance	EN 60695-11-5	-
IEC 60825-1	-	Safety of laser products Part 1: Equipment classification and requirements	EN 60825-1	-
IEC/TR 61931	-	Fibre optic - Terminology	-	-
ISO 129-1	-	Technical drawings - Indication of dimensions and tolerances Part 1: General principles	-	-
ISO 286-1	-	Geometrical product specifications (GPS) - ISO code system for tolerances on linear sizes Part 1: Basis of tolerances, deviations and fits	EN ISO 286-1	-
ISO 1101	-	Geometrical product specifications (GPS) - Geometrical tolerancing - Tolerances of form, orientation, location and run-out	EN ISO 1101	-
ISO 8601	-	Data elements and interchange formats - Information interchange - Representation of dates and times	-	-

CONTENTS

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – FIBRE OPTIC WDM DEVICES –

Part 1: Generic specification

1 Scope

This part of IEC 62074 applies to fibre optic wavelength division multiplexing (WDM) devices. These have all of the following general features:

- they are passive, in that they contain no optoelectronic or other transducing elements; however they may use temperature control only to stabilize the device characteristics; they exclude any optical switching functions;
- they have three or more ports for the entry and/or exit of optical power, and share optical power among these ports in a predetermined fashion depending on the wavelength;
- the ports are optical fibres, or optical fibre connectors.

This standard establishes uniform requirements for the following:

- optical, mechanical and environmental properties.

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

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61931, *Fibre optics – Terminology*

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, apply.

3.1 Basic term definitions

3.1.1
port
optical fibre or optical fibre connector attached to a passive device for the entry and/or exit of the optical power

3.1.2
transfer matrix
optical properties of a fibre optic wavelength-selective branching device can be defined in terms of an n x n matrix of coefficients, where n is the number of ports, and the coefficients represent the fractional optical power transferred between designated ports

Note 1 to entry: A detailed explanation of the transfer matrix is shown in Annex A. The ports are numbered sequentially, so that the transfer matrix is developed to show all ports and all possible combinations. The port numbering is arbitrary.

Note 2 to entry: Figure 1 below shows an example of a six-port device, with two input ports and four output ports. This WDM device can operate as four input ports and two output ports for their reciprocity characteristics. Also, it shall be noted that a combination of input and output port number can be selected, for example, 1 input port and 5 output ports, 3 input ports and 3 output ports and so on, especially for bi-directional transmission system application. Refer to Annex B.

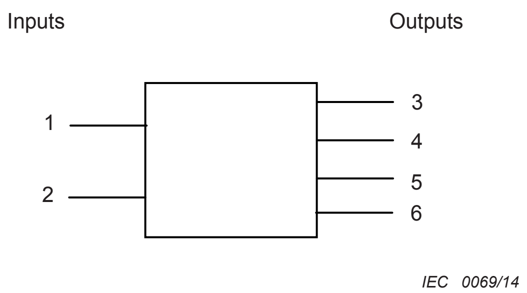


Figure 1 – Example of a six-port device, with two input and four output ports

Note 3 to entry: If there are four operating wavelengths, then the resulting transfer matrix becomes a 6 × 6 × 4 matrix: Optical attenuation at λ_1 from port 1 to port 6 would use a_{161}. Return loss of port 2 at λ_4 would use a_{224}. Optical attenuation from port 5 to port 2 at λ_3 would use a_{523}.

3.1.3
transfer matrix coefficient
element t_{ij} of the transfer matrix

Note 1 to entry: t_{ij} is the number of more than or equal to zero, and less than or equal to one.

Note 2 to entry: A detailed explanation is shown in Annex A.

3.1.4
logarithmic transfer matrix
transfer matrix whose matrix element a_{ij} is a logarithmic value of transfer matrix element t_{ij}. a_{ij} is a number of positive and expressed in dB

Note 1 to entry: A detailed explanation is shown in Annex A.

3.1.5
conducting port pair
port pair consisting of i and j where t_{ij} is nominally greater than zero (ideally t_{ij} is 1 and a_{ij} is 0) at a specified wavelength

3.1.6
isolated port pair
pair i and j consisting where t_{ij} is nominally zero, and a_{ij} is nominally infinite at a specified wavelength

3.1.7
channel
wavelength (frequency) band in which an optical signal is transmitted for a WDM device

Note 1 to entry: WDM devices have two or more channels.

3.1.8
channel spacing
centre-to-centre differences in frequency or wavelength between adjacent channels in a WDM device

3.2 Component definitions

3.2.1
wavelength-selective branching device
passive component with three or more ports that shares optical power among its ports in a predetermined fashion, without any amplification or other active modulation but only depending on the wavelength, in the sense that at least two different wavelength ranges are nominally transferred between two different pairs of ports

3.2.2
wavelength division multiplexing device
wavelength division multiplexer
WDM device
synonym for a wavelength-selective branching device

Note 1 to entry: The term of wavelength-selective device is the contrast with the term of non-wavelength-selective branching device. The term of WDM device is frequently used.

3.2.3
dense wavelength division multiplexing device
DWDM device
WDM device which is intended to operate for a channel spacing equal or less than 1 000 GHz (approximately 8 nm at 1 550 nm and 5,7 nm at 1 310 nm)

3.2.4
coarse wavelength division multiplexing device
CWDM device
WDM device which is intended to operate for channel spacing less than 50 nm and greater than 1 000 GHz

3.2.5
wide WDM device
WWDM
WDM device which is intended to operate for channel spacing equal to or greater than 50 nm

3.2.6
wavelength multiplexer
MUX
WDM (DWDM, CWDM or WWDM) device which has n input ports and one output port, and whose function is to combine n different optical signals differentiated by wavelength from n corresponding input ports on to a single output port

3.2.7
wavelength demultiplexer
DEMUX
WDM (DWDM, CWDM or WWDM) device which has one input port and n output ports, and whose function is to separate n different optical signals differentiated by wavelength from a single input port to n corresponding output ports

3.2.8
interleaver
DWDM device which has three ports, and which function is to separate n different optical signals differentiated by wavelength from a common port and transmit an odd channel signal to one branching port and an even channel signal to the other branching port alternately

Note 1 to entry: An interleaver can operate as a wavelength multiplexer (OMUX) by reversing the demultiplexer.

3.3 Performance parameter definitions

3.3.1
operating wavelength
nominal wavelength λ_h at which a WDM device operates with the specified performance

Note 1 to entry: The term "operating wavelength" includes the wavelength to be nominally transmitting, designated attenuating and isolated.

Note 2 to entry: Operating frequency is also used for DWDM devices.

3.3.2
operating wavelength range
specified range of wavelengths including all operating wavelengths

Note 1 to entry: It includes all passbands and isolation wavelength ranges corresponding to all channels.

Note 2 to entry: The term "operating wavelength range" is defined for a WDM device, not for each channel or port.

3.3.3
channel wavelength range
range within which a CWDM or WWDM device operates with less than or equal to a specified optical attenuation for the conducting port pair

Note 1 to entry: For a particular nominal channel centre wavelength, λ_{nom}, this wavelength range from λ_{imin} = (λ_{nom} - $\Delta\lambda_{max}$) to λ_{imax} = (λ_{nom} + $\Delta\lambda_{max}$), where $\Delta\lambda_{max}$ is the maximum channel centre wavelength deviation.

Note 2 to entry: For CWDM devices, channel centre wavelengths and maximum channel centre wavelength deviations are defined as nominal central wavelengths and wavelength deviations in ITU-T. G 694.2.

Note 3 to entry: An illustration of channel wavelength range is shown in Figure 2.

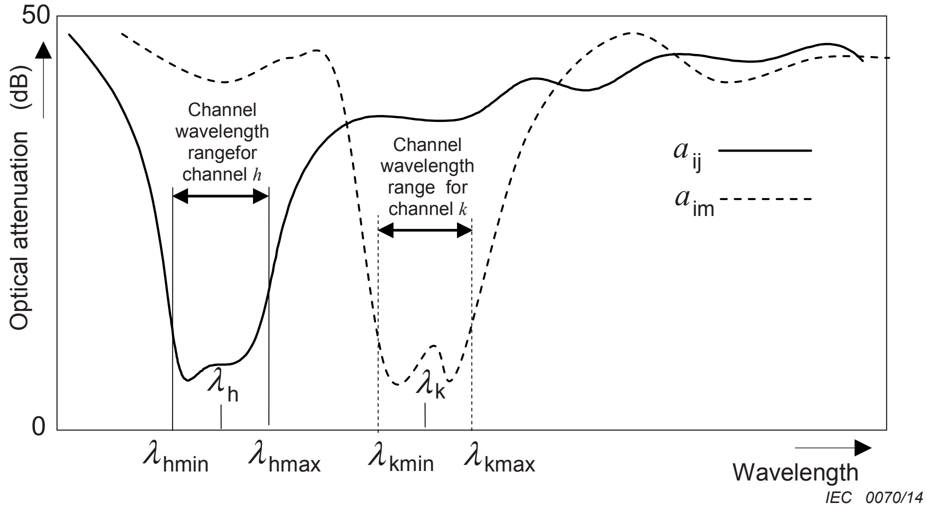


Figure 2 – Illustration of channel wavelength range

3.3.4
channel frequency range
frequency range within which a DWDM device is required to operate with less than or equal to a specified optical attenuation for the conducting port pair

Note 1 to entry: For a particular nominal channel frequency, f_{nomi}, this frequency range is from f_{imin} = (f_{nomi} - Δf_{max}) to $_{fimax}$ = (f_{nomi} + Δf_{max}), where Δf_{max} is the maximum channel centre frequency deviation.

Note 2 to entry: Nominal channel centre frequency and maximum channel centre frequency deviation are defined in ITU-T. G.694.1.

3.3.5
passband
channel passband
synonym for channel wavelength range (channel frequency range)

Note 1 to entry: Passband is frequently used.

Note 2 to entry: There are two or more passbands for WDM devices. Each passband is defined corresponding to each channel.

3.3.6
insertion loss
maximum value of a_{ij} (where $i \neq j$) within the passband for conducting port pair

Note 1 to entry: It is the optical attenuation from a given port to a port which is another port of conducting port pair of the given port of a WDM device. Insertion loss is a positive value in decibels. It is calculated as:

$$IL = -10\log\left(\frac{P_{out}}{P_{in}}\right)$$

where

P_{in} is the optical power launched into the port;

P_{out} is the optical power received from the other port of the conducting port pair.

Note 2 to entry: An illustration of insertion loss is shown in Figure 3.

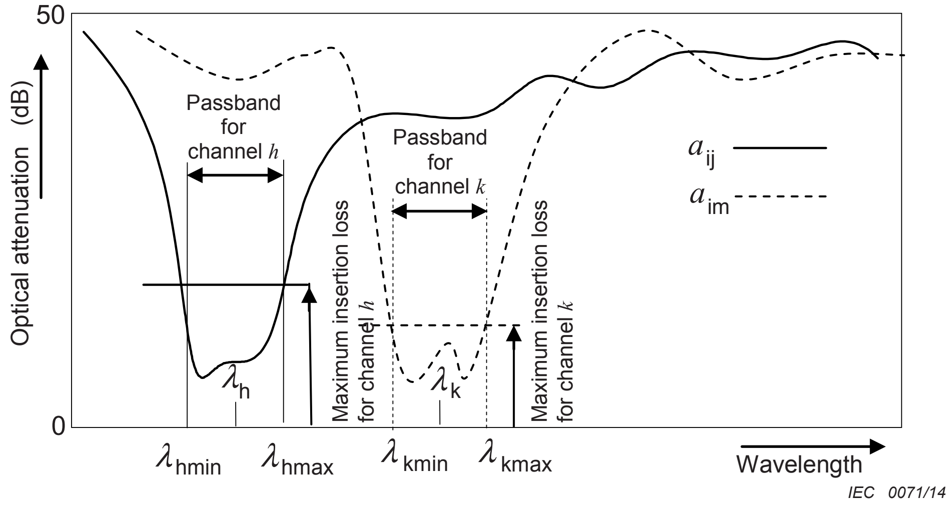


Figure 3 – Illustration of insertion loss

Note 3 to entry: For a WDM device, the insertion loss shall be specified as a maximum value of the insertion losses of all channels

3.3.7
channel insertion loss
term used for WDM devices which has a similar same meaning as insertion loss except that channel insertion loss is used for a channel whereas insertion loss is used in the specifications of both a WDM device and for a channel

3.3.8
passband ripple
maximum peak-to-peak variation of the insertion loss (absolute value) over the passband (within a channel frequency or wavelength range) (refer to Figure 4 below)

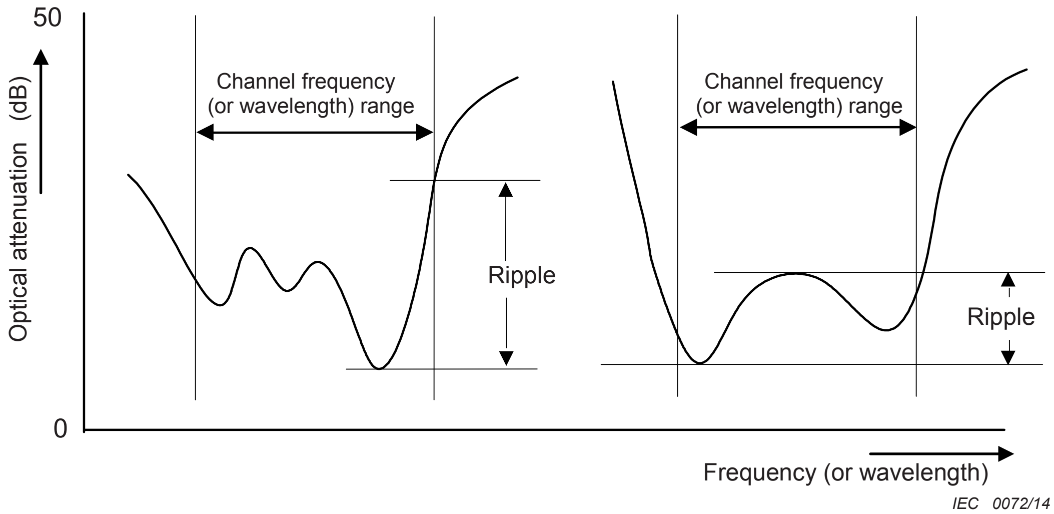


Figure 4a – Ripple at band edges **Figure 4b – Ripple in band**

Figure 4 – Illustration of ripple

3.3.9
maximum channel insertion loss deviation
maximum variation of the insertion loss (absolute value) within the passband (channel frequency range for a DWDM device or channel wavelength range for a coarse WDM (CWDM) and a wide WDM (WWDM) device) (See Figure 5)

Note 1 to entry: Channel insertion loss deviation should not to be confused with ripple defined in Figure 5 below.

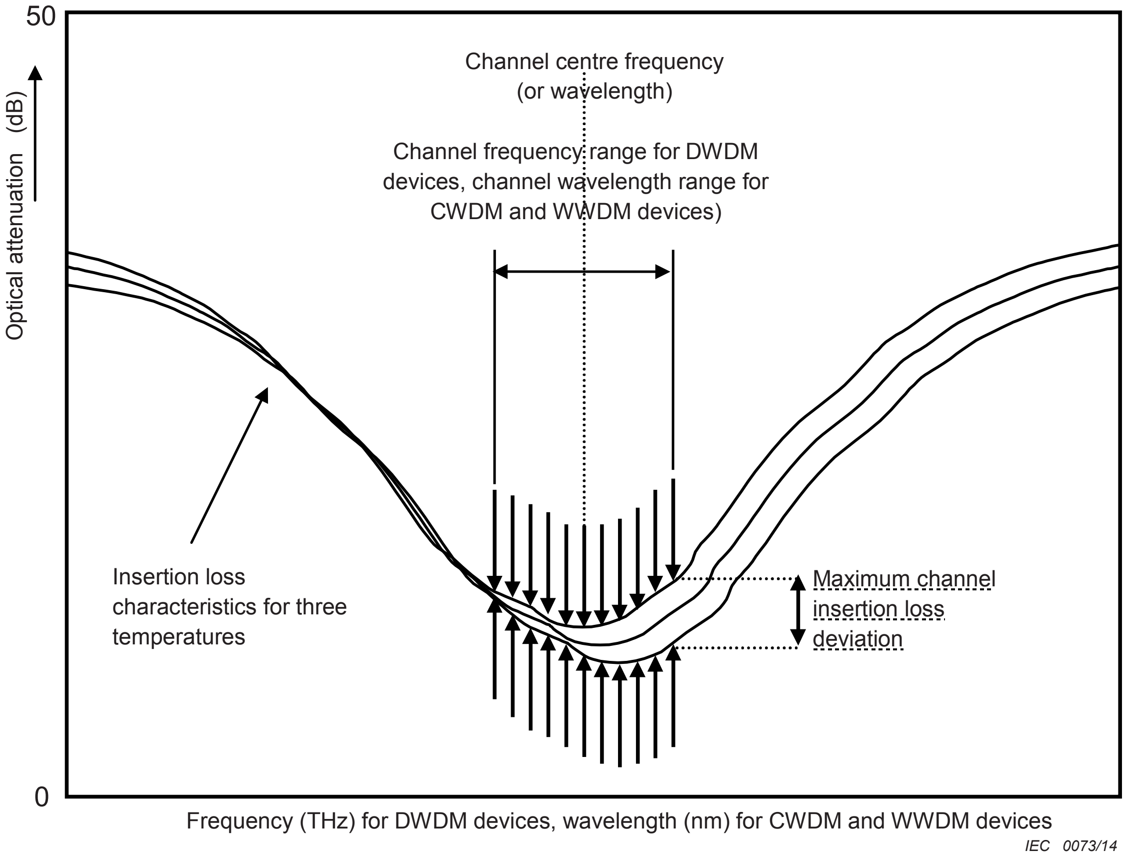


Figure 5 – Illustration of channel insertion loss variation

3.3.10
channel non-uniformity
insertion loss channel non-uniformity
for a specified set of branching ports the difference between the maximum and the minimum insertion loss at the common port

Note 1 to entry: Channel non-uniformity is defined for a MUX (N x 1 WDM device) and a DEMUX (1 x N WDM device). Channel non-uniformity is a positive value, and expressed in dB.

Note 2 to entry: For CWDM and DWDM devices, channel non-uniformity should be defined as the differences between the maximum and the minimum insertion loss at nominal wavelengths (frequencies) of all channels.

3.3.11
centre wavelength deviation
difference between the centre wavelength and nominal wavelength (frequency) of the specified channel for DWDM devices, where the centre wavelength is defined as the centre of the wavelength range which is x dB less than the minimum optical attenuation for the specified passband (channel)

Note 1 to entry: 0,5, 1 or 3 are generally used for x.

3.3.12
crosstalk
for WDM devices, the value of the ratio between the optical power of the specified signal and the specified noise

Note 1 to entry: Crosstalk is a negative value given in dB. The crosstalk is defined for each output port. Crosstalk for WDM devices is defined for a DEMUX (1 x N WDM device). The crosstalk for port o to port j is subtraction from the insertion loss of port i to o (conducting port pair) to the isolation of port j to o (isolated port pair). Crosstalk for WDM devices is defined for a DEMUX (1 x N WDM device). For an MxN WDM device, crosstalk can be defined to as expanding M of a 1 x N WDM device.

Note 2 to entry: For WDM devices with three of more ports, the crosstalk should be specified as the maximum value of the crosstalk for each output port.

Note 3 to entry: Care should be taken not to confuse crosstalk and isolation.

3.3.13
isolation
minimum value of a_{ij} (where $i \neq j$) within isolation wavelength range for isolated port pair

Note 1 to entry: Isolation is a positive value expressed in dB.

3.3.14
isolation wavelength
for a pair of ports i and j (where $i \neq j$), that are conducting port pair at a wavelength λ_h, a nominal wavelength λ_k (where $\lambda_h \neq \lambda_k$), that is an operating wavelength for a different pair of ports, at which i and j are isolated port pair (refer to Figure 6 below)

Note 1 to entry: Isolation frequency is also used for DWDM device.

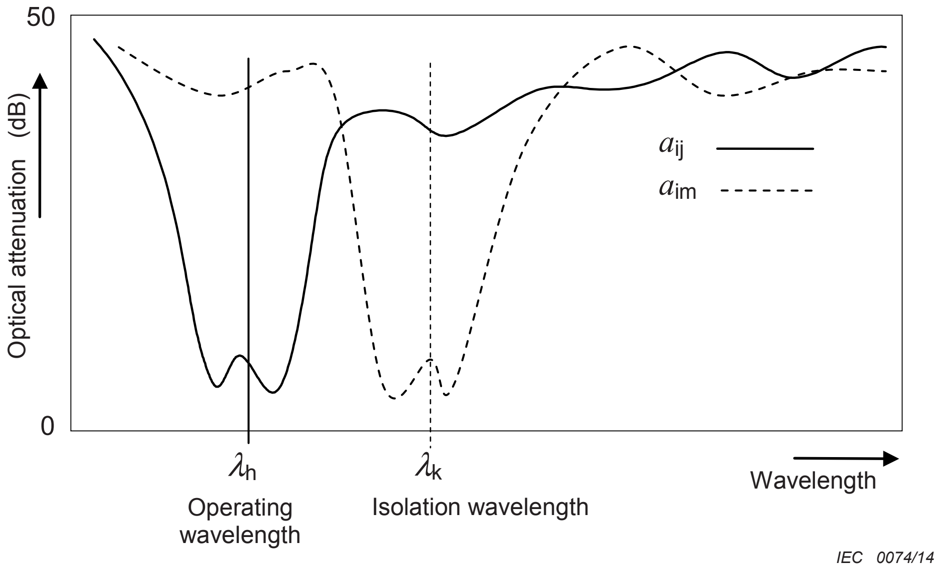


Figure 6 – Illustration of isolation wavelength

3.3.15
isolation wavelength range
for a pair of ports i and j that are a conducting port pair at wavelength λ_h, the range of wavelengths from λ_{kmin} to λ_{kmax} centred about an operating wavelength λ_k that is an operating wavelength for a different pair of ports but at which i and j are an isolated port pair (refer to Figure 7 below)

Note 1 to entry: Isolation frequency range is also used for DWDM devices.

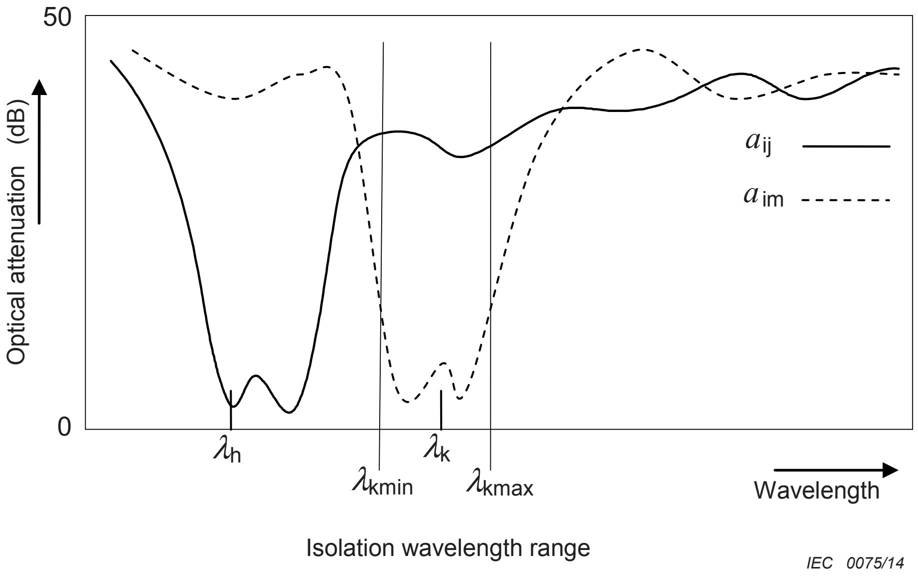


Figure 7 – Illustration of isolation wavelength range

3.3.16
wavelength isolation
value of a_{ij} (where $i \neq j$) in the isolation wavelength range

Note 1 to entry: The wavelength isolation shall be defined as the minimum value of wavelength isolation over the isolation wavelength range.

3.3.17
adjacent channel isolation
isolation with the restriction that x, the isolation wavelength number, is restricted to the channels immediately adjacent to the (channel) wavelength number associated with port o

Note 1 to entry: Adjacent channel isolation is a positive value expressed in dB

Note 2 to entry: This is illustrated in Figure 8 below. The adjacent channel isolation is different from adjacent channel crosstalk. In Figure 8, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value. Generally, there are two adjacent channel isolations for the shorter wavelength (higher frequency) side and the longer wavelength (lower frequency) side.

3.3.18
adjacent channel crosstalk
crosstalk with the restriction that x, the isolation wavelength number, is restricted to the channels immediately adjacent to the (channel) wavelength number associated with port o

Note 1 to entry: Adjacent channel crosstalk is a negative value expressed in dB.

Note 2 to entry: This is illustrated in Figure 8 below. Adjacent channel crosstalk is different from adjacent channel isolation. In Figure 8, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value. Generally, there are two adjacent channel crosstalks for the shorter wavelength (higher frequency) side and the longer wavelength (lower frequency) side.

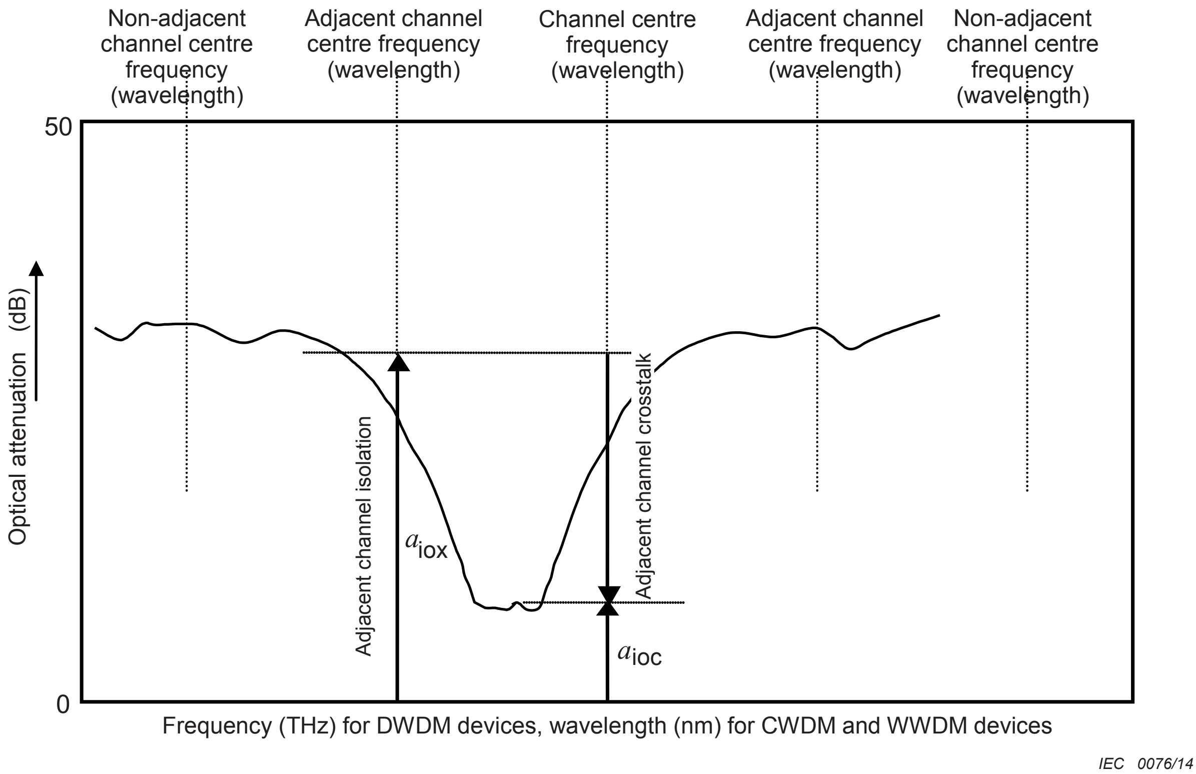


Figure 8 – Illustration of adjacent channel isolation

3.3.19
non-adjacent channel isolation
isolation with the restriction that the isolation wavelength (frequency) is restricted to each of the channels not immediately adjacent to the channel associated with port *o* (refer to Figure 9 below)

Note 1 to entry: The non-adjacent channel isolation is different from non-adjacent channel crosstalk. In Figure 9, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value.

3.3.20
non-adjacent channel crosstalk
crosstalk where the isolation wavelength (frequency) is restricted to each of the channels not immediately adjacent to the channel associated with port *o* (refer to Figure 9 below)

Note 1 to entry: Non-adjacent channel crosstalk is different from non-adjacent channel isolation. In Figure 9, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value.

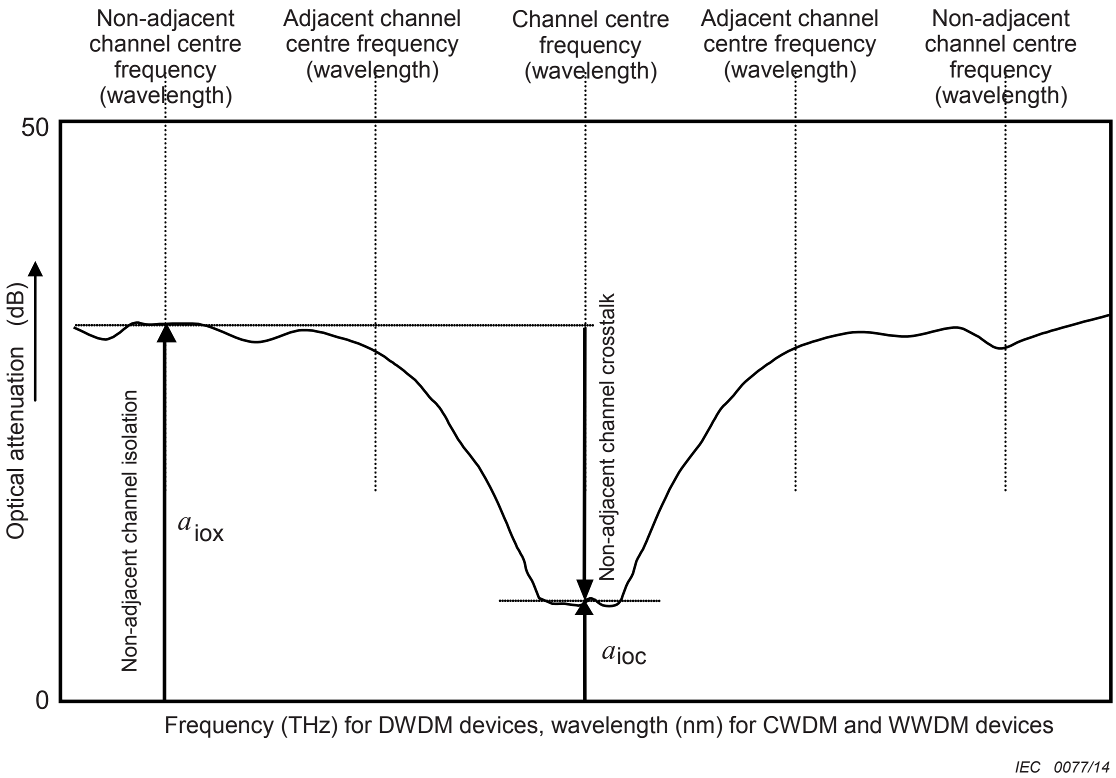


Figure 9 – Illustration of non-adjacent channel isolation

3.3.21
minimum adjacent channel isolation
minimum value of a_{ij} within the adjacent operating wavelength (or frequency) range (adjacent channel passband). The minimum adjacent channel isolation is positive in dB

Note 1 to entry: Refer to Figure 10 below. Generally, there are two minimum adjacent channel isolations. For a channel, the minimum value of two minimum adjacent channel isolations is selected.

Note 2 to entry: The minimum adjacent channel isolation is different from the maximum adjacent channel crosstalk. In Figure 10, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value.

3.3.22
maximum adjacent channel crosstalk
maximum value of adjacent channel crosstalk within adjacent channel wavelength (frequency) range (adjacent channel passband)

Note 1 to entry: This is the maximum value of the subtraction from the maximum insertion loss to the minimum adjacent isolation. Maximum adjacent channel crosstalk is negative value in dB. Refer to Figure 10 below. Generally, there are two maximum adjacent channel crosstalks. For a channel, the maximum value of two maximum adjacent channel crosstalks is selected.

Note 2 to entry: The maximum adjacent channel crosstalk is different from the minimum adjacent channel isolation. In Figure 10, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value.

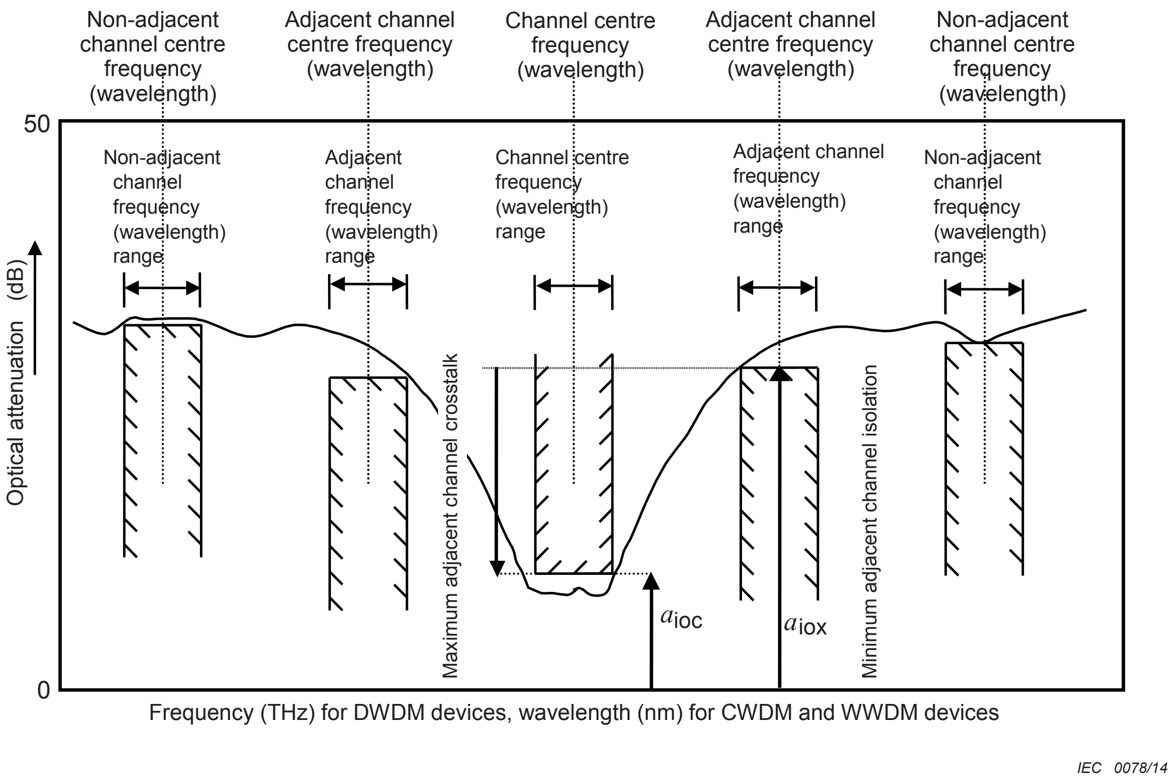


Figure 10 – Illustration of maximum adjacent channel crosstalk

3.3.23
minimum non-adjacent channel isolation
minimum difference between the minimum peak of a_{ij} in the operating wavelength (or frequency) range and the maximum value of a_{ij} in a specified range of wavelengths (or frequencies) from λ_{kmin} to λ_{kmax} centred about an isolation wavelength (or frequency) λ_k for any two ports *i* and *j*, λ_{kmin} and λ_{kmax} defining an operating wavelength (or frequency) range for a different pair of ports for which λ_k is an operating wavelength (or frequency) (refer to Figure 11 below).

Note 1 to entry: The minimum adjacent channel isolation is different from the maximum adjacent channel crosstalk. In Figure 10, the upward-pointing arrow indicates a positive value, and the down-pointing arrow indicates a negative value.

3.3.24
maximum non-adjacent channel crosstalk
minimum difference between the minimum peak of a_{ij} in the operating wavelength (or frequency) range and the maximum value of a_{ij} in a specified range of wavelengths (or frequencies) from λ_{kmin} to λ_{kmax} centred about an isolation wavelength (or frequency) λ_k for any two ports *i* and *j*, λ_{kmin} and λ_{kmax} defining an operating wavelength (or frequency) range for a different pair of ports for which λ_k is an operating wavelength (or frequency) (refer to Figure 11 below)

Note 1 to entry: The minimum adjacent channel isolation is different from the maximum adjacent channel crosstalk. In Figure 10, the upward-pointing arrow indicates a positive value, and the downward-pointing arrow indicates a negative value.

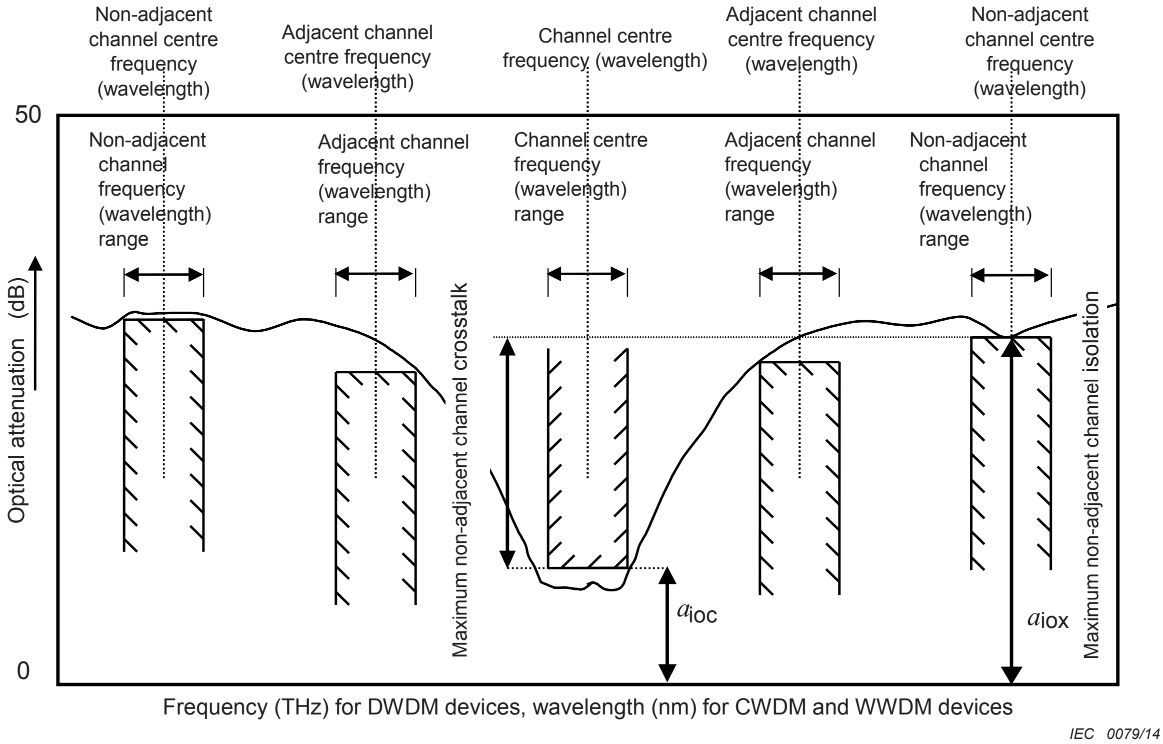


Figure 11 – Illustration of maximum non-adjacent channel crosstalk

3.3.25
total channel isolation
for any two ports i and j (where $i \neq j$) it is the cumulative isolation due to the contributions at all the isolation wavelengths (frequencies) and is defined as:

$$I_{\text{tot}} = -10 \times Log\left[\sum_{k(k \neq h)}^{N} t_{\text{ij}}(\lambda_{\text{k}})\right]$$

where

N is the number of channels of the device;

H is the channel number corresponding to the conducting port pair of i and j;

λ_{k} are the nominal isolation wavelengths (frequencies) for the same pair of ports.

Note 1 to entry: Total channel isolation is positive in dB. For a WDM device, total channel isolation shall be specified as a minimum value of the total channel isolations of all channels

3.3.26
total channel crosstalk
for any two ports i and j (where $i \neq j$) it is the ratio of cumulative isolation due to the contributions at all the isolation wavelengths (frequencies) and transfer matrix coefficient for ports i and j, t_{ij} and is defined as:

$$XT_{\text{tot}} = -10 \times \text{Log}\left[\frac{t_{\text{ij}}(\lambda_{\text{h}})}{\sum_{k(k \neq h)}^{N} t_{\text{ij}}(\lambda_{\text{k}})}\right]$$

where

N is the number of channels of the device;

λ_h is the nominal operating wavelength (frequency) for the couple of port *i* and *j*;

λ_k are the nominal isolation wavelengths (frequencies) for the same pair of ports.

Note 1 to entry: Total channel crosstalk is also expressed by total channel isolation as shown in the following equation:

$$XT_{tot} = a_{ij}(\lambda_h) - I_{tot}$$

Note 2 to entry: Total channel crosstalk is negative value in dB. For a WDM device, total channel crosstalk shall be specified as the maximum value of total channel crosstalks of all channels

3.3.27
minimum total channel isolation
for any two ports i and j (where $i \neq j$) the minimum value of the cumulative isolation due to the minimum spectral contributions about all the isolation wavelengths (frequencies) and is defined as:

$$I_{tot}^{min} = -10 \times \text{Log}\left[\sum_{k(k \neq h)}^{N} t_{ij}^{*}\left(\lambda_k^{*}\right)\right]$$

where

N is the number of channels of the device;

h is the channel number corresponding to the conducting port pair of i and j;

k is the channel number except corresponding to the conducting port pair of i and *j*. It is the channel number to be isolated for the combination of ports i and j;

t_{ij}^* is the maximum value of t_{ij} at the wavelength is λ_k * (channel wavelength range; (passband) of channel k);.

λ_k^* are the wavelengths (frequencies) corresponding to the maximum value of t_{ij} in the specified ranges of wavelengths (frequencies) from λ_{kmin} to λ_{kmax} about the isolation wavelengths (frequencies) λ_k for the pair of ports *i* and j, λ_{kmin} and λ_{kmax} defining the operating wavelength (frequency) range for the pair of ports for which λ_k is an operating wavelength (frequency).

Note 1 to entry: Minimum total channel isolation is positive value in dB. For a WDM device, minimum total channel isolation shall be specified as the minimum value of minimum total channel isolation.

3.3.28
maximum total channel crosstalk
for any two ports i and j (where $i \neq j$), it is the ratio of the minimum value of the cumulative isolation due to the minimum spectral contributions about all the isolation wavelengths (frequencies), and minimum transfer matrix coefficient for port i and j, at the channel wavelength range of channel h, $t_{ij}^{+}(\lambda_h^{+})$ and is defined as:

$$I_{tot}^{max} = -10 \times \text{Log}\left[\frac{t_{ij}^{+}(\lambda_h^{+})}{\sum_{k(k \neq h)}^{N} t_{ij}^{*}(\lambda_k^{*})}\right]$$

where

N is the number of channels of the device;

h is the channel number corresponding to the conducting port pair of i and j;

k is the channel number except corresponding to the conducting port pair of i and j. It is the channel number to be isolated for the combination of ports i and j;

t_{ij}^{+} is the minimum value of t_{ij} at the wavelength is λ_h^{+} (channel wavelength range; (passband) of channel h);

t_{ij}^{*} is the maximum value of t_{ij} at the wavelength is λ_k^{*} (channel wavelength range; (passband) of channel k);

λ_h^{+} is the wavelength (frequency) corresponding to the minimum peak of t_{ij} in the operating wavelength (frequency) range (channel h) for the pair of ports i and j;

λ_k^{*} are the wavelengths (frequencies) corresponding to the maximum value of t_{ij} in the specified ranges of wavelengths (frequencies) from λ_{kmin} to λ_{kmax} about the isolation wavelengths (frequencies) λ_k for the pair of ports i and j, λ_{kmin} and λ_{kmax} defining the operating wavelength (frequency) range for the pair of ports for which λ_k is an operating wavelength (frequency).

3.3.29
out-of-band attenuation
minimum optical attenuation (in dB) of channels that fall outside of shortest channel wavelength range (highest channel frequency range; passband) and longest channel wavelength range (lowest channel frequency range; passband)

3.3.30
channel extinction
within the operating wavelength range, the difference (in dB) between the minimum powers of the conducting channels (in dBm) and the maximum power of the isolated channels (in dBm)

Note 1 to entry: Channel extinction is specified for each channel for a DEMUX. It has an absolute value (positive) in dB. Refer to Figure 12.

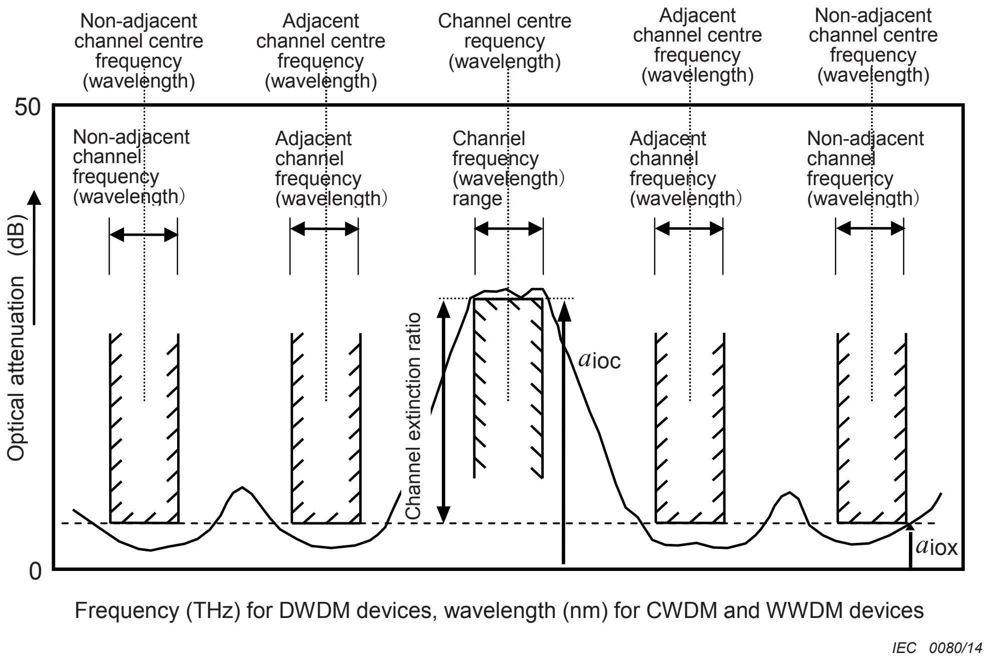


Figure 12 – Illustration of channel extinction ratio

3.3.31
chromatic dispersion
group delay difference between two closely spaced wavelengths (or frequencies) inside an optical signal going through a pair of conducting ports of a WDM device

Note 1 to entry: It corresponds to the difference between the arrival times of these two closely spaced wavelengths (or frequencies). Chromatic dispersion is defined as the variation (first order derivative) of this group delay over a range of wavelengths (or frequencies) especially over the channel operating wavelength (or frequency) range at a given time, temperature, pressure and humidity. It is expressed as D in terms of units of ps/nm or ps/GHz and it is a predictor of the broadening of a pulse transmitted through the device.

Note 2 to entry: Tthe unit of ps/GHz is generally better definition for system influence, even though it is not commonly used.

3.3.32
slope of chromatic dispersion
slope of chromatic dispersion S (with units of ps/nm^2 or ps/GHz^2) corresponds to the variation (first order derivative) of D as a function of wavelength (or frequency) (or second order derivative of the group delay) over the operating wavelength (or frequency) range, channel per channel

Note 1 to entry: It is particularly critical in the context of large channel counts (DWDM) or over a wide wavelength range (CWDM or WWDM).

Note 2 to entry: The unit of ps/GHz^2 is generally better definition for system influence, even though it is not commonly used.

3.3.33
directivity
value of a_{ij} for two ports which is not conducting nor isolated at any wavelength (or frequency for a DWDM device)

Note 1 to entry: Directivity is positive value expressed in dB. For a WDM device, directivity shall be specified as the minimum value of directivities for all combination of port pair and for all channels.

Note 2 to entry: For the example of 6 ports WDM devices shown in Figure 1, the directivity is a_{12} and a_{21} between two input ports, and a_{34}, a_{43}, etc. between two output ports.

3.3.34
free spectral range
FSR
difference between two adjacent operating wavelengths for a given input output path (refer to Figure 13 below)

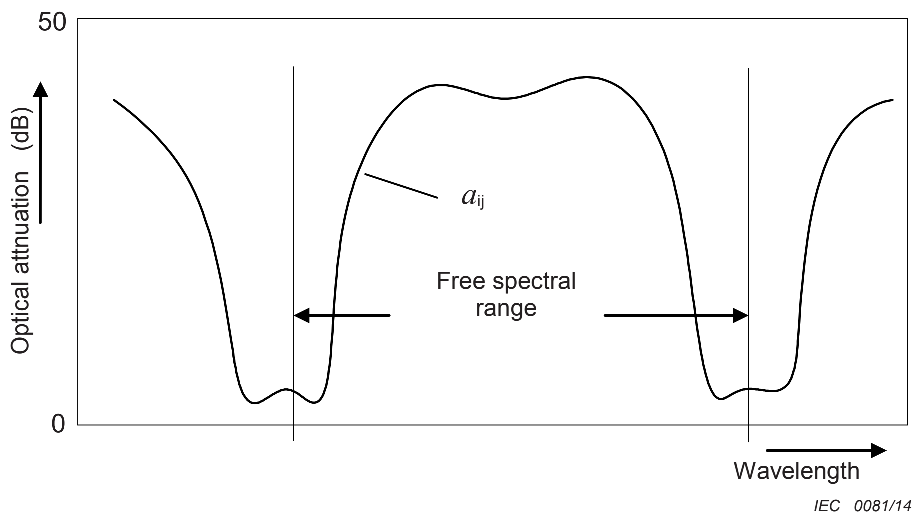


Figure 13 – Illustration of free spectral range

3.3.35
polarization dependent centre wavelength
PDCW
maximum variation of channel centre wavelength due to a variation of the state of polarization (SOP) over all SOPs (refer to Figure 14 below)

Note 1 to entry: PDCW is defined for conducting port pair.

Note 2 to entry: For DWDM device polarization dependent centre frequency may also be used.

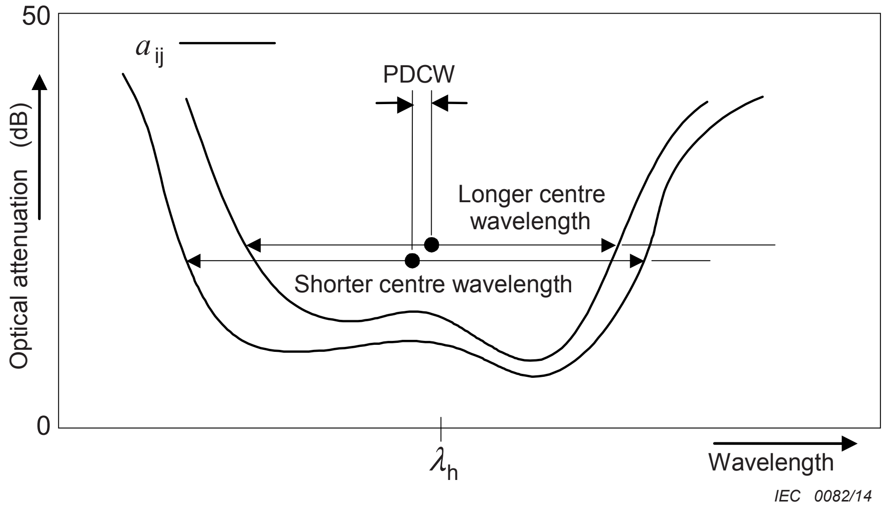


Figure 14 – Illustration of polarization dependent centre wavelength (PDCW)

3.3.36
polarization dependent isolation
PDI
maximum variation of isolation over all the states of polarization. PDI is defined for isolated port pair

3.3.37
polarization dependent loss
PDL
maximum variation of insertion loss caused by a variation in the state of polarization (SOP) over all the SOPs. PDL is defined for conducting port pair

3.3.38
wavelength dependent loss
WDL
maximum variation of the insertion loss over the passband (channel wavelength range)

Note 1 to entry: Wavelength dependent loss is generally used for WWDM devices.

3.3.39
polarization dependent reflectance
maximum variation of reflectance due to a variation of the state of polarization (SOP) over all SOPs

3.3.40
principal states of polarization
PSP
at a given optical frequency (or wavelength), the two input (and orthogonal) states of polarization (SOP) for which the corresponding output SOP are independent of optical frequency to first order

Note 1 to entry: In the absence of PDL, the PSPs are orthogonal SOPs with the fast axis PSP having the shortest arrival time and the slow axis PSP having the longest, the DGD being the difference between these two arrival times.

Note 2 to entry: An optical fibre, component or subsystem is typically characterized by two PSPs that are an intrinsic function of the material birefringence and the induced external and internal stresses acting on it.

Note 3 to entry: The DGD between these two PSPs can vary with time and wavelength.

Note 4 to entry: A signal whose SOP is aligned with one of the PSPs will be unaffected by the amount of PMD, at least to first order.

3.3.41
polarization mode dispersion
PMD
when an optical signal passes through an optical fibre, component or subsystem, such as going through a pair of conducting ports of a WDM device, the change in the shape and r.m.s. width of the pulse due to the average delay of the travelling time between the two principal states of polarization (PSP), differential group delay (DGD), and/or to the waveform distortion for each PSP, is called PMD. PMD, together with polarization dependent loss (PDL) and polarization dependent gain (PDG), when applicable, may introduce waveform distortion leading to unacceptable bit error rate increase

Note 1 to entry: PMD may depend on environmental conditions.

3.3.42
return loss
value of a_{ij} (where $i = j$) at the operating wavelength. It is the fraction of input power that is returned from the port of a passive component expressed in decibels. It is a positive value. It is calculated as:

$$RL = -10\log\left(\frac{P_{\mathrm{refl}}}{P_{\mathrm{in}}}\right)$$

where

P_{in} is the optical power launched into the port;

P_{refl} is the optical power received back from the same port.

Note 1 to entry: For WWDM devices, it shall be specified as a minimum value at each operating wavelength range. For CWDM devices, it shall be specified as a minimum value within the channel wavelength range. For DWDM devices, it shall be specified as a minimum value within the channel frequency range.

Note 2 to entry: Return loss is also a system/network parameter and has a positive sign; reflectance may also be a component (for instance in the context of a network element) or interface parameter and has a negative sign.

Note 3 to entry: Return losses as well as reflectance may have a wavelength dependency.

3.3.43
***X* dB bandwidth**
defined through the spectral dependence of a_{ij} (where $i \neq j$) as the minimum wavelength range centred about the operating wavelength λ_h within which the variation of a_{ij} is less than "X" dB

Note 1 to entry: The minimum wavelength range is determined considering thermal wavelength shift, polarization dependence and long term aging shift (refer to Figure 15 below).

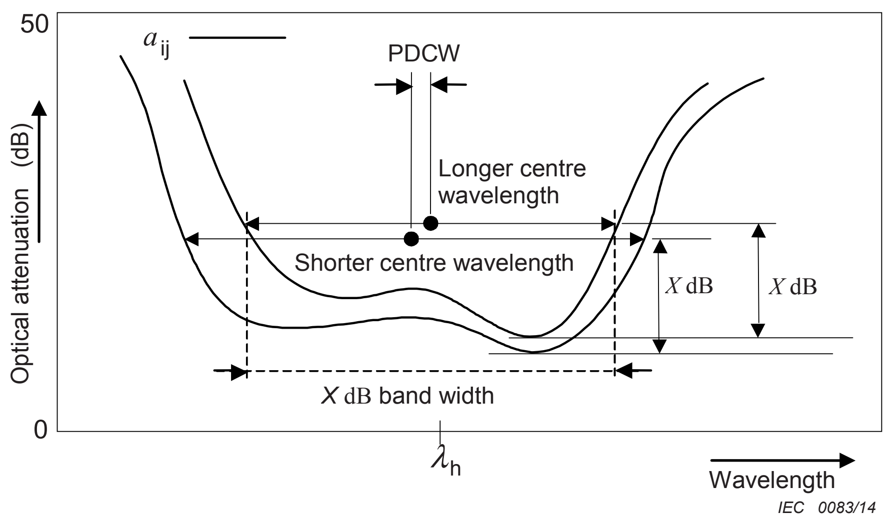


Figure 15 – Illustration of X dB bandwidth

Note 1 to entry: For a WDM device, the operating wavelength range and the X dB bandwidth corresponding to different operating wavelengths are not necessarily equal.

4 Requirements

4.1 Classification

4.1.1 General

Fibre optic WDM devices shall be classified as follows:

- type;
- style;
- variant;
- environmental category;
- assessment level;
- extensions.

4.1.2 Type

WDM devices can be categorized into types:

- By port-configuration
  - 1 x N
  - N x 1
  - M x N (M, N > = 2);

NOTE A 1 x N or N x 1 WDM device is used as a wavelength multiplexer, a wavelength demultiplexer or wavelength multiplexer and demultiplexer. An M x N WDM device is used as wavelength router or wavelength channel add/drop device. These applications of WDM devices are expressed by the transfer matrixes, shown in Annex C.

- By internal structure
  - transmissive
  - reflective;
- By channel spacing
  - WWDM
  - CWDM
  - DWDM;
- By channel wavelength range or operating wavelength range;
- By temperature control
  - active temperature control
  - passively compensated.

4.1.3 Style

Fibre optic WDM devices may be classified into styles based on the fibre type(s), the connector type(s), cable type(s), housing shape and the configuration. The configurations of branching device ports are classified as follows:

Configuration A

A device containing integral fibre optic pigtails, without connectors (see Figure 16).

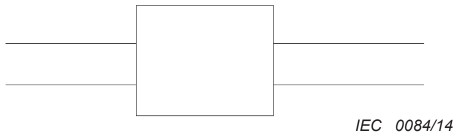


Figure 16 – Wavelength-selective branching device

Configuration B

A device containing integral fibre optic pigtails, with a connector on each pigtail (see Figure 17).

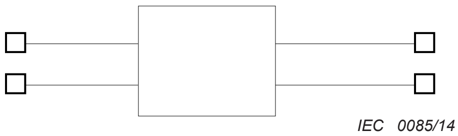


Figure 17 – Wavelength-selective branching device

Configuration C

A device containing fibre optic connectors as an integral part of the device housing (see Figure 18).

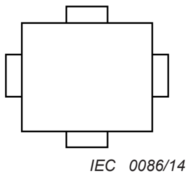


Figure 18 – Wavelength-selective branching device

Configuration D

A device containing some combination of the interfacing features of the preceding configurations (see Figure 19).

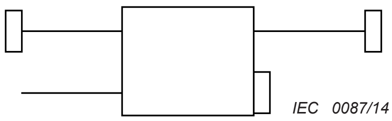


Figure 19 – Wavelength-selective branching device

4.1.4 Variant

The wavelength-selective branching device variant identifies the common features which encompass structurally similar components.

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

- orientation of ports;
- means of mounting;
- type of fibre.

4.1.5 Assessment level

Relevant specifications shall specify one or more assessment levels, each of which shall be designated by a capital letter. The assessment level defines the relationship between groups A and B inspection levels and groups C and D inspection periods.

The following are the preferred levels.

Assessment level A:

- group A inspection: inspection level II, AQL = 4 %;
- group B inspection: inspection level II, AQL = 4 %;
- group C inspection: 24 month periods;
- group D inspection: 48 month periods.

Assessment level B:

- group A inspection: inspection level II, AQL = 1 %;
- group B inspection: inspection level II, AQL = 1 %;
- group C inspection: 18 month periods;
- group D inspection: 36 month periods.

Assessment level C:

- group A inspection: inspection level II, AQL = 0,4 %;
- group B inspection: inspection level II, AQL = 0,4 %;
- group C inspection: 12 month periods;
- group D inspection: 24 month periods.

where AQL is the acceptable quality level.

One additional assessment level (other than those specified above) can be given in the relevant specification. When this is done, the capital letter X shall be used.

NOTE Groups A and B are subject to lot-by-lot inspection. Groups C and D are subject to periodic inspection.

4.1.6 Normative reference extension

Other documents may be referenced.

4.2 Documentation

4.2.1 Symbols

Graphical and letter symbols shall, whenever possible, be taken from the IEC 60027 series, IEC 60050-731 and IEC 61931.

4.2.2 Specification system

This specification is part of the IEC specification system. Subsidiary specifications shall consist of relevant specifications. This system is shown in Table 1. There are no sectional specifications for WDM devices.

Table 1 – Three-level IEC specification structure

Specification level	Examples of information to be included	Applicable to
Basic	Assessment system rules Inspection rules Optical measuring methods Environmental test methods Sampling plans	Two or more component families or subfamilies

Specification level	Examples of information to be included	Applicable to
	Identification rule Marking standards Dimensional standards Terminology standards Symbol standards Preferred number series SI units	
Generic	Specific terminology Specific symbols Specific units Preferred values Marking Quality assessment procedures Selection of tests Qualification approval and/or Capability approval procedures	Component family
Relevant	Individual values Specific information Completed quality conformance test schedules	Individual type

A specific wavelength-selective branching device is described by a corresponding relevant specification. Within the constraints imposed by this generic specification, the relevant specification may be prepared by any national committee of the IEC, thereby defining a particular wavelength-selective branching device design as an IEC standard.

Relevant specifications shall specify the following as applicable:

- type (see 4.1.2);
- style (see 4.1.3);
- variant (s) (see 4.1.4);
- assessment level (see 4.1.5);
- variant identification number (s) (see 4.6.2);
- performance requirements (see 4.5).

4.2.3 Drawings

4.2.3.1 General

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

4.2.3.2 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.

4.2.3.3 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.

4.2.4 Measurements

4.2.4.1 Measurement method

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

4.2.4.2 Reference components

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

4.2.4.3 Gauges

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

4.2.5 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 and the variant identification number;
- 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.

4.2.6 Instructions for use

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

4.3 Standardization system

4.3.1 Performance standards

Performance standards contain a series of set 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 products ability to satisfy the “performance standards” requirement. Each performance standard has a different set of tests, and or severities (and or groupings) represents the requirements of a market sector, user group or system location.

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.

A key point of the performance standards is the selection of test and severity from the tests and measurements standards, for application in conjunction with interface standards on inter product compatibility (this particularly relates to attenuation and return loss). Certainly conformance of each individual product to this standard will be ensured.

4.3.2 Reliability standard

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 need to be identified (and appear in the reliability standard):

- failure modes (observable general mechanical or optical effects of failure);
- failure mechanisms (general causes of failure, common to several components), and failure effects (detailed causes of failure, specific to component).

These are all related to environmental and material aspects.

Initially, immediately 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 screen process in the factory, involving environmental stresses that may be mechanical, thermal and 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 some defined threshold. At this point the useful life ends and the “wear-out region” begins, and the component needs to 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 done by utilising 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 are 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.

4.3.3 Interlinking

With regard to interface, performance and reliability standards, once all these three standards are in place, the matrix given in Table 2 demonstrates some of other options available for product standardization.

Table 2 – Standards interlink matrix

	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

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

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

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

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

4.4 Design and construction

4.4.1 Materials

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

4.4.2 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.

4.5 Performance requirements

Fibre optic WDM devices shall meet the performance requirements specified in appropriate IEC performance standard.

4.6 Identification and marking

4.6.1 General

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

4.6.2 Variant identification number

Each variant in a relevant specification shall be assigned a unique identification number. This number shall be set out as follows:

- relevant specification number;
- a three digit variant number;
- a letter indicating assessment level.

Example: **QC210101/US0001 001 A**

Relevant specification number	QC210101/US0001
Variant number	001
Assessment level	A

4.6.3 Component marking

Component marking, if required, shall be specified in the relevant 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 relevant 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.

4.6.4 Package marking

Several fibre optic WDM devices may be packed together for shipment.

Package marking, if required, shall be specified in the relevant 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 4.6.2);
e) the type designation (see 4.1.2);
f) the assessment level;
g) any additional marking required by the relevant 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.

4.7 Safety

Fibre optic WDM devices, 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 fibre optic WDM devices 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 relevant specification shall include the following:

WARNING NOTE

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 of output level.

Reference shall be made to IEC 60825-1, the relevant standard on safety.

Annex A
(informative)

Transfer matrix

A.1 General

The optical properties of a fibre optic wavelength-selective branching device can be defined in terms of an n x n matrix of coefficients, where n is the number of ports, and the coefficients represent the fractional optical power transferred between designated ports. Figure A.1 shows the one example of six port device that has two input ports and four output ports. The ports are numbered sequentially. So, the possible combinations of two ports are six by six, given a total of 36 combinations. These 36 combinations are expressed by a matrix.

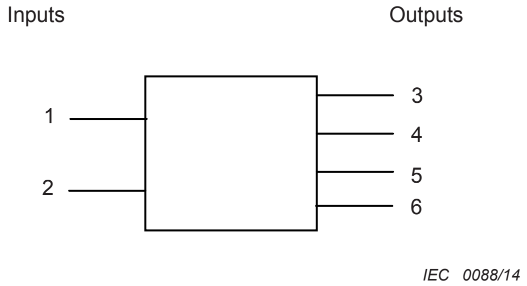


Figure A.1 – Example of a six-port device, with two input and four output ports

A.2 Transfer matrix

In general, the transfer matrix T is:

$$T = \begin{bmatrix} t_{11} & t_{12} & \cdot & \cdot & \cdot & t_{1n} \\ t_{21} & & & & & \\ \cdot & & & & & \\ \cdot & & & t_{ij} & & \\ \cdot & & & & & \\ t_{n1} & & & & & t_{nn} \end{bmatrix}$$

where

t_{ij} is the ratio of the optical power P_{ij} transferred out of port j (output port) with respect to input power P_i into port i (input port), that is:

$$t_{ij} = P_{ij}/P_i$$

where t_{ij} is a number more than zero, and less than or equal to one ($0 \leq t_{ij} \leq 1$). In a wavelength-selective branching device the coefficient t_{ij} is a function of the wavelength and may be a function of the input polarization or modal power distribution.

Single-mode fibre optic WDM devices may operate in a coherent fashion with respect to multiple inputs. Consequently, the transfer coefficients may be affected by the relative phase and intensity of simultaneous coherent optical power inputs at two or more ports.

The wavelength dependency of the transfer matrix coefficient should be considered. A matrix coefficient may be expressed as t_{ijk}, where k is the wavelength number, λ_k. For more generic expression, the transfer matrix is shown as follows:

$$T = \left[\begin{bmatrix} t111 & t121 & . & t1n1 \\ t211 & t221 & . & t2n1 \\ . & . & . & . \\ tn11 & tn21 & . & tnn1 \end{bmatrix}, \begin{bmatrix} t112 & t122 & . & t1n2 \\ t212 & t222 & . & t2n2 \\ . & . & . & . \\ tn12 & tn22 & . & tnn2 \end{bmatrix}, \ldots\ldots\ldots\ldots \begin{bmatrix} t11k & t12k & . & t1nk \\ t21k & t22k & . & t2nk \\ . & . & . & . \\ tn1k & tn1k & . & tnnk \end{bmatrix} \right]$$

A.3 Transfer matrix coefficient

An element t_{ij} of the transfer matrix (refer to Figure A.2 below).

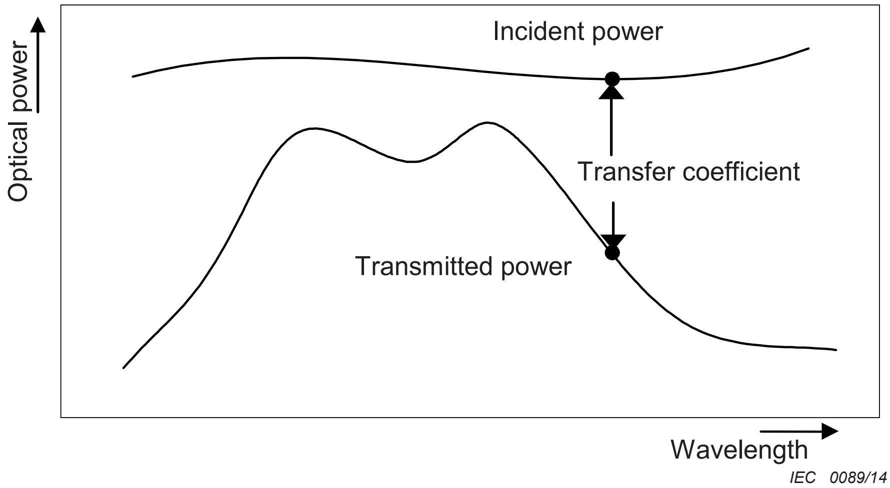


Figure A.2 – Illustration of transfer matrix coefficient

A.4 Logarithmic transfer matrix

In general, the logarithmic transfer matrix is:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot & \cdot & \cdot & a_{1n} \\ a_{21} & & & & & \\ \cdot & & & & & \\ \cdot & & & a_{ij} & & \\ \cdot & & & & & \\ a_{n1} & & & & & a_{nn} \end{bmatrix}$$

where

a_{ij} is the optical power reduction in decibels out of port j with unit power into port i, that is:

$$a_{ij} = -10\log t_{ij}$$

where

t_{ij} is the transfer matrix coefficient;

a_{ij} is a positive number larger than or equal to zero. The same as the transfer matrix coefficient. A more generic expression of the logarithmic transfer matrix is shown as follows:

$$A = \left[\begin{bmatrix} a111 & a121 & . & a1n1 \\ a211 & t221 & . & a2n1 \\ . & . & . & . \\ an11 & an21 & . & ann1 \end{bmatrix}, \begin{bmatrix} a112 & a122 & . & a1n2 \\ a212 & a222 & . & a2n2 \\ . & . & . & . \\ an12 & an22 & . & ann2 \end{bmatrix}, \ldots\ldots\ldots \begin{bmatrix} a11k & a12k & . & a1nk \\ a21k & a22k & . & a2nk \\ . & . & . & . \\ an1k & an1k & . & annk \end{bmatrix} \right]$$

Annex B
(informative)

Specific performances of WDM devices for bidirectional transmission system (example)

B.1 Generic

The typical port configuration of WDM devices is 1 x N. 1 x N WDM devices can be used for MUXs (wavelength multiplexers) and DEMUXs (wavelength demultiplexers). Another application of 1 x N WDM devices is to bidirectional transmission system. Figure B.1 shows the examples of a unidirectional transmission application and a bidirectional transmission application of a 1 x 2 WDM device. Figure B.1a shows a unidirectional transmission system application (DEMUX application) and Figure B.1b shows a bidirectional transmission system application.

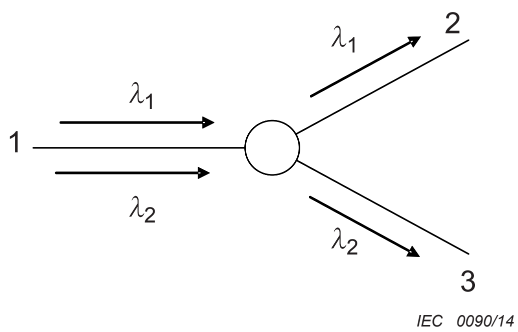


Figure B.1a – Unidirectional transmission system application of a 1x2 WDM device (DEMUX)

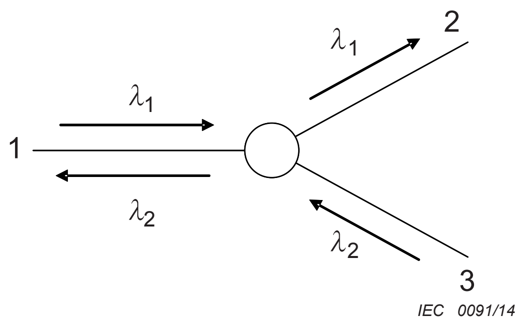


Figure B.1b – Bidirectional transmission system application of a 1x2 WDM device

Key

λ_k wavelength

Figure B.1 – Uni-directional and bi-directional transmission system application of a 1 x 2 DM device

For the unidirectional transmission system in Figure B.1a, port 1 is an input port and port 2 and 3 are output ports. Wavelength λ_1 transmits to port 2 and wavelength λ_2 to port 3. For this application, far-end crosstalk can be defined for a WDM device. The meaning of "far-end" is the other side. Far-end crosstalk, XT_{FE} for port 2 (λ_1) is defined as the following formula used by logarithmic transfer matrix coefficient.

$$XT_{FE} \text{ (port 2, } \lambda_1) = a_{121} - a_{122}$$

For port 3 and λ_2, the far-end crosstalk is $a_{132} - a_{131}$. Far-end crosstalk is negative value expressed in dB.

Far-end isolation can also be defined. Far-end isolation is a_{122} for port 2, a_{131} for port 3. Far-end isolation has the same meaning as "commonly-used" isolation.

For the bidirectional transmission system in Figure B.1b, port 1 is the input port for λ_1 and the output port for λ_2. For this application, near-end isolation and near-end crosstalk can be defined. The meaning of "near-end" is the same side. Near-end isolation for port 2 (λ_1) is a_{322}. Near-end crosstalk, XT_{NE} for port 2 (λ_1), is defined as the following formula by logarithmic transfer matrix coefficient.

$$XT_{NE}\ (\text{port } 2,\ \lambda_1) = a_{121} - a_{322}$$

B.2 Definition of near-end isolation and near-end crosstalk

More generic definitions of near-end isolation and near-end crosstalk are explained as shown below.

B.2.1

bidirectional (near-end) isolation

for a bidirectional WDM multiplexer (MUX)/demultiplexer (DMUX) device, bidirectional (near-end) isolation is defined as

$$BCA = a_{mox}$$

where

a_{mox} is an element of the logarithmic transfer matrix;

m is the MUX input port number;

o is the DMUX output port number;

x is the wavelength number associated with port m.

B.2.2

bidirectional (near-end) crosstalk

for a bidirectional WDM-MUX/DEMUX device, near-end crosstalk is defined by subtraction from the logarithmic transfer matrix coefficient of conducting port pair with conducting channel, to bidirectional near-end isolation

Note 1 to entry: Because bidirectional WDM-MUX/DMUX devices have both input channels and output channels at the same side of the device, input light for one direction can appear on the output port for the other direction. The bidirectional (near-end) crosstalk is defined to be:

$$I_B = a_{mox} - a_{doc}$$

where

a_{mox} is an element of the logarithmic transfer matrix;

a_{doc} is an element of the logarithmic transfer matrix;

d is the DMUX input port number;

o is the DMUX output port number;

c is the (channel) wavelength number associated with port o;

m is the MUX input port number;

x is the wavelength number associated with port m.

Note 2 to entry: In the example given below of a four-wavelength bidirectional system, wavelengths 1 and 2 travel from left to right and wavelengths 3 and 4 from right to left (see Figure B.2).

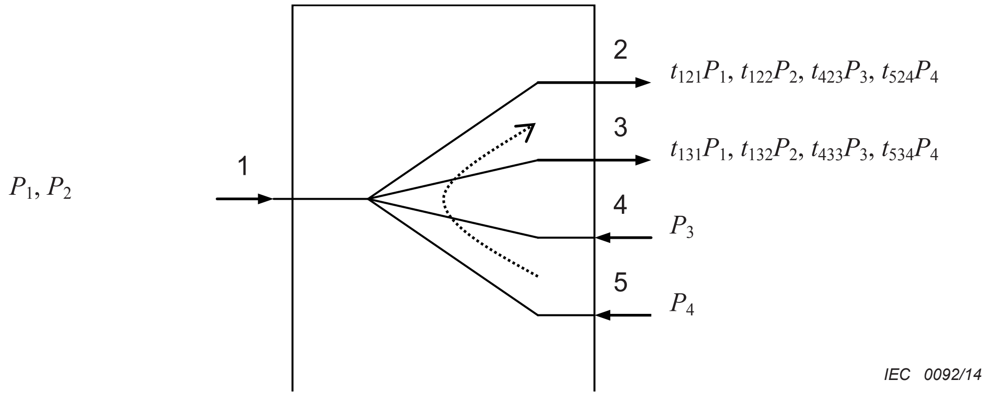


Figure B.2 – Illustration of a four-wavelength bidirectional system

For the example given above, the bidirectional isolation of port 2 to wavelength 3 is $a_{423} - a_{121}$.

Annex C
(informative)

Transfer matrix as applications of WDM devices (example)

C.1 Generic

There are several applications of WDM devices for fibre optic communication systems, such as wavelength multiplexer, wavelength demultiplexer, wavelength multiplexer/demultiplexer, wavelength router and wavelength channel add/drop. These applications of WDM devices can be recognized as a function used in optical transmission systems. These functions can be expressed by transfer matrixes.

The schematic diagrams which follow do not necessarily correspond to the physical layout of the branching device and its ports.

In the diagrams shown below, the arrows on the ports indicate the direction of travel of optical power. A port with no arrow is nominally isolated from the indicated launched port.

The following devices include only those which are in common use within industry at present. They do not include every possible form of transfer matrix.

For the definition of the transfer matrix refer to 3.1.2.

The transfer coefficients are nominally equal to zero or greater than zero. The nominal values of the transfer coefficients are indicated.

C.2 Wavelength multiplexer

A wavelength-selective branching device whose function is to combine N different optical signals differentiated by wavelength from N corresponding input ports on to a single output port. Port 0 is the output port (see Figure C.1).

Key

λ_k wavelength

Figure C.1 – Example of a wavelength multiplexer

The wavelength dependent transfer matrix is:

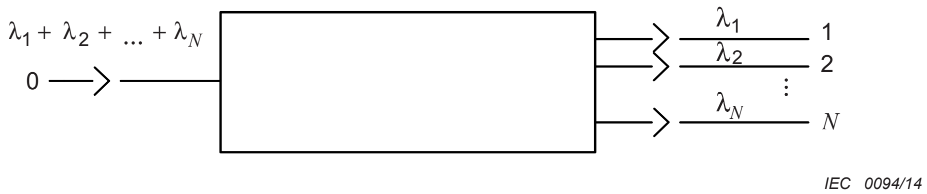
Receive ports

Launch ports	0	1		. . .	N
0	n/a	n/a		. . .	n/a
1	t_{10}	t_{11}	t_{12}	. .	t_{1N}
2	t_{20}				
.	.				
.	.				
N	t_{N0}	t_{N1}			t_{NN}

For $i \neq 0$ each coefficient t_{i0} is ideally 1 at wavelength i and 0 at all other operating wavelengths. The coefficients t_{ij} (where i , $j \neq 0$ and $i \neq j$) are related to the directivity, while the coefficients t_{ii} are related to the return loss.

C.3 Wavelength demultiplexer

A wavelength-selective branching device whose function is to separate N different optical signals, differentiated by wavelength from a single input port to N corresponding output ports. Port 0 is the input port (see Figure C.2).



Key

λ_k wavelength

Figure C.2 – Example of a wavelength demultiplexer

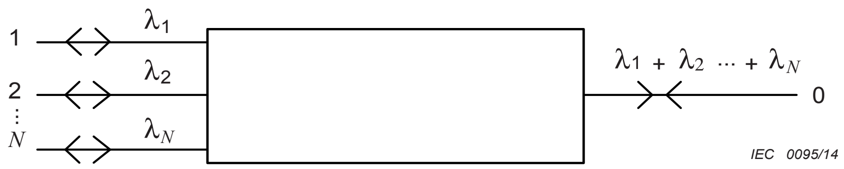
The wavelength dependent transfer matrix is:

Launch ports \ Receive ports	0	1	.	.	.	N
0	t_{00}	t_{01}	t_{02}	.	.	t_{0N}
1	n/a	n/a	.	.	.	n/a
2	.					
.	.					
.	.					
N	n/a	n/a				n/a

For $i \neq 0$ each coefficient t_{0i} is ideally 1 at wavelength i and 0 at all other operating wavelengths. t_{ii} is related to the return loss.

C.4 Wavelength multiplexer/demultiplexer

A wavelength-selective branching device which performs functions both of a wavelength multiplexer and demultiplexer. Port 0 is the output for the multiplexer and input for the demultiplexer (see Figure C.3).



Key

λ_k wavelength

Figure C.3 – Example of a wavelength multiplexer/demultiplexer

The wavelength dependent transfer matrix is:

Receive ports

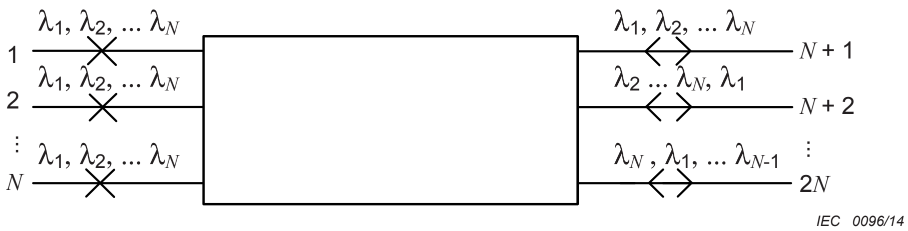
Launch ports

$$
\begin{array}{c} \\ 0 \\ 1 \\ 2 \\ \cdot \\ \cdot \\ N \end{array}
\begin{array}{c}
\begin{array}{cccccc} 0 & 1 & . & . & . & N \end{array} \\
\left[
\begin{array}{c|ccccc}
t_{00} & t_{01} & t_{02} & \cdot & \cdot & t_{0N} \\
\hline
t_{10} & t_{11} & t_{12} & \cdot & \cdot & t_{1N} \\
t_{20} & & & & & \\
\cdot & & & & & \\
\cdot & & & & & \\
t_{N0} & t_{N1} & & & & t_{NN}
\end{array}
\right]
\end{array}
$$

For $i \neq 0$ each coefficient t_{0i} and t_{i0} is ideally 1 at wavelength i and 0 at all other operating wavelengths. The coefficients t_{ij} (where $i, j \neq 0$ and $i \neq j$) are related to the directivity, while the coefficients t_{ij} are related to the return loss.

C.5 Wavelength router

A wavelength-selective branching device which performs functions of routing on a set of N operating wavelengths, i.e. each of the N operating wavelengths is transmitted through the device to any of the output ports, depending on the selected input ports (see Figure C.4).



Key

λ_k wavelength

Figure C.4 – Example of a wavelength router

The wavelength dependent transfer matrix is:

Receive ports

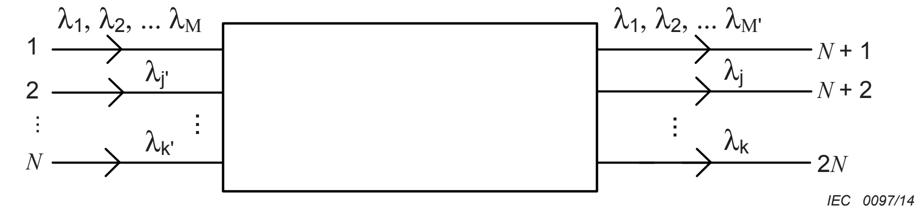
Launch ports

$$
\begin{array}{c} \\ 1 \\ 2 \\ . \\ . \\ N \\ (N+1) \\ . \\ . \\ (2N) \end{array}
\begin{array}{c} \begin{array}{cccc|cc} 1 & 2 & . & N & (N+1) & (2N) \end{array} \\
\left[\begin{array}{cccc|cc}
t_{11} & t_{12} & . & t_{1N} & t_{1(N+1)} & t_{1(2N)} \\
t_{21} & & & & & . \\
. & & & & & . \\
. & & & & & . \\
t_{N1} & & & t_{NN} & t_{N(N+1)} & t_{N(2N)} \\
\hline
t_{(N+1)1} & & & t_{(N+1)N} & t_{(N+1)(N+1)} & t_{(N+1)(2N)} \\
 & & & & & . \\
 & & & & & . \\
t_{(2N)1} & & & t_{(2N)N} & t_{(2N)(N+1)} & t_{(2N)(2N)}
\end{array} \right] \end{array}
\qquad
\left[\begin{array}{c|c} A & C \\ \hline C & B \end{array} \right]
$$

In zones A and B of the matrix the coefficients t_{ij} are related to the return loss, while the coefficients t_{ij}, where $i \neq j$, are related to the directivity. The zones C are nominally symmetric and identical matrices; in these zones t_{ij} is nominally 1 at the operating wavelength $[i + j - N - 2]_{N+1}$ (where $[M]_N$ defines the function M mod N) and 0 at all other operating wavelengths.

C.6 Wavelength channel add/drop

A wavelength-selective branching device which performs functions of dropping (N-1) channels in a set of M operating wavelengths (where N = 2..M +1), and inserting, at the same time (N-1) channels at the same nominal operating wavelength of the dropped channels (see Figure C.5).



Key

λ_k wavelength

Figure C.5 – Example of wavelength channel add/drop

The wavelength dependent transfer matrix is:

Receive ports

$$
\text{Launch ports}\quad
\begin{array}{c}
 \\ 1 \\ 2 \\ \cdot \\ \cdot \\ N \\ (N+1) \\ \cdot \\ \cdot \\ (2N)
\end{array}
\begin{array}{cccc|cc}
1 & 2 & . & N & (N+1) & (2N) \\
t_{11} & t_{12} & . & t_{1N} & t_{1(N+1)} & t_{1(2N)} \\
t_{21} & & & & & \cdot \\
\cdot & & & & & \cdot \\
\cdot & & & & & \cdot \\
t_{N1} & & & t_{NN} & t_{N(N+1)} & t_{N(2N)} \\
\hline
\text{n/a} & & & \text{n/a} & \text{n/a} & \text{n/a} \\
 & & & & & \cdot \\
 & & & & & \cdot \\
\text{n/a} & & & \text{n/a} & \text{n/a} & \text{n/a}
\end{array}
\qquad
\left[\begin{array}{c|c}
A & B \\
\hline
\text{n/a} & \text{n/a}
\end{array}\right]
$$

The transfer coefficients in the zone A of the matrix are nominally zero (in this zone of the matrix the coefficients t_{ii} are related to the return loss, while the coefficients t_{ij}, where $i \neq j$, are related to the near-end crosstalk). In the zone B the coefficient $t_{1(N+1)}$ is nominally 1 at all the $M - N + 1$ operating wavelength $\lambda_i \neq \lambda_{j,k}$ and nominally 0 at all other operating wavelength; the coefficients $t_{j\,(N+1)}$ where $j \neq 1$ are nominally 1 at the operating wavelength λ_j and 0 at all other operating wavelength and are nominally identical to the coefficients t_{1j} where $j \neq (N+1)$; all the other coefficients are nominally zero (they are related to the directivity).

Annex D
(informative)

Example of technology of thin film filter WDM devices

D.1 General

A WDM device using thin film filter (TTF) technology consists of a thin film filter coated on a substrate (generally glass plate), optical fibres as input/output ports and lenses that convert divergent light to/from collimated light (refer Figure D.1).

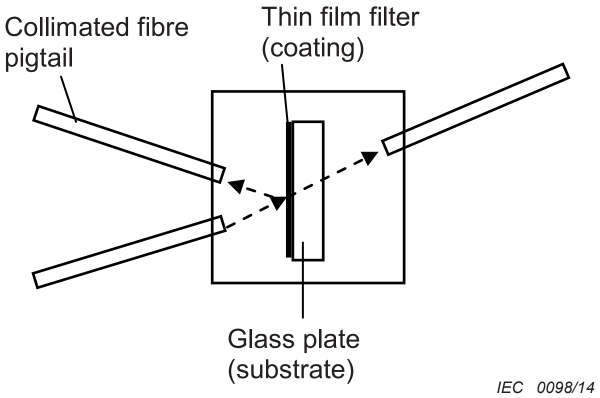
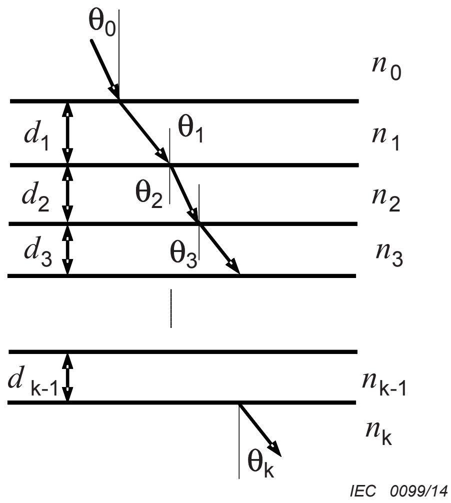


Figure D.1 – Schematic configuration of a thin film filter WDM device

D.2 Thin film filter technology

The fundamental structure of a thin-film filter is based on the Fabry-Perot etalon, which acts as a bandpass filter. A signal at the passband wavelength passes through the filter, and other wavelengths are reflected with high reflectivity. The centre wavelength of the passband is determined by the cavity length of the filter.

Multilayer thin-film filters are known as wavelength selective optical filters. The structure of multiplayer thin-film filters is one where alternating layers of an optical coating are built up on a glass substrate. By controlling the thickness and number of the layers, the wavelength of the passband of the filter can be tuned and made as wide or as narrow as desired.



Key

d_k thickness;

n_k refractive index;

θ_k incident angle

Figure D.2 – Structure of multilayer thin film

D.3 Typical characteristics of thin film filter

Figure D.3 shows the typical characteristics of a 1 510 nm and C-band WDM device that uses thin film filter technology. This device has three ports.

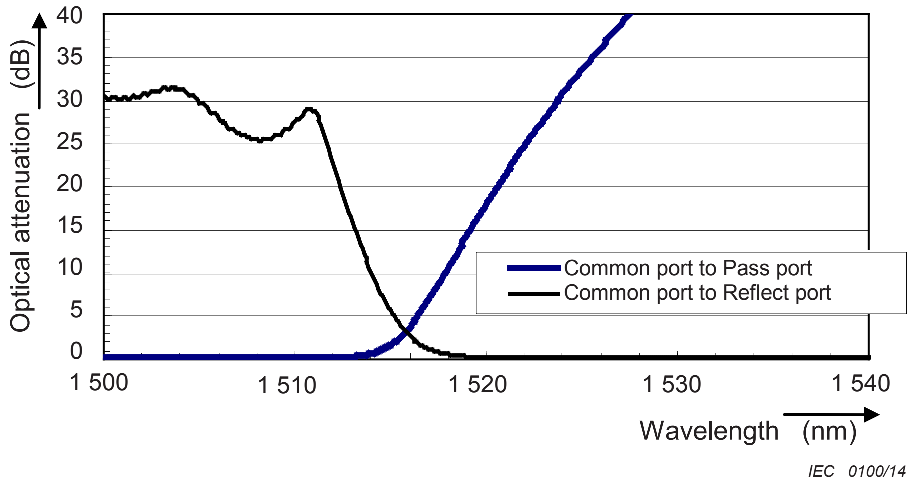


Figure D.3 – Typical characteristics of 1 510 nm and C-band WDM device using thin film filter technology

Annex E
(informative)

Example of technology of fibre fused WDM devices

E.1 General

A fused coupler is an important passive component in optical telecommunication systems, which perform functions including light branching and splitting in optical fibre circuits, MUX/ DEMUX, filtering, wavelength independent splitting and polarization selective splitting.

The simplest fusion coupler is a 2 x 2 bidirectional type, and it is made by joining two independent single mode fibres, which work on the fundamental principle of coupling between parallel optical waveguides; where the claddings of each fibre are fused over a small region (Figure E.1). Therefore, the two fibres must be brought sufficiently close to each other.

The fundamental rule in theory involves a partial or complete transfer of power between the two waveguides as a result of energy transfer. The exchange of optical power occurs due to optical coupling between the evanescent wave of the guided mode of one core and that of the natural mode of the second core.

The uniformly spaced parallel interaction region plays the key role in the coupling process. The interaction region has a longitudinally invariant structure and the optical coupling that takes place in this waist region can be understood in terms of coupling mode analysis.

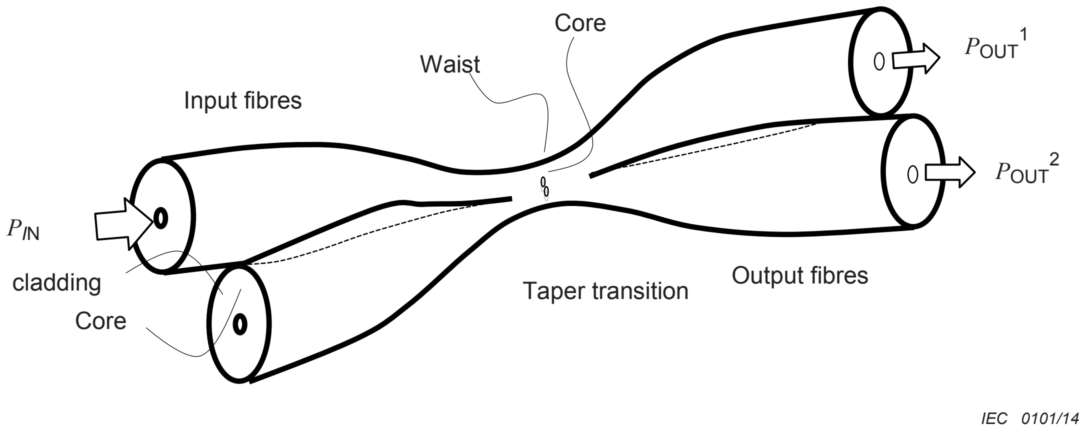


Figure E.1 – Structure of a fused bi-conical tapered 2x2 coupler

One of the various packaging schemes of the fused couplers is shown in Figure E.2. The package generally involves a double-layered structure designed to protect the fused bi-conical region.

The material properties of the primary packaging substrate have a large influence on the performance of the coupler because of the variations in the environmental and thermal conditions. The best material for the primary package is synthetic quartz (SQ) since it exhibits the same behaviour as of the fibre. The primary packaging substrate is semi-cylindrical type with a rectangular groove, which can be easily positioned and fixed by using a positioning stage. And it is fixed at the ends of a parallel region using a suitable adhesive. After primary packaging, the fused coupler is still bare and needs to be further encapsulated for the protection. The device with the primary package is inserted into a metal tube and is shielded at the both ends with sealants to keep it airtight. As the material of the main body, the metal alloy is used, which has approximately the same coefficient of thermal expansion as SQ.

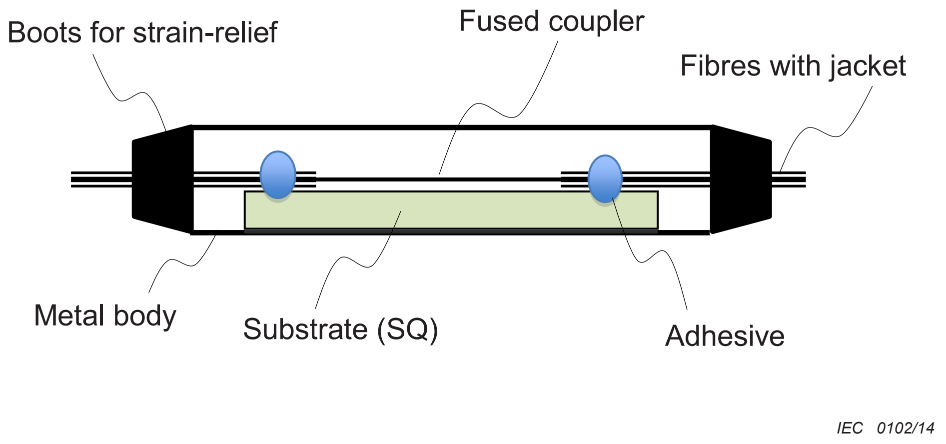


Figure E.2 – Typical scheme for a fused coupler

E.2 Typical characteristics of fibre fused WDM devices

Figure E.3 shows typical wavelength dependent characteristics of the transmittance for bar ports and cross ports.

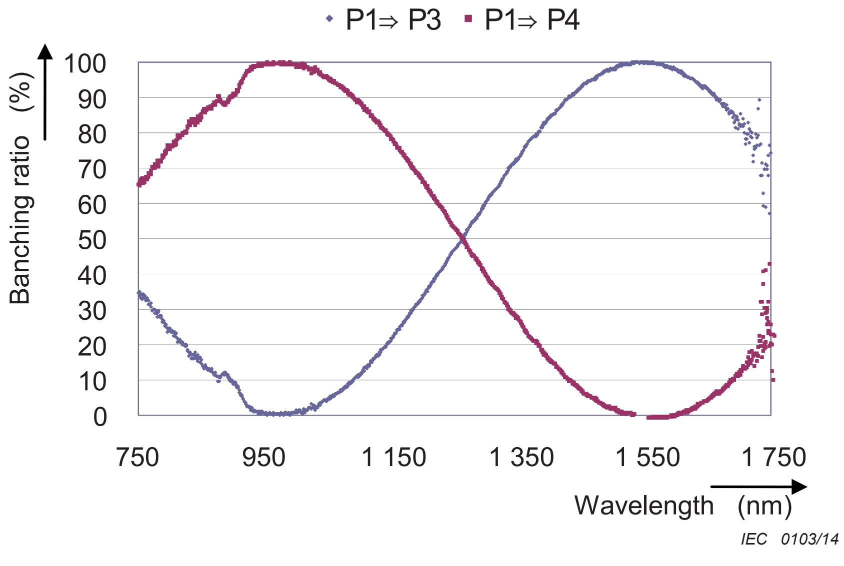


Figure E.3 – Typical characteristics of a fibre fused WDM device

Annex F
(informative)

Example of arrayed waveguide grating (AWGs) technology

F.1 General

An arrayed waveguide grating is an optical dispersive element based on planar lightwave circuit technology. It is integrated with two slab waveguides, and input and output waveguides in a single chip. The integrated chip works like a spectrometer and is used as a multi/demultiplexer in DWDM transmission systems.

Figure F.1 shows the basic configuration of an AWG. The incoming light diffracts in the first slab waveguide and enters an array of channel waveguides with different lengths and thus provides a wavelength-dependent phase shift in the array. After propagating through the array, the light converges in the other slab waveguide like a concave mirror. Thanks to the phase shift, the focusing position depends on the input light wavelength. As a result, the wavelength multiplexed input light is demultiplexed to the respective output ports. In many cases, AWG chips are made of silica glass on a silicon substrate because it has a low propagation loss and can be efficiently coupled with single mode optical fibres.

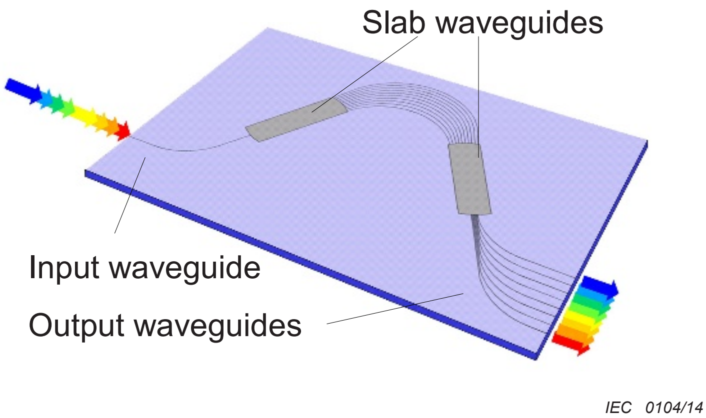
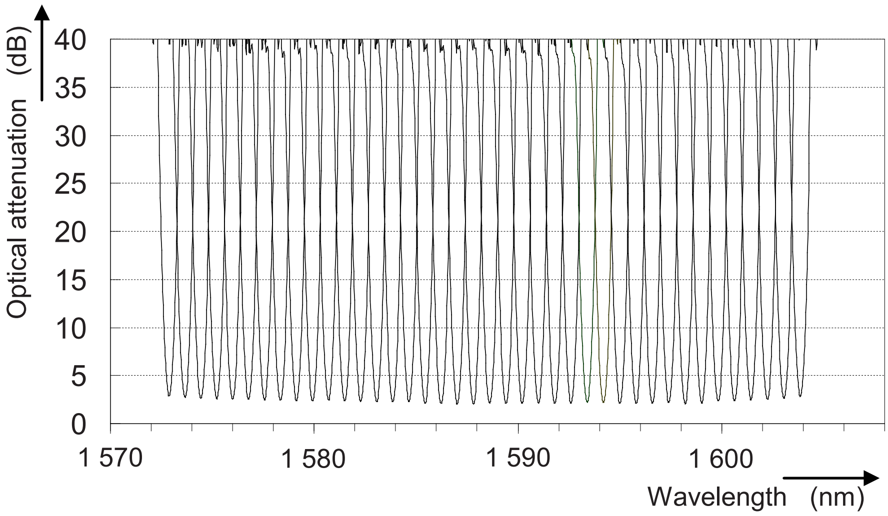


Figure F.1 – Basic configuration of AWG

F.2 Typical characteristics of AWG

Figure F.2 shows a typical optical attenuation spectrum of an AWG wavelength multi/demultiplexer which is designed for 100 GHz-spacing, 40-channel DWDM systems. Each spectral curve has a Gaussian profile in the vicinity of its peak transmission wavelength. A flat non-Gaussian spectrum can be realized by installing a parabolic input waveguide aperture or a Mach-Zehnder interferometer in front of the input side slab waveguide.



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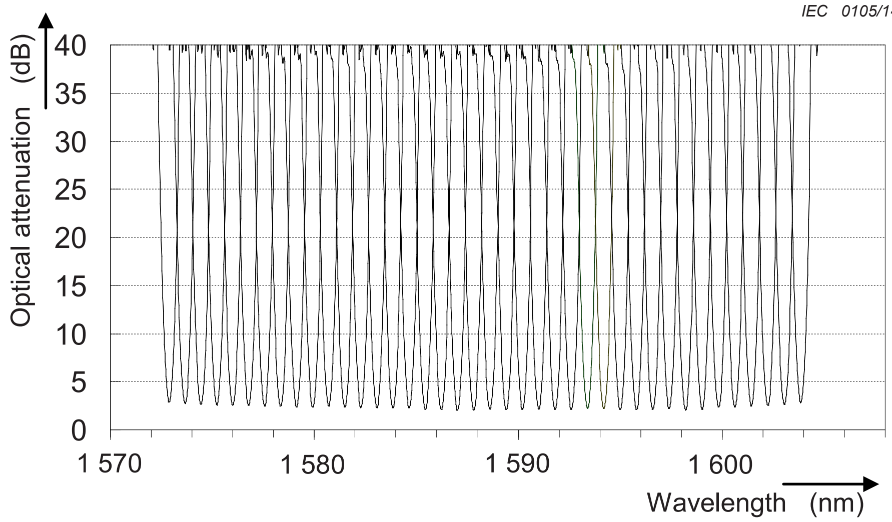

IEC 0106/14

Figure F.2 – Example of AWG characteristics

Annex G
(informative)

Example of FBG filter technology

G.1 General

A fibre Bragg grating (FBG) can reflect particular light wavelengths of light and transmit other wavelengths. It is used with an optical circulator in order to pick up reflected particular wavelengths as shown in Figure G.1.

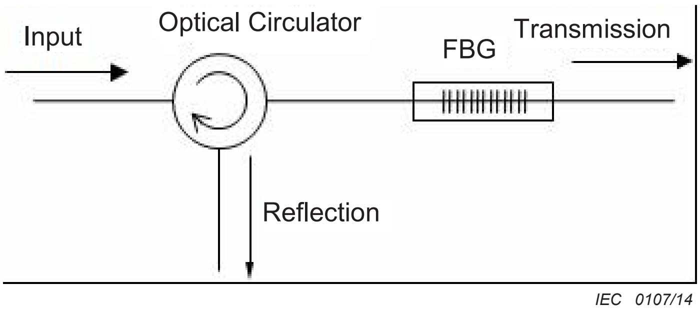

Figure G.1 – Usage of fibre Bragg grating filter

An FBG has a periodic variation to the refractive index of the fibre core as shown in Figure G.2 and this periodic variation to the refractive index generates a wavelength specific mirror. Therefore, an FBG can be used as an optical filter or as a wavelength-specific reflector.

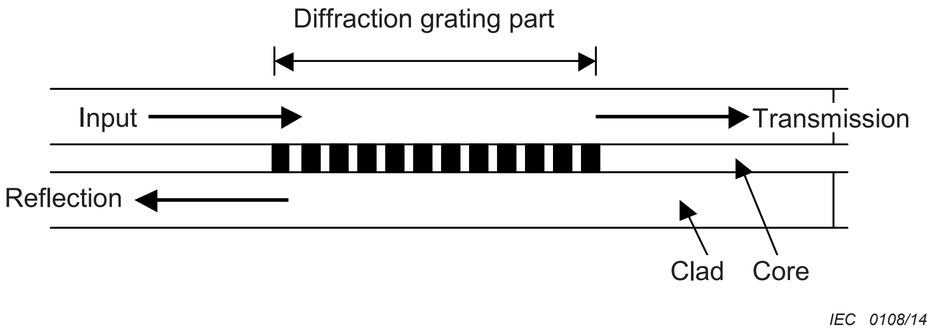

Figure G.2 – Function and mechanism of fibre Bragg grating

The fundamental principle of a FBG is Bragg reflection. The refractive index is assumed to exhibit a periodic variation over a defined length. The reflected wavelength (λ_B), called the Bragg wavelength, is defined by the relationship,

$$\lambda_B = 2n\Lambda$$

where n is the average refractive index of the grating and Λ is the period of the refractive index variation.

The bandwidth ($\Delta\lambda$), is given by

$$\Delta\lambda = \left[\frac{2\delta n_0 \eta}{\pi}\right]\lambda_B$$

where δn_0 is the variation in the refractive index, and η is the power fraction in the core.

The peak reflection ($P_B(\lambda_B)$) is approximately given by

$$P_B(\lambda_B) \approx \tanh^2\left[\frac{N\eta\delta n_0}{n}\right]$$

G.2 Typical characteristics of FBG filter

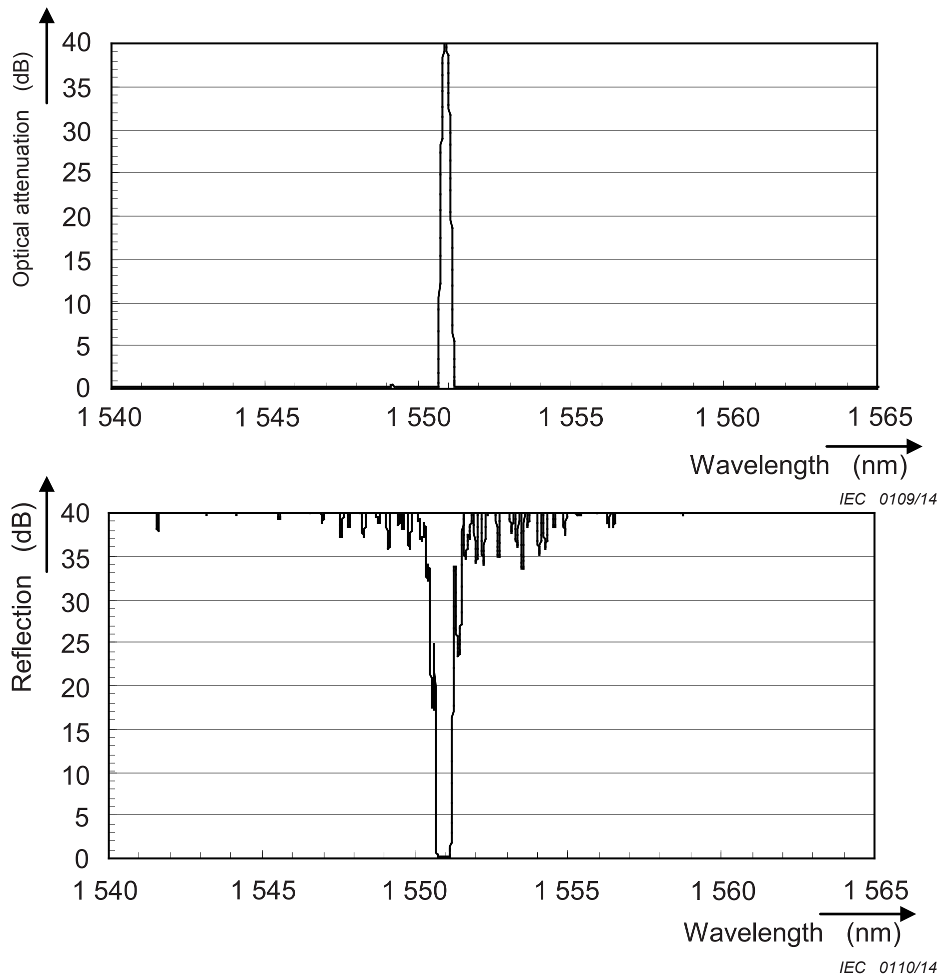

Figure G.3 – Example of FBG filter characteristics

Bibliography

ITU-T Recommendation G.694.1, *Spectral grids for WDM applications: DWDM frequency grid*

ITU-T Recommendation G.694.2, *Spectral grids for WDM applications: CWDM wavelength grid*

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