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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Transmission media characteristics – Characteristics of optical components and subsystems

# Transmission characteristics of optical components and subsystems

ITU-T Recommendation G.671

ITU-T G-SERIES RECOMMENDATIONS

**TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS**

| | |
|---|---|
| INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS | G.100–G.199 |
| GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS | G.200–G.299 |
| INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES | G.300–G.399 |
| GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES | G.400–G.449 |
| COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY | G.450–G.499 |
| TESTING EQUIPMENTS | G.500–G.599 |
| TRANSMISSION MEDIA CHARACTERISTICS | G.600–G.699 |
| General | G.600–G.609 |
| Symmetric cable pairs | G.610–G.619 |
| Land coaxial cable pairs | G.620–G.629 |
| Submarine cables | G.630–G.649 |
| Optical fibre cables | G.650–G.659 |
| **Characteristics of optical components and subsystems** | **G.660–G.699** |
| DIGITAL TERMINAL EQUIPMENTS | G.700–G.799 |
| DIGITAL NETWORKS | G.800–G.899 |
| DIGITAL SECTIONS AND DIGITAL LINE SYSTEM | G.900–G.999 |
| QUALITY OF SERVICE AND PERFORMANCE | G.1000–G.1999 |
| TRANSMISSION MEDIA CHARACTERISTICS | G.6000–G.6999 |
| DIGITAL TERMINAL EQUIPMENTS | G.7000–G.7999 |
| DIGITAL NETWORKS | G.8000–G.8999 |

*For further details, please refer to the list of ITU-T Recommendations.*

# ITU-T Recommendation G.671

## Transmission characteristics of optical components and subsystems


### Summary

This Recommendation covers the transmission related aspects of all types of optical components used in long haul networks and access networks. A broad range of types of optical components is included in this Recommendation. This Recommendation also includes transmission characteristics of optical components under the full range of operating conditions, but does not specify the operating service conditions, installation aspects, or other aspects of components not affecting the optical transmission path. This Recommendation also draws upon the relevant IEC definitions and test methods where applicable.



### Source

ITU-T Recommendation G.671 was revised by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 29 June 2002.

## FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

## NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

## INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

## CONTENTS

# ITU-T Recommendation G.671

## Transmission characteristics of optical components and subsystems

### 1 Scope

The object of this Recommendation is to identify the transmission related parameters for each of the components listed below and define the values of such parameters specifiable for each of the most relevant system applications. Where applicable, IEC definitions will be used. Applicable systems are anticipated to be covered by the following ITU-T Recommendations:

- Long haul terrestrial networks: Networks using equipment with interfaces according to ITU-T Rec. G.957, and Recommendations of optical interfaces for single channel and multichannel systems with optical amplifiers including ITU-T Recs G.691, G.692 and G.959.1.
- Access networks: Networks using equipment according to ITU-T Rec. G.982, and the Recommendation of optical access networks to support services greater than the ISDN primary bit-rate (when published).

This Recommendation covers optical components used in the optical networks described in the Recommendations above. Where possible, common parameter values will be defined across all applications, but where necessary, specific values to each of the application groups may be given.

This Recommendation covers the transmission characteristics in the various operating conditions of the following optical components (listed in alphabetical order):

- Optical add drop multiplexer (OADM) subsystem;
- Asymmetric branching component;
- Optical attenuator;
- Optical branching component (wavelength non-selective);
- Optical connector;
- Dynamic channel equalizer (DCE);
- Optical filter;
- Optical isolator;
- Passive dispersion compensator;
- Optical splice;
- Optical switch;
- Optical termination;
- Tuneable filter;
- Optical wavelength multiplexer (MUX)/demultiplexer (DMUX);
  - Coarse WDM device;
  - Dense WDM device;
  - Wide WDM device.

This Recommendation does not cover:

- Installation aspects, service conditions and environmental and mechanical characteristics not affecting the optical transmission path of the various optical components.

- Specific details of test methods. According to an agreement with IEC TC86 and its subcommittees, the guidelines to be followed for the measurement of most of the parameters defined in clause 5 are given in the IEC 61300-3 series of Transmission and Geometrical Test Methods. The tables in clause 5 indicate the recommended test methods, collecting the test parameters into homogeneous groups and quoting for each group the relevant IEC Basic Specification number(s).

## 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.


[1] ITU-T Recommendation G.650.1 (2002), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable*.

[2] ITU-T Recommendation G.650.2 (2002), *Definitions and test methods for statistical and non-linear attributes of single-mode fibre and cable*.

[3] ITU-T Recommendation G.652 (2000), *Characteristics of a single-mode optical fibre cable*.

[4] ITU-T Recommendation G.653 (2000), *Characteristics of dispersion-shifted single-mode optical fibre cable*.

[5] ITU-T Recommendation G.654 (2002), *Characteristics of cut-off single-mode optical fibre and cable*.

[6] ITU-T Recommendation G.655 (2000), *Characteristics of a non-zero dispersion shifted single-mode optical fibre cable*.

[7] ITU-T Recommendation G.661 (1998), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.

[8] ITU-T Recommendation G.662 (1998), *Generic characteristics of optical amplifier devices and subsystems*.

[9] ITU-T Recommendation G.691 (2000), *Optical interfaces for single-channel STM-64, STM-256 and other SDH systems with optical amplifiers*.

[10] ITU-T Recommendation G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[11] ITU-T Recommendation G.693 (2001), *Optical interfaces for intra-office systems*.

[12] ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid*.

[13] ITU-T Recommendation G.694.2 (2002), *Spectral grids for WDM applications: CWDM wavelength grid*.

[14] ITU-T Recommendation G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[15] ITU-T Recommendation G.959.1 (2001), *Optical transport network physical layer interfaces*.

[16] ITU-T Recommendation G.982 (1996), *Optical access network to support services up to the ISDN primary rate or equivalent bit rates*.

[17] IEC-61300-3 *series of Transmission and geometrical parameters*.

[18] IEC 61300-3-2:1999, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-2: Examinations and measurements – Polarization dependence of attenuation in a single-mode fibre optic device*.

[19] IEC 61300-3-4:2001, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-4: Examinations and measurements – Attenuation*.

[20] IEC 61300-3-6:1997, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements –Return loss*.

[21] IEC 61300-3-7:2000, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-7: Examinations and measurements – Wavelengh dependence of attenuation and return loss*.

[22] IEC 61300-3-12:1997, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-12: Examinations and measurements – Polarization dependence of attenuation of a single-mode fibre-optic component: Matrix calculation method*.

[23] IEC 61300-3-19:1997, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-19: Examinations and measurements – Polarization dependence of return loss of a single-mode fibre-optic component*.

## 3 Terms and definitions

Most of the definitions of parameters specified in this Recommendation, for each of the abovementioned passive components, are given in the corresponding IEC generic specification and summarized below:

IEC 60869-1 (1999), Generic specification for fibre-optic attenuators.

IEC 60875-1 (2000), Generic specification for fibre-optic branching devices.

IEC 60876-1 (2001), Generic specification for fibre-optic switches.

IEC 61202-1 (2000), Generic specification for fibre-optic isolators.

IEC 61931-1, Fibre-optic terminology.

Where IEC definitions are used, they are noted as such. Additional parameters under study or not defined in IEC documents are also given in this clause.

### 3.1 Component definitions

**3.1.1 optical add/drop multiplexer (OADM) subsystem**: For further study.

**3.1.2 asymmetric branching component**: A passive component (wavelength non-selective) possessing three or more ports which shares optical power among its ports in a predetermined fashion, without any amplification, switching, or other active modulation (1.1/IEC 60875-1). A tap coupler is used as a synonym for an asymmetric branching device.

The majority of the optical power is normally transferred to the main port of a tap coupler while a small fraction (1% to 20%) is transferred to the tap port. The ratio of the optical power in the main port to the tap port in percent is called the coupling fraction F.

Optical branching devices can be divided into categories of symmetric and asymmetric. A device whose transfer matrix is diagonally asymmetric, i.e. where for all $i$ and $o$, $t_{io}$ and $t_{oi}$ are nominally unequal (1.3.19/IEC 60875-1).

**3.1.3 optical attenuator**: A passive component that produces a controlled signal attenuation in an optical fibre transmission line (1.3.1/IEC 60869-1).

**3.1.4 optical branching component (wavelength non-selective)**: A passive component (wavelength non-selective) possessing three or more ports which shares optical power among its ports in a predetermined fashion, without any amplification, switching, or other active modulation (1.1/IEC 60875-1). The term coupler (splitter-combiner) is used as a synonym for a branching device. The term is also used to define a structure for transferring optical power between two fibres or between an active device and a fibre (1.3.2/IEC 60875-1).

Optical branching devices can be divided into categories of symmetric and asymmetric. A symmetric branching component is a device whose transfer matrix is diagonally symmetric, i.e. where for all $i$ and $o$, $t_{io}$ and $t_{oi}$ are nominally equal (1.3.18/IEC 60875-1).

**3.1.5 optical connector**: A component normally attached to an optical cable or piece of apparatus for the purpose of providing frequent optical interconnection/disconnection of optical fibres or cables (6.01/IEC 61931-1).

**3.1.6 dynamic channel equalizer (DCE)**: A device that is capable of transforming, by internal or external automatic control, a multichannel input signal with time-varying averaged powers into an output signal in which all working channel powers are nominally equal or are set for a required level of pre-emphasis.

NOTE – This device may also provide the extinction of one or more of the input channels.

**3.1.7 optical filter**: A passive component used to modify the optical radiation passing through it, generally by altering the spectral distribution (6.35/IEC 61931-1). Alternative: In particular, optical filters are usually employed to reject or absorb optical radiation in particular ranges of wavelength, while transmitting optical radiation in other ranges of wavelength.

NOTE – A tuneable optical filter has the ability to track the signal wavelength variation over its operating wavelength range. A non-tuneable optical filter has a fixed value over the operating wavelength range.

**3.1.8 optical isolator**: A non-reciprocal optical device intended to suppress backward reflections along an optical fibre transmission line while having minimum insertion loss in the forward direction (1.3.1/IEC 61202-1).

**3.1.9 passive (chromatic) dispersion compensator**: A passive component used to compensate the chromatic dispersion of an optical path.

**3.1.10 optical splice**: A permanent or semi-permanent joint whose purpose is to couple optical power between two optical fibres (6.08/IEC 61931-1).

Fusion splice: a splice in which the fibre ends are joined in a permanent manner by means of fusion (6.09/IEC 61931-1).

Mechanical splice: a splice in which the fibre ends are joined in a permanent or separable manner by means other than fusion (6.10/IEC 61931-1).

**3.1.11 optical switch**: A passive component possessing two or more ports which selectively transmits, redirects, or blocks optical power in an optical fibre transmission line (1.3.1/IEC 60876-1).

**3.1.12 optical termination**: A component used to terminate a fibre (connectorized or not) in order to suppress reflections.

**3.1.13 tuneable filter**: See 3.1.7.

**3.1.14 optical wavelength multiplexer (MUX)/demultiplexer (DMUX)**: WDM Device: A wavelength selective branching device (used in WDM transmission systems) in which optical signals can be transferred between two predetermined ports, depending on the wavelength of the signal (6.51/IEC 61931-1).

Both wavelength multiplexers (MUX) and wavelength demultiplexers (DMUX) are generally called 'WDM Devices' since often the same device can be used to multiplex and demultiplex channels.

Wavelength MUX: A branching device with two or more input ports and one output port where the light in each input port is restricted to a preselected wavelength range and the output is the combination of the light from the input ports (6.52/IEC 61931-1).

Wavelength DMUX: A device which performs the inverse operation of a wavelength multiplexer, where the input is an optical signal comprising two or more wavelength ranges and the output of each port is a different preselected wavelength range (6.53/IEC 61931-1).

**3.1.14.1 coarse WDM (CWDM) device**: A class of WDM devices having a channel wavelength spacing less than 50 nm but greater than 1000 GHz (about 8 nm at 1550 nm and 5.7 nm at 1310 nm). Devices within this class can cover several spectral bands.

**3.1.14.2 dense WDM (DWDM) device**: A class of WDM devices having a channel spacing less than or equal to 1000 GHz. Devices within this class can cover one or more spectral bands.

**3.1.14.3 wide WDM (WWDM) device**: A class of WDM devices having a channel wavelength spacing greater than or equal to 50 nm. This device class typically separates a channel in one conventional transmission window (e.g. 1310 nm) from another (e.g. 1550 nm).

## 3.2 Parameter definitions

NOTE – Not all of the definitions cited in this clause apply to all devices. The relevance of a particular definition to a specific type of device will be found in clause 5.

**3.2.1 1 dB and 3 dB passband width**: The 1 dB passband width $D_1$ of an optical filter is the total frequency range over which the filter is required to have less than 1 dB of loss with respect to the minimum loss within that range. The 1 dB passband width is symmetrical with respect to the nominal centre frequency $f_c$ of the filter, i.e. the loss is required to be within 1 dB of the minimum at all frequencies between $f_c - D_1/2$ and $f_c + D_1/2$. This is illustrated in Figure 1.

The 3 dB passband width $D_3$ of an optical filter is the total frequency range over which the filter is required to have less than 3 dB of loss with respect to the minimum loss within that range. The 3 dB passband width is symmetrical with respect to the nominal centre frequency $f_c$ of the filter, i.e. the loss is required to be within 3 dB of the minimum at all frequencies between $f_c - D_3/2$ and $f_c + D_3/2$. This is illustrated in Figure 1.

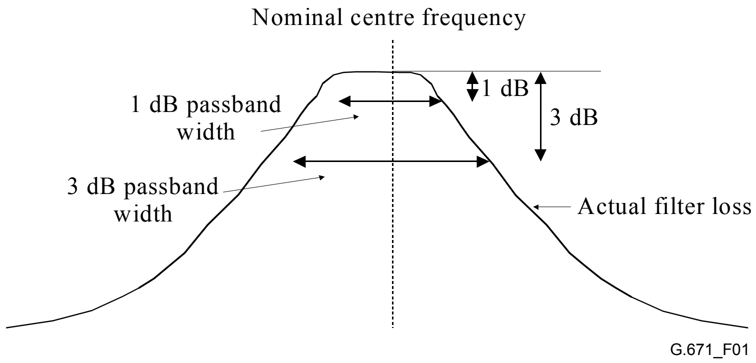


**Figure 1/G.671 – Illustration of 1 dB and 3 dB passband width**

**3.2.2 adjacent channel isolation**: The adjacent channel isolation (of a WDM device) is defined to be equal to the unidirectional (far-end) isolation of that device 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*. This is illustrated in Figure 2.

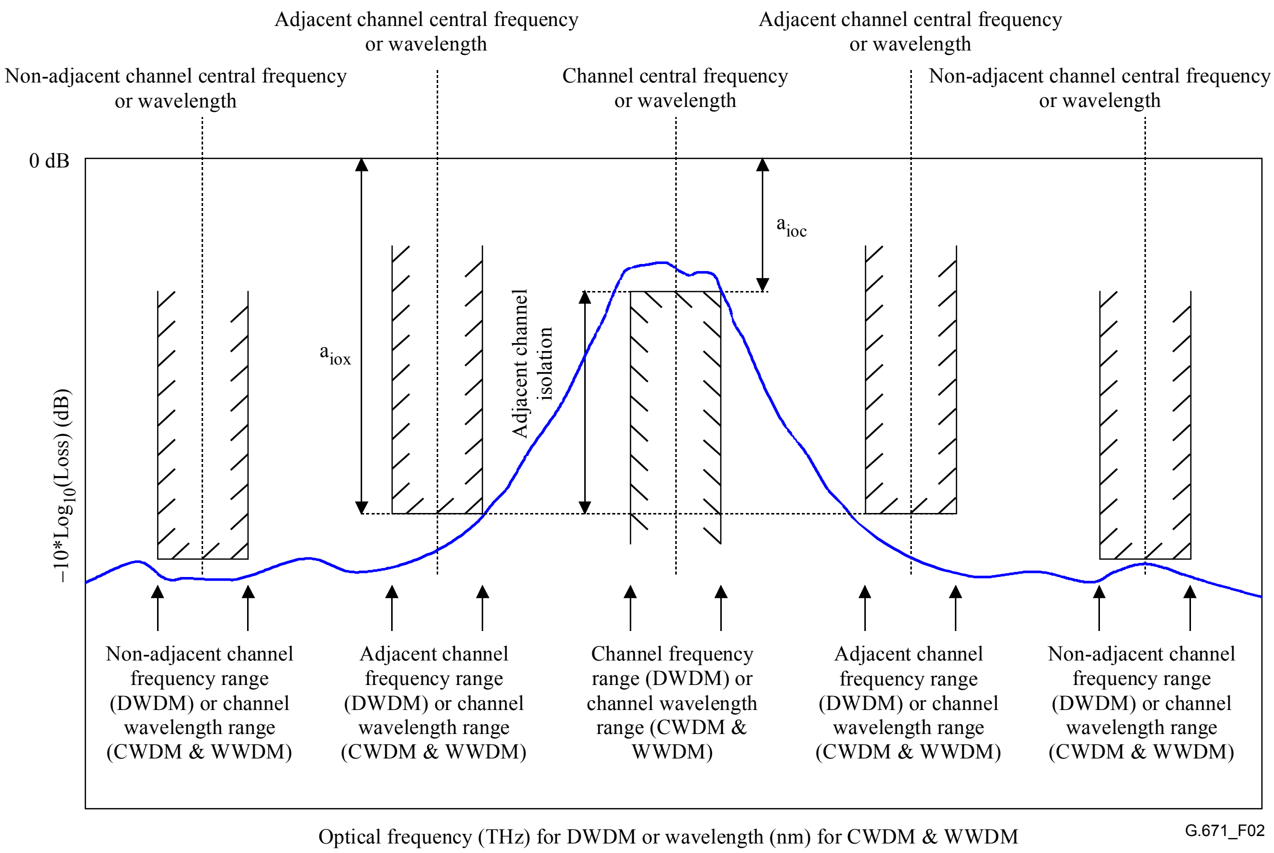


**Figure 2/G.671 – Illustration of adjacent channel isolation for a WDM device**

**3.2.3 attenuation range (variable attenuators only)**: The attenuation range (of a variable attenuator) is the difference (in dB) between the maximum and minimum nominal loss settings.

**3.2.4 backward loss (isolation) (for an optical isolator)**: A measure of the decrease in optical power (dB) resulting from the insertion of an isolator in its backward direction. The launching port is the output port and the receiving port is the input port of the isolator. It is given by the following formula:

$$BL = -10\log\left(\frac{P_{ob}}{P_{ib}}\right)$$

where:

$P_{ob}$ is the optical power emerging from the input port of the isolator when $P_{ib}$ is launched into the output port. In operating conditions, $P_{ib}$ is the optical power reflected in the backward direction into the output port of the isolator being measured (1.3.10/IEC 61202-1).

**3.2.5 bidirectional (near-end) crosstalk attenuation (for a WDM device)**: In a bidirectional WDM-MUX/DMUX device the bidirectional (near-end) crosstalk attenuation is defined to be:

$$BCA = a_{mox}$$

where:

$a_{mox}$ is an element of the logarithmic transfer matrix where *m* is the MUX input port number, *o* is the DMUX output port number and *x* is the wavelength number associated with port *m*.

**3.2.6 bidirectional (near-end) isolation (for a WDM device)**: 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.

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.

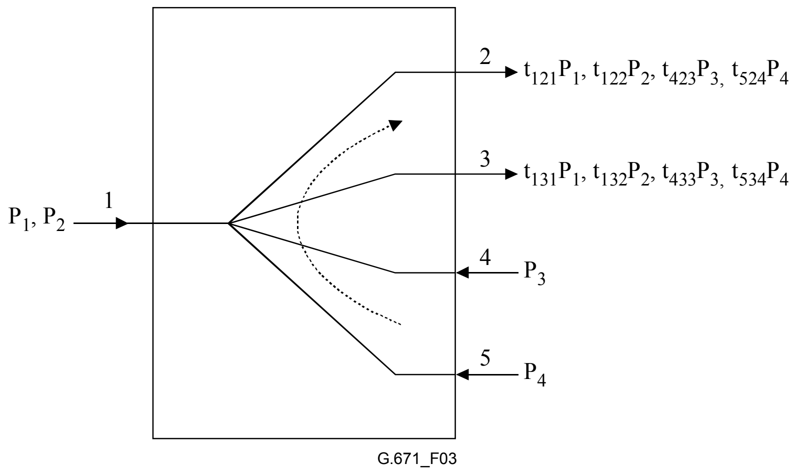


**Figure 3/G.671 – Example of bidirectional (near-end) isolation**

The bidirectional (near-end) isolation is therefore defined to be:

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

$a_{mox}$ and $a_{doc}$ are elements of the logarithmic transfer matrix where $d$ 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 and $x$ is the wavelength number associated with port $m$.

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

**3.2.7 channel extinction**: Within the operating wavelength range, the difference (in dB) between the minimum power of the non-extinguished channels (in dBm) and the maximum power of the extinguished channels (in dBm).

**3.2.8 channel frequency range**: The frequency range within which a DWDM device is required to operate with a specified performance. For a particular nominal channel central frequency, $f_{nomi}$, this frequency range is from $f_{imin} = (f_{nomi} - \Delta f_{max})$ to $f_{imax} = (f_{nomi} + \Delta f_{max})$, where $\Delta f_{max}$ is the maximum channel central frequency deviation. Nominal channel central frequency and maximum channel central frequency deviation are defined in ITU-T Rec. G.692.

**3.2.9 channel insertion loss (WDM devices)**: It is the reduction in optical power between an input and output port of a WDM device in decibels (dB). It is defined as:

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

where:

$P_{in}$ is the optical power launched into the input port and $P_{out}$ the optical power received from the output port.

NOTE – For a WDM device, it is an element $a_{iow}$ of the $n \times n \times k$ element logarithmic transfer matrix. Here $i$ is the input port number, $o$ is the output port number and $w$ is the wavelength number associated with port $i$ or $o$, $n$ is the total number of input + output ports and $k$ is the total number of wavelengths of the logarithmic transfer matrix. For WWDM devices, it shall be specified as a maximum value and a minimum value at each operating wavelength range. For DWDM and CWDM devices, it shall be specified as a maximum value and a minimum value within the channel frequency (or wavelength) range as illustrated in Figure 4.

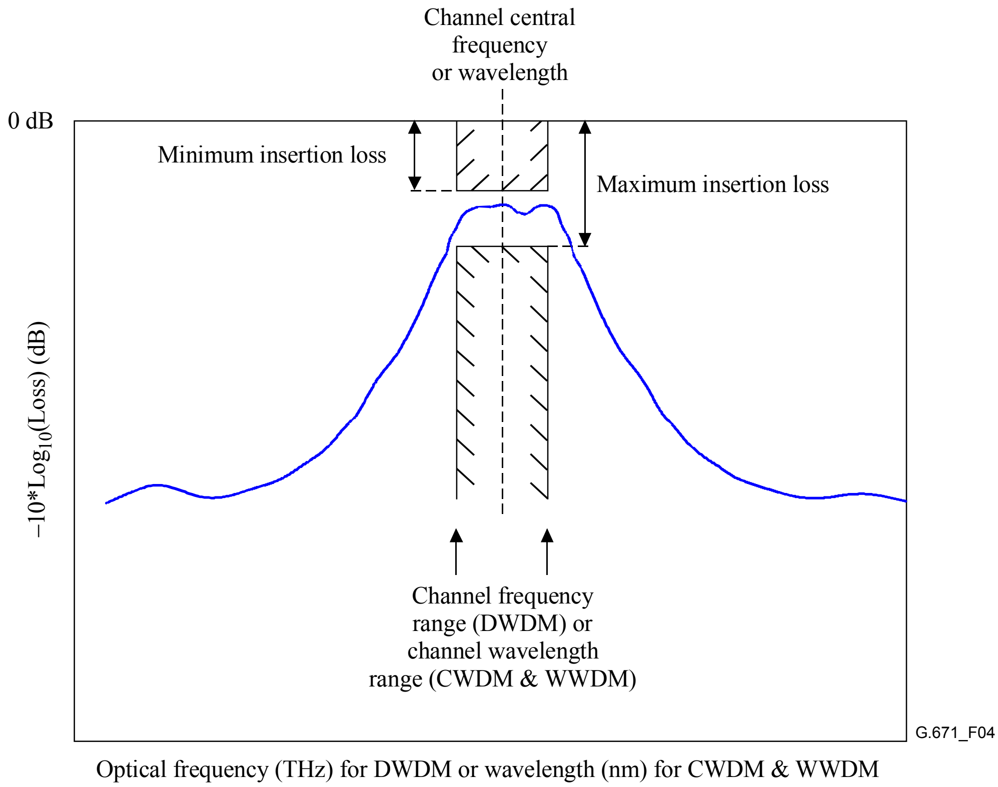


**Figure 4/G.671 – Illustration of maximum and minimum insertion loss of a WDM device**

**3.2.10 channel insertion loss deviation (WDM devices)**: This is the maximum variation of insertion loss at any frequency within the channel frequency range (DWDM devices) or channel wavelength range (CWDM and WWDM devices). This is illustrated in Figure 5.

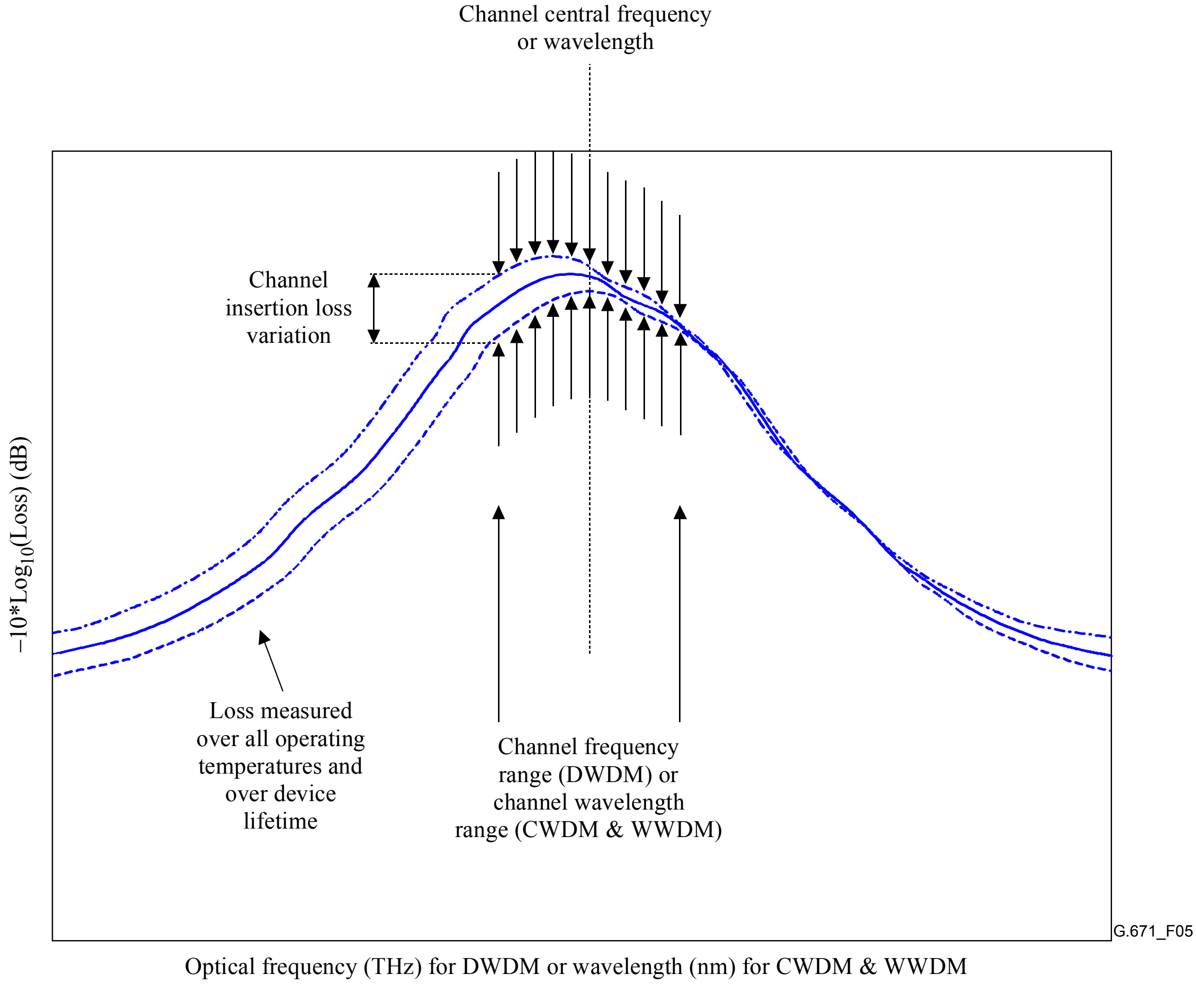


**Figure 5/G.671 – Illustration of channel insertion loss variation of a WDM device**

**3.2.11 channel non-uniformity**: The difference (in dB) between the powers of the channel with the most power (in dBm) and the channel with the least power (in dBm). This applies to a multichannel signal across the operating wavelength range.

**3.2.12 channel response time**: The elapsed time it takes a device to transform a channel from a specified initial power level to a specified final power level desired state, when the resulting output channel non-uniformity tolerance is met, measured from the time the actuation energy is applied or removed.

**3.2.13 channel spacing**: The centre-to-centre difference in frequency or wavelength between adjacent channels in a WDM device. DWDM channel spacings are based on the grid found in ITU-T Rec. G.694.1. CWDM channel spacings are based on the grid found in ITU-T Rec. G.694.2.

**3.2.14 channel wavelength range**: The wavelength range within which a CWDM or WWDM device is required to operate with a specified performance. For a particular nominal channel central wavelength, $\lambda_{nomi}$, this wavelength range is from $\lambda_{imin} = (\lambda_{nomi} - \Delta\lambda_{max})$ to $\lambda_{imax} = (\lambda_{nomi} + \Delta\lambda_{max})$, where $\Delta\lambda_{max}$ is the maximum channel wavelength deviation.

**3.2.15 directivity**: For an optical branching component or an optical switch, the value $a_{sr}$, of the logarithmic transfer matrix, where $s$ and $r$ are the port numbers of two nominally isolated ports (1.3.11/IEC 60875-1).

**3.2.16 incremental attenuation (variable attenuators only)**: A term applicable only to variable attenuators. It refers to the difference between the nominal attenuation of the component at a given setting and the minimum nominal attenuation (1.3.6/IEC 60869-1).

**3.2.17 insertion loss (non-WDM devices)**: It is the reduction in optical power between an input and output port of a passive component in decibels. It is defined as:

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

where:

$P_{in}$ is the optical power launched into the input port and $P_{out}$ the optical power received from the output port.

NOTE 1 – For an optical branching component, it is an element $a_{io}$ (where $i$ is the input port number and $o$ is the output port number), of the logarithmic transfer matrix (1.3.7/IEC 60875-1).

NOTE 2 – For an optical switch, it is an element $a_{io}$ (where $i$ is the input port number and $o$ is the output port number), of the logarithmic transfer matrix. It depends on the state of the switch (1.3.9/IEC 60876-1).

NOTE 3 – For an optical filter, it shall be specified as a maximum value and a minimum value over each operating wavelength range.

**3.2.18 insertion loss tolerance (optical attenuators only)**: The difference between nominal and actual insertion loss of the attenuator.

**3.2.19 isolation of an optical switch**: The isolation of an optical switch is the minimum value of the ratio of the transfer coefficient of the switch in its on state to the transfer coefficient in its off state, over the operating wavelength range. It is defined as:

$$IOS = 10\log\left(\frac{t_{io}}{t^{o}{}_{io}}\right)$$

Where $t_{io}$ is the transfer coefficient (as defined in 3.3) from port $i$ to port $o$ with path $io$ switched on and $t^{o}{}_{io}$ is the transfer coefficient from port $i$ to port $o$ with path $io$ switched off.

**3.2.20 non-adjacent channel isolation**: The non-adjacent channel isolation (of a WDM device) is defined to be equal to the unidirectional (far-end) isolation of that device with the restriction that $x$, the isolation wavelength number, is restricted to each of the channels **not** immediately adjacent to the (channel) wavelength number associated with port $o$. This is illustrated in Figure 6.

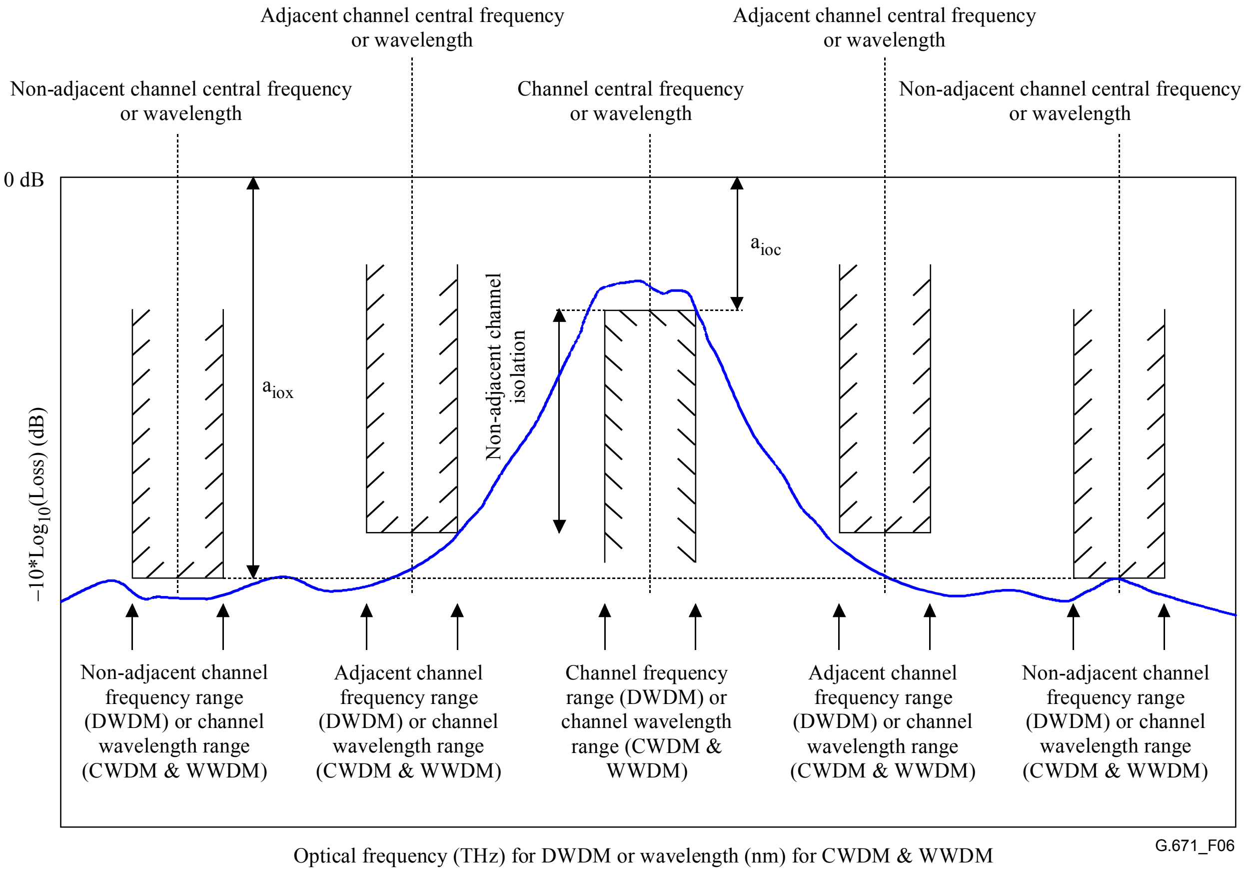


**Figure 6/G.671 – Illustration of non-adjacent channel isolation for a WDM device**

**3.2.21 operating wavelength range**: The specified range of wavelengths from $\lambda_{imin}$ to $\lambda_{imax}$ about a nominal operating wavelength $\lambda_i$, within which a passive component is designed to operate with a specified performance (1.3.21/IEC 60875-1).

NOTE 1 – For an optical branching component with more than one operating wavelength, the corresponding wavelength ranges are not necessarily equal (1.3.21/IEC 60875-1).

NOTE 2 – The components including attenuators, terminations, connectors and splices may operate with a specified performance or acceptable performance even outside the specified range of wavelengths.

**3.2.22 out-of-band attenuation**: The minimum attenuation (in dB) of channels that fall outside of the operating wavelength range.

**3.2.23 polarization dependent loss (PDL)**: Maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all SOPs.

**3.2.24 polarization dependent reflectance**: Maximum variation of reflectance due to a variation of the state of polarization (SOP) over all SOPs.

**3.2.25 polarization mode dispersion (PMD)**: Polarization mode dispersion (PMD) is usually described in terms of a differential group delay (DGD), which is the time difference between the principal states of polarization (SOPs) of an optical signal at a particular wavelength and time.

The goal of the PMD specifications in this Recommendation is to be able to define a single parameter for each component that can be substituted in the equation below which calculates the maximum DGD of a link (containing one or more of the components in question) with a defined probability of being exceeded.

$$DGD\max_{link} = \left[ DGD\max_F^2 + S^2 \sum_i PMD_{Ci}^2 \right]^{1/2}$$

where:

| | |
|---|---|
| $DGD\max_{link}$: | maximum link DGD (ps); |
| $DGD\max_F$: | maximum concatenated optical fibre cable DGD (ps); |
| $S$: | Maxwell adjustment factor (see Table 1); |
| $PMD_{Ci}$: | PMD value of the ith component (ps). |

This equation assumes that the statistics of the instantaneous DGD are approximated by a Maxwell distribution, with the probability of the instantaneous DGD exceeding $DGD\max_{link}$ being controlled by the value of the Maxwell adjustment factor taken from Table 1.

**Table 1/G.671 – S values and probabilities**

| Ratio of max. to mean (S) | Probability of exceeding max. | Ratio of max. to mean (S) | Probability of exceeding max. |
|---|---|---|---|
| 3 | $4.2 \times 10^{-5}$ | 4 | $7.4 \times 10^{-9}$ |
| 3.2 | $9.2 \times 10^{-6}$ | 4.2 | $9.6 \times 10^{-10}$ |
| 3.4 | $1.8 \times 10^{-6}$ | 4.4 | $1.1 \times 10^{-10}$ |
| 3.6 | $3.2 \times 10^{-7}$ | 4.6 | $1.2 \times 10^{-11}$ |
| 3.8 | $5.1 \times 10^{-8}$ | | |

Within this Recommendation, the PMD value of an optical component is defined as the maximum DGD over the operating wavelength range unless it can be shown that the component characteristics are such that the alternative definition of PMD used does not lead to the value of $DGD\max_{link}$ predicted by the above equation being an underestimate for any of the operating wavelengths.

Where it can be established that for a particular component the distribution of DGD with time is approximately Maxwell then the PMD value can be defined to be the value of the time averaged DGD at the worst wavelength. If it can also be shown that the distribution of DGD with wavelength is Maxwell with a mean value approximately the same as for the distribution of DGD with time, then the PMD value can be defined to be the value of the wavelength averaged DGD. This condition would be expected to be true for fibre-based components such as dispersion compensating fibre.

Alternatively, for components where the DGD may vary with wavelength, but not appreciably with time and the distribution of DGD vs. wavelength is such that the Maxwell distribution does not underestimate the maximum DGD for probabilities less than $4.2 \times 10^{-5}$, the PMD may also be defined to be the value of the wavelength averaged DGD. This, however, also requires that there is negligible correlation between the DGD of one device and that of another at the same wavelength.

Some optical components consist of multiple optical paths. Examples include WDM MUX/DMUX and hybrid C-band/L-band amplifiers or compensators. When these multi-path components are specified with a single value then the PMD of each distinct optical path should be found separately and the resulting component PMD defined to be the maximum of these values.

**3.2.26 reflectance**: The ratio of reflected power $P_r$ to incident power, $P_i$ at a given port of a passive component, for given conditions of spectral composition, polarization and geometrical distribution. Generally expressed in dB as:

$$R = 10\log\left(\frac{P_r}{P_i}\right) \qquad \text{(1.34/IEC 61931-1)}$$

NOTE 1:

- For an optical branching component, it is an element $a_{ii}$ (where $i$ is the input port number), of the logarithmic transfer matrix (1.3.8/IEC 60875-1).
- For a WDM device, it is an element $a_{iiw}$ (where $i$ is the input port number, $w$ is the wavelength number), of the logarithmic transfer matrix. For WWDM devices, it shall be specified as a maximum value at each operating wavelength range. For CWDM devices, it shall be specified as a maximum value within the channel wavelength range. For DWDM devices, it shall be specified as a maximum value within the channel frequency range.
- For an optical switch, it is an element $a_{ii}$ (where $i$ is the input port number), of the logarithmic transfer matrix. It depends on the state of the switch (1.3.10/IEC 60876-1).
- For an optical filter, it shall be specified in each operating wavelength range.

NOTE 2 – For clarity, reflectance values for optical devices do not include the reflectance contributions of connectors or unterminated optical ports. Reflectance contributions from connectors will be considered separately.

NOTE 3 – Generally, within the ITU-T, components are specified in terms of their reflectance (a negative value in dB) while systems are specified using the term return loss (a positive value in dB). In some IEC documents, components (which may have multiple interfaces) are normally specified in terms of return loss.

**3.2.27 repeatability of an optical switch**: For further study.

**3.2.28 reproducibility of passband setting**: The variance of the difference between the demanded centre frequency and the centre of the tuneable filter 3 dB passband when set-up is repeated many times.

**3.2.29 ripple**: For WDM devices and tuneable filters, the peak-to-peak difference in insertion loss within a channel frequency (or wavelength) range. Future work on possible additional specifications is needed on the use and application of this parameter for cascading of multiple devices. This is illustrated in Figure 7.

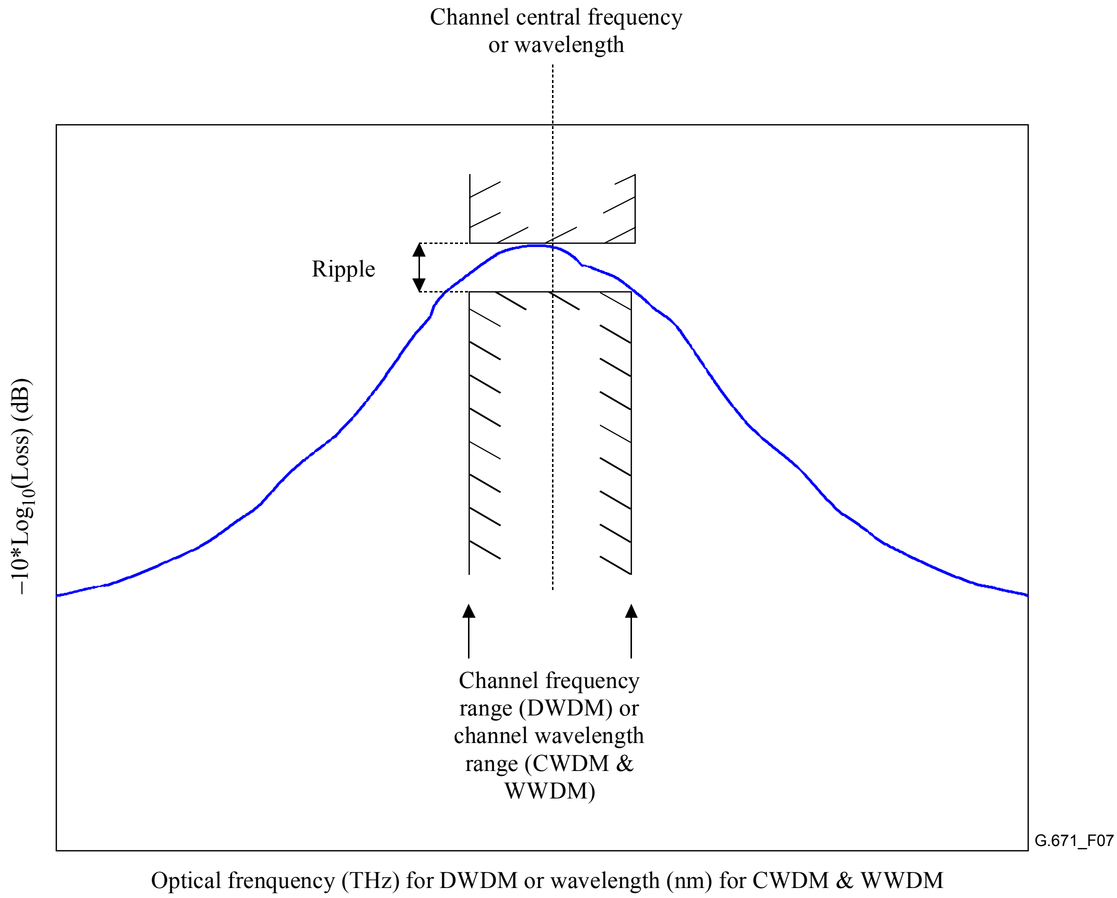


**Figure 7/G.671 – Illustration of ripple for a WDM device**

**3.2.30 switching time**: The elapsed time it takes the switch to turn path *io* on or off from a particular initial state, measured from the time the actuation energy is applied or removed (1.3.19/IEC 60876-1).

**3.2.31 tuning (settling) time**: The tuning (settling) time of a tuneable filter is defined as the time-duration from the start of frequency tuning to the time when the tuneable filter loss converges to within (ffs) dB of its final value at the demanded filter centre frequency ± half of the 3 dB passband width.

NOTE – 0.1 dB has been proposed.

**3.2.32 unidirectional (far-end) crosstalk attenuation (for a WDM device)**: In a WDM device able to separate $k$ wavelengths ($\lambda_1$, $\lambda_2$, ... , $\lambda_k$) radiation coming from one input port into $k$ output ports, each one nominally passing radiation at one specific wavelength only. The unidirectional (far-end) crosstalk attenuation is a measure of the part of the optical power at each wavelength exiting from the port at wavelengths different from the nominal wavelength. It is given by the following formula:

$$UCA = a_{iox}$$

The term $a_{iox}$ is an element of the logarithmic transfer matrix where $i$ is the input port number, $o$ is the output port number and $x$ is the isolation wavelength number, where $x$ is any wavelength number not equal to the (channel) wavelength number associated with port $o$. In each output port $o$ there are $k$–1 isolation wavelengths $\lambda_x$.

**3.2.33 Unidirectional (far-end) isolation (for a WDM device)**: In a WDM device able to separate $k$ wavelengths ($\lambda_1, \lambda_2, ..., \lambda_k$) radiation coming from one input port into $k$ output ports, each one nominally passing radiation at one specific wavelength only. The unidirectional (far-end) isolation is a measure of the part of the optical power at each wavelength exiting from the port at wavelengths different from the nominal wavelength relative to the power at the nominal wavelength. It is given by the following formula:

$$I_U = a_{iox} - a_{ioc}$$

The terms $a_{iox}$ and $a_{ioc}$ are elements of the logarithmic transfer matrix (defined in 3.3), where $i$ is the input port number, $o$ is the output port number, $c$ is the (channel) wavelength number associated with port $o$ and $x$ is the isolation wavelength number, where $x$ is any wavelength number not equal to $c$. In each output port $o$ there is one channel wavelength $\lambda_c$ and $k$–1 isolation wavelengths $\lambda_x$. This is illustrated in Figure 8.

NOTE – $\lambda_c$ is used in this Recommendation to denote channel wavelength and not fibre cut-off wavelength.

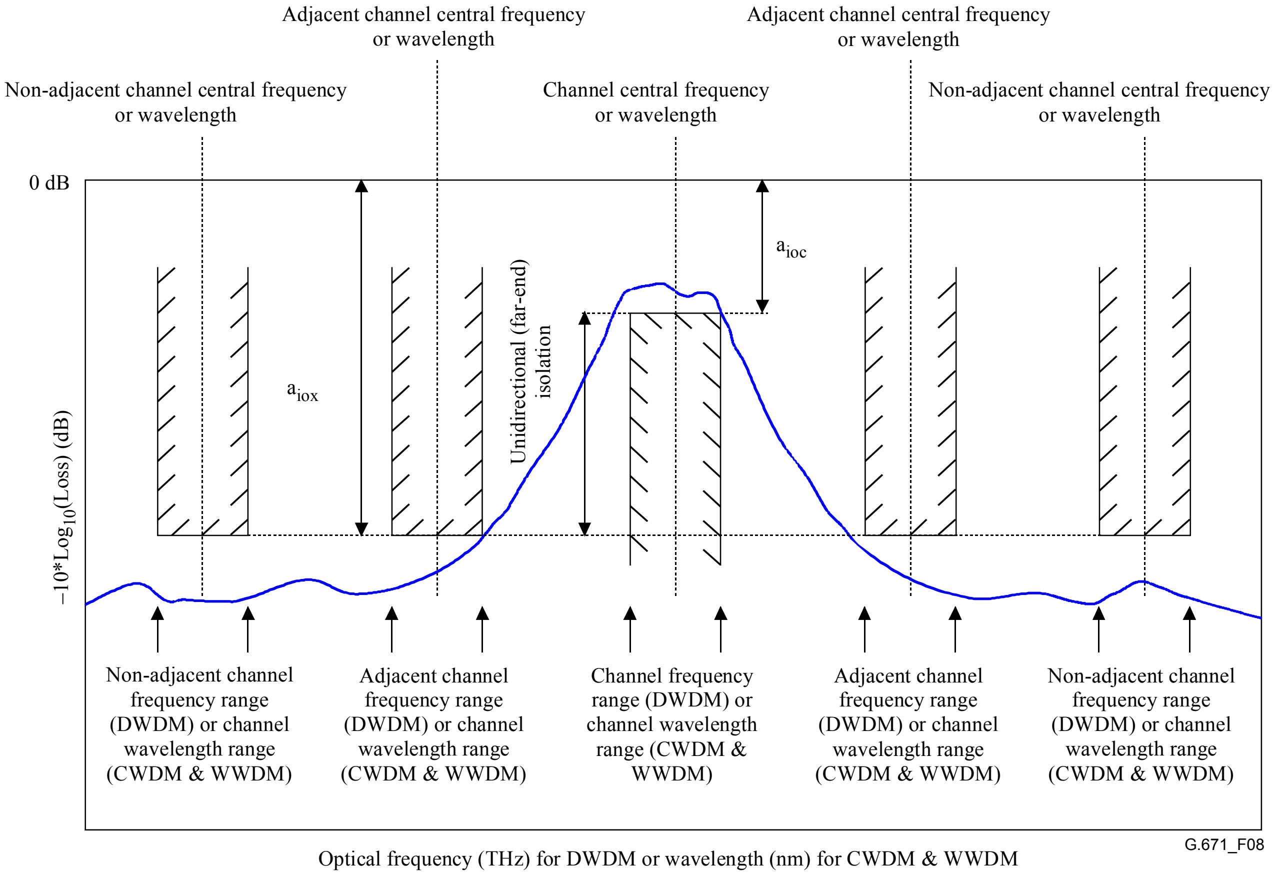


**Figure 8/G.671 – Illustration of unidirectional (far-end) isolation of a WDM device**

Figure 9 illustrates an example using the transfer matrix defined in 3.3, if powers $P_1$, $P_2$, $P_3$, … $P_k$ were launched into a WDM DMUX device at wavelengths 1, 2, 3, … $k$ respectively, then the signals emerging from port $x$ would be:

$$t_{1x1}P_1, t_{1x2}P_2, t_{1x3}P_3, \ldots t_{1xk}P_k$$

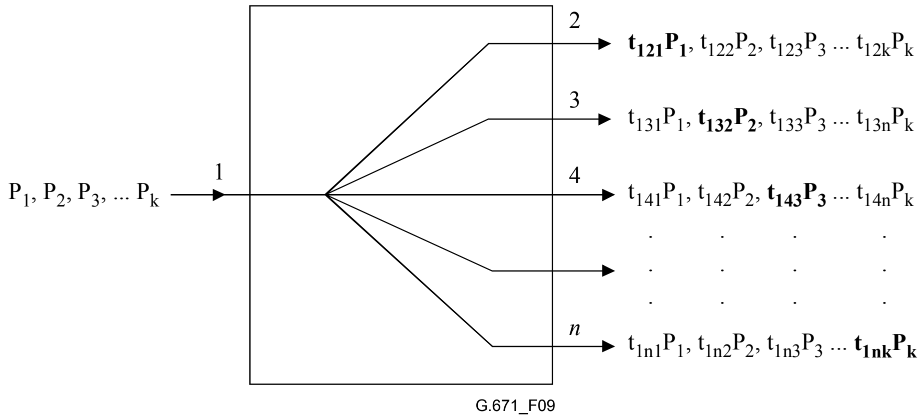


**Figure 9/G.671 – Example of WDM demultiplexer device**

So the isolation of port 2 to wavelength 3 would be $a_{123} - a_{121}$.

**3.2.34 uniformity**: The logarithmic transfer matrix of a component may contain a specified set of coefficients that are nominally finite and equal. In this case, the range of these coefficients $a_{io}$, expressed in decibels, is termed the uniformity of the component (1.3.16/IEC 60875-1).

### 3.3 Definition of terms

The following terms are used in the parameter definitions in 3.2.

**3.3.1 conducting port**: Two ports $i$ and $o$ between which $t_{io}$ is nominally greater than zero (1.3.12/IEC 60875-1).

**3.3.2 coupling ratio**: For a given input port $i$, this is the ratio of light at a given output port $o$ to the total light from all output ports. It is defined as:

$$CR_{io} = \frac{t_{io}}{\Sigma_n t_{in}}$$

where $n$ are the operational output ports (1.3.17/IEC 60875-1).

**3.3.3 Input/output port pair**: Conducting ports $i$ and $o$ ($t_{io}$ nominally greater than zero) that are isolated from any other ports $j$ ($a_{ij}$ nominally infinite).

Figure 10 shows an example of a six-port device, with two input ports and four output ports. 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.

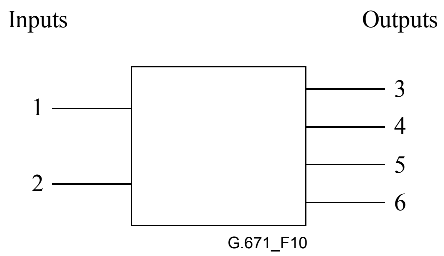


**Figure 10/G.671 – An example of the port assignments for the transfer matrix**

For the example shown, if there are four operating wavelengths, then the resulting transfer matrix becomes a 6 × 6 × 4 matrix: loss at $\lambda_1$ from port 1 to port 6 would use $a_{161}$. Reflectance of port 2 at $\lambda_4$ would use $a_{224}$. Loss from port 5 to port 2 at $\lambda_3$ would use $a_{523}$.

**3.3.4 isolated port**: Two ports $i$ and $o$ between which $t_{io}$ is nominally zero and $a_{io}$ is nominally infinite (1.3.13/IEC 60875-1).

**3.3.5 logarithmic transfer matrix (for an optical switch)**: A general logarithmic transfer matrix is shown in Figure 11

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & a_{2n} \\ \cdot & \cdot & a_{io} & \cdot \\ a_{n1} & a_{n2} & \cdot & a_{nn} \end{pmatrix}$$

**Figure 11/G.671 – Logarithmic transfer matrix for an optical switch**

where $a_{io}$ is the optical power reduction in decibels out of port $o$ with unit power into port $i$, i.e.:

$$a_{io} = -10 \log (t_{io})$$

where $t_{io}$ is the transfer matrix coefficient.

Similarly, for the off state, $a^o_{io} = -10 \log (t^o_{io})$. This matrix is intended for definition purposes only (1.3.8/IEC 60876-1).

**3.3.6 logarithmic transfer matrix coefficient (for optical branching and WDM devices)**: In general, the logarithmic transfer matrix is shown in Figure 12.

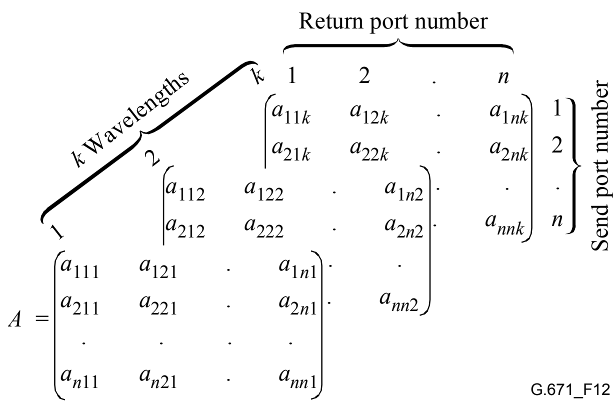


**Figure 12/G.671 – Logarithmic transfer matrix**

where $a_{srw}$ is the optical power reduction in decibels out of port number $r$ with unit power into port number $s$, at wavelength number $w$, i.e.:

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

where $t_{srw}$ is the transfer matrix coefficient, $s$ is the port number into which optical power is **s**ent to the device for measurement, $r$ is the port number used to measure the **r**eturn and $w$ the **w**avelength number of the measurement (i.e. the measurement is performed at wavelength $\lambda_w$). This matrix is intended for definition purposes only (1.3.9/IEC 60875-1).

NOTE – If the device is wavelength insensitive, then $A$ becomes an $n \times n$ matrix with elements $a_{sr}$.

**3.3.7 operating wavelength**: A nominal wavelength λ, at which a passive component is designed to operate with the specified performance (1.3.20/IEC 60875-1).

**3.3.8 port**: An optical fibre or an optical fibre connector attached to an optical component for the entry and/or exit of the optical power (1.3.1/IEC 60875-1).

**3.3.9 specified by application (sba)**: In the tables of parameter values in clause 5, some parameters are given as "sba". This means that the value of this parameter for this component must be determined from the application in the relevant transmission system Recommendation rather than being specified here.

**3.3.10 switching time matrix (for an optical switch)**: A matrix of coefficients in which each coefficient $s_{io}$ is the longest switching time to turn path $io$ on or off from any initial state, as shown in Figure 13. This matrix is intended for definition purposes only (1.3.20/IEC 60876-1).

$$S = \begin{pmatrix} s_{11} & s_{12} & \cdot & s_{1n} \\ s_{21} & s_{22} & \cdot & s_{2n} \\ \cdot & \cdot & s_{io} & \cdot \\ s_{n1} & s_{n2} & \cdot & s_{nn} \end{pmatrix}$$

**Figure 13/G.671 – Switching time matrix for an optical switch**

**3.3.11 transfer coefficient (for optical branching and WDM devices)**: An element $t_{io}$ of the transfer matrix (1.3.8/IEC 60875-1).

**3.3.12 transfer coefficient (for an optical switch)**: An element $t_{io}$ or $t^{o}_{io}$ of the transfer matrix. Each coefficient $t_{io}$ is the worst case (minimum) fraction of power transferred from port $i$ to port $o$ for any state with path $io$ switched on. Each coefficient $t^{o}_{io}$ is the worst case (maximum) fraction of power transferred from port $i$ to port $o$ for any state with path $io$ switched off (1.3.7/IEC 60876-1).

**3.3.13 transfer matrix (for optical branching and WDM devices)**: The optical properties of an optical branching device can be defined in terms of an $n \times n \times k$ matrix of coefficients, where $n$ is the total number of (input and output) ports, and $k$ is the number of wavelengths. The coefficients represent the fractional optical power transferred between designated ports. In general, the transfer matrix $T$ is shown in Figure 14.

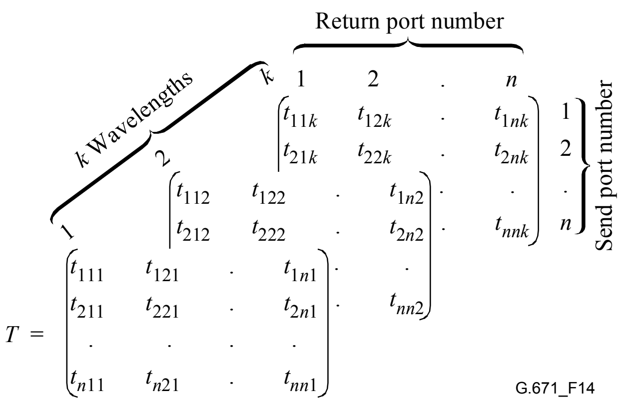


**Figure 14/G.671 – Transfer matrix**

where $t_{srw}$ is the ratio of optical power $P_{out}$ transferred out of port number $r$ with respect to input power $P_{in}$ into port number $s$ at wavelength number $w$, i.e.:

$$t_{srw} = P_{out}/P_{in} \text{ at wavelength number } w$$

The first index of the term $t_{srw}$ is always used to denote the port into which optical power is **s**ent to the device for measurement, the second index always denotes the port number used to measure the **r**eturn and the third index is always the **w**avelength number of the measurement (i.e. the measurement is performed at wavelength $\lambda_w$). This matrix is intended for definition purposes only.

NOTE – If the device is wavelength insensitive, then $T$ becomes an $n \times n$ matrix with elements $t_{sr}$.

**3.3.14 transfer matrix (for an optical switch)**: The optical properties of an optical switch can be defined in an $n \times n$ matrix of coefficients ($n$ is the total number of ports). The $T$ matrix represents the on-state paths (worst-case transmission), and the $T^o$ matrix represents the off-state paths (worst-case isolation). In general, the transfer matrices are shown in Figure 15. This matrix is intended for definition purposes only (1.3.6/IEC 60876-1).

$$T = \begin{pmatrix} t_{11} & t_{12} & \cdots & t_{io} \\ t_{21} & t_{22} & \cdots & t_{nn} \\ \cdots & \cdots & t_{io} & \cdots \\ t_{n1} & t_{n2} & \cdots & t_{nn} \end{pmatrix}$$

$$T^o = \begin{pmatrix} t_{11}^o & t_{12}^o & \cdots & t_{1n}^o \\ t_{21}^o & t_{22}^o & \cdots & t_{2n}^o \\ \cdots & \cdots & t_{io}^o & \cdots \\ t_{n1}^o & t_{n2}^o & \cdots & t_{nn}^o \end{pmatrix}$$

**Figure 15/G.671 – Transfer matrix for an optical switch**

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

| | |
|---|---|
| CWDM | Coarse Wavelength Division Multiplexing |
| DCE | Dynamic Channel Equalizer |
| DGD | Differential Group Delay |
| DWDM | Dense Wavelength Division Multiplexing |
| ffs | for further study |
| IL | Insertion Loss |
| ISDN | Integrated Services Digital Network |
| MUX/DMUX | Multiplexer/Demultiplexer |
| na | not applicable |
| OADM | Optical Add Drop Multiplexer |
| PDL | Polarization Dependent Loss |

| | |
|---|---|
| PMD | Polarization Mode Dispersion |
| sba | specified by application |
| SOP | State of Polarization |
| WDM | Wavelength Division Multiplexing |
| WWDM | Wide Wavelength Division Multiplexing |

## 5 Parameter test methods and values

Generally, in this Recommendation, the test methods for relevant parameters will not be developed. However, full reference to existing IEC basic specifications are made according to the lists provided in the following tables. The measurement and environmental test procedures that are reported in the IEC Generic Specifications cited in clause 3 and in the IEC 61300 Basic Standard on tests and measurement procedures for interconnecting devices and passive components are referenced to the functional parameters.

Values for statistical approach are ffs and will eventually be considered in an appendix.

All table values represent worst-case end of life values over all specified temperature, humidity, and perturbations.

For particular applications, tighter reflectance values than those indicated in these tables could be required.

Inclusion of polarization-dependent reflectance is under study.

For some components, (e.g. branching components, fibre optic filters, passive dispersion compensators, optical connectors and tuneable filters), the values for the maximum insertion loss reflect the current technological status. Further reduction of the maximum insertion loss is subject to technological progress and joint engineering.

In the tables below, X = the number of wavelength-specific ports.

The following Notes apply in the tables below:

NOTE 1 – Assumes operation at either or both passbands, but if a restricted wavelength range exists over a passband, then parameter values like loss apply only over that restricted band as well.

NOTE 2 – The maximum value of allowable input power is under discussion. A value of +20 dBm is considered a starting point. When high input power is launched into optical components, care must be taken to eliminate contamination such as dust or particles from the connector end faces.

NOTE 3 – The measurement methods outlined in ITU-T Rec. G.650 can be used only where it can be shown that the use of the wavelength averaged DGD does not lead to an underestimate of the total link DGD.

NOTE 4 – Dual values (a | b) indicate values for "slow" and "fast" switches respectively.

NOTE 5 – For some passive dispersion compensators, the operating wavelength range can be narrower, but covering the wavelength range of the used optical source.

NOTE 6 – Values derived from assumptions of compensating a specific length of G.652 type fibre, using the equation found in I.2/G.652, although other lengths and assumptions are under study. Values for compensators of lengths of G.653 and G.655 fibre are under study.

NOTE 7 – When used over an extended operating temperature range, these values may be exceeded and are under study.

NOTE 8 – For networks other than those covered by G.982, including other access networks, a value of –27 dB is allowed, however, care should be taken to ensure system functionality in systems implemented with several optical components with reflectance values at, or near, this limit. In consideration of future network evolutions, a value of –40 dB is under study.

NOTE 9 – These values assume the joining of fibre types covered by the same Recommendation. These values are worst-case over all environments and for a large sample size. Typical values of insertion loss for mechanical splices are 0.15 dB, actively aligned fusion splices 0.08 dB and passively aligned fusion splices 0.15 dB.

## 5.1 Optical add/drop multiplexer (OADM) subsystems (for WDM)

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.1.1 | Channel insertion loss (dB) | sba | sba | |
| 5.1.2 | Channel insertion loss deviation (dB) | ffs | ffs | ffs |
| 5.1.3 | Reflectance (dB) | ffs | na | |
| 5.1.4 | Polarization dependent loss (PDL) (dB) | ffs | na | |
| 5.1.5 | Type of OADM subsystem | sba | sba | |
| 5.1.6 | Number of add/drop/through channels | sba | sba | |
| 5.1.7 | Type of passband profile (flat-top or Gaussian) | ffs | ffs | |
| 5.1.8 | Channel wavelength range (nm) (CWDM and WWDM devices) | sba | sba | |
| 5.1.9 | Channel frequency range (GHz) (DWDM devices) | sba | sba | |
| 5.1.10 | 1 dB passband width (nm) | sba | sba | |
| 5.1.11 | 3 dB passband width (nm) | sba | sba | |
| 5.1.12 | Ripple (dB) | ffs | na | |
| 5.1.13 | Adjacent channel isolation (dB) | na | sba | |
| 5.1.14 | Non-adjacent channel isolation (dB) | na | sba | |
| 5.1.15 | Allowable input power (dBm) | ffs (Note 2) | na | |
| 5.1.16 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |

### 5.2 Asymmetric branching component (wavelength non-selective)

Tap couplers with coupling factors F = 20%, 10%, 5%, 2% and 1%.

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.2.1 | Insertion loss – main port (dB) | See table below | See table below | IEC 61300-3-4, IEC 61300-3-7 |
| 5.2.2 | Insertion loss – tap port (dB) | See table below | See table below | IEC 61300-3-4, IEC 61300-3-7 |
| 5.2.3 | Reflectance (dB) | ffs | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.2.4 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.2.5 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.2.6 | Polarization dependent loss (PDL) – main port (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.2.7 | Polarization dependent loss (PDL) – tap port (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.2.8 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.2.9 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.2.10 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.2.11 | Directivity (dB) | na | ffs | ffs |

| F | Main port | | Tap port | |
|---|---|---|---|---|
| | Min. IL (dB) | Max. IL (dB) | Min. IL (dB) | Max. IL (dB) |
| 80/20 | ffs | ffs | ffs | ffs |
| 90/10 | ffs | ffs | ffs | ffs |
| 95/5 | ffs | ffs | ffs | ffs |
| 98/2 | ffs | ffs | ffs | ffs |
| 99/1 | ffs | ffs | ffs | ffs |

## 5.3 Optical attenuator

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.3.1 | Insertion loss (dB) (fixed attenuator) | sba | sba | IEC 61300-3-4, IEC 61300-3-7 |
| 5.3.2 | Reflectance (dB) | –40 | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.3.3 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.3.4 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.3.5 | Polarization dependent loss (PDL) (dB) | 0.3 | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.3.6 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.3.7 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.3.8 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.3.9 | Insertion loss tolerance (dB) | ±15% | ±15% | ffs |
| 5.3.10 | Attenuation range (variable attenuator) (dB) | sba | sba | ffs |
| 5.3.11 | Incremental attenuation (variable attenuator) (dB) | sba | sba | ffs |

### 5.4 Optical branching component (wavelength non-selective)

1 × X and 2 × X ports where X = 2, 3, 4, 6, 8, 12, 16, 24 and 32.

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.4.1 | Insertion loss (dB) | See table below | See table below | IEC 61300-3-4, IEC 61300-3-7 |
| 5.4.2 | Reflectance (dB) | –40 | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.4.3 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.4.4 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.4.5 | Polarization dependent loss (PDL) (dB) | $0.1 (1 + \log_2 X)$ | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.4.6 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.4.7 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.4.8 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.4.9 | Directivity (dB) | na | 50 | ffs |
| 5.4.10 | Uniformity (dB) | $1.0 \log_2 X$ | na | ffs |

This table assumes symmetrical power distribution between the output ports of the branching device.

| X | 1 × X | | 2 × X | |
|---|---|---|---|---|
| | Min. IL (dB) | Max. IL (dB) | Min. IL (dB) | Max. IL (dB) |
| 2 | 2.6 | 4.2 | 2.5 | 4.5 |
| 3 | 4.1 | 6.3 | 4.0 | 6.6 |
| 4 | 5.4 | 7.8 | 5.3 | 8.1 |
| 6 | 6.8 | 9.9 | 6.7 | 10.2 |
| 8 | 8.1 | 11.4 | 8.0 | 11.7 |
| 12 | 9.5 | 13.5 | 9.4 | 13.8 |
| 16 | 10.8 | 15.0 | 10.7 | 15.3 |
| 24 | 12.0 | 17.1 | 11.95 | 17.4 |
| 32 | 13.1 | 18.6 | 13.1 | 18.9 |

## 5.5 Optical connector

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| | Insertion loss (dB) | | | |
| 5.5.1 | for single fibre (Note 7) | 0.5 | na | IEC 61300-3-4, IEC 61300-3-7 |
| 5.5.2 | for multifibre (Note 7) | 1.0 | na | IEC 61300-3-4, IEC 61300-3-7 |
| 5.5.3 | Reflectance (dB) | –35 (Notes 7 and 8) | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.5.4 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.5.5 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.5.6 | Polarization dependent loss (PDL) (dB) | 0.1 | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.5.7 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.5.8 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.5.9 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| NOTE – Insertion loss and reflectance values also include effects of mating durability. | | | | |

## 5.6 Dynamic channel equalizer (DCE)

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.6.1 | Insertion loss (dB) | 6 | ffs | IEC 61300-3-4, IEC 61300-3-7 |
| 5.6.2 | Reflectance (dB) | na | –45 | IEC 61300-3-6 |
| 5.6.3 | Operating wavelength range (nm) | sba | sba | IEC 61300-3-7 |
| 5.6.4 | Polarization dependent loss (PDL) (dB) | 0.2 | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.6.5 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.6.6 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.6.7 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.6.8 | Channel extinction (dB) | na | 40 | |
| 5.6.9 | Out-of-band attenuation (dB) | na | 40 | |
| 5.6.10 | Channel non-uniformity (of output signal) (dB) | 1 | na | |
| 5.6.11 | Input channel non-uniformity (for specified output channel non-uniformity) (dB) | 20 | na | |
| 5.6.12 | Ripple (dB) | 0.2 | na | |
| 5.6.13 | Channel response time (ms) | 30 | na | |
| 5.6.14 | Channel spacing (nm) | sba | sba | |
| 5.6.15 | Number of channels | sba | sba | |

## 5.7 Optical filter

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| | Insertion loss (dB) | | | |
| 5.7.1 | Pass band | sba | sba | IEC 61300-3-4, IEC 61300-3-7 |
| 5.7.2 | Stop band | na | sba | |
| 5.7.3 | Reflectance (dB) | –40 | na | IEC 61300-3-6 |
| 5.7.4 | Operating wavelength range (nm) | sba | sba | IEC 61300-3-7 |
| 5.7.5 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.7.6 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.7.7 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.7.8 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.7.9 | Ripple (dB) | ffs | na | ffs |

## 5.8 Optical isolator

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.8.1 | Insertion loss (dB) | ffs | na | |
| 5.8.2 | Backward loss (isolation) | na | sba | IEC 61300-3-4, IEC 61300-3-7 |
| 5.8.3 | Reflectance (dB) | –40 | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.8.4 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.8.5 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.8.6 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.8.7 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.8.8 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.8.9 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |

## 5.9 Passive (chromatic) dispersion compensator

| Clause | Parameter<br>(km of G.652 equivalent compensation) | Max | Min | Test method |
|---|---|---|---|---|
| | Insertion loss (dB) | | | IEC 61300-3-4, IEC 61300-3-7 |
| 5.9.1 | 2.5 | ffs | na | |
| 5.9.2 | 5 | ffs | na | |
| 5.9.3 | 7.5 | ffs | na | |
| 5.9.4 | 10 | ffs | na | |
| 5.9.5 | 20 | 3.6 | ffs | |
| 5.9.6 | 30 | ffs | ffs | |
| 5.9.7 | 40 | 5.5 | ffs | |
| 5.9.8 | 50 | ffs | ffs | |
| 5.9.9 | 60 | 7.5 | ffs | |
| 5.9.10 | 70 | ffs | ffs | |
| 5.9.11 | 80 | 9.5 | ffs | |
| 5.9.12 | 90 | ffs | ffs | |
| 5.9.13 | 100 | 11.5 | ffs | |
| 5.9.14 | 110 | ffs | ffs | |
| 5.9.15 | 120 | 13.5 | ffs | |
| 5.9.16 | Reflectance (dB) | –27 | na | IEC 61300-3-6 |
| 5.9.17 | Operating wavelength range (nm) (Note 5) | 1565 | 1525 | IEC 61300-3-7 |
| 5.9.18 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.9.19 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.9.20 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| | Dispersion over operating wavelength range (Note 6) (ps/nm) | | | ffs |
| 5.9.21 | 2.5 | ffs | ffs | |
| 5.9.22 | 5 | ffs | ffs | |

| Clause | Parameter<br>(km of G.652 equivalent compensation) | Max | Min | Test method |
|---|---|---|---|---|
| 5.9.23 | 7.5 | ffs | ffs | |
| 5.9.24 | 10 | ffs | ffs | |
| 5.9.25 | 20 | –310 | –360 | |
| 5.9.26 | 30 | ffs | ffs | |
| 5.9.27 | 40 | –620 | –710 | |
| 5.9.28 | 50 | ffs | ffs | |
| 5.9.29 | 60 | –930 | –1070 | |
| 5.9.30 | 70 | ffs | ffs | |
| 5.9.31 | 80 | –1240 | –1420 | |
| 5.9.32 | 90 | ffs | ffs | |
| 5.9.33 | 100 | –1550 | –1780 | |
| 5.9.34 | 110 | ffs | ffs | |
| 5.9.35 | 120 | –1860 | –2140 | |
| | Polarization mode dispersion (PMD) (Note 7) (ps) | | | G.650 (Note 3) |
| 5.9.36 | 2.5 | ffs | na | |
| 5.9.37 | 5 | ffs | na | |
| 5.9.38 | 7.5 | ffs | na | |
| 5.9.39 | 10 | ffs | na | |
| 5.9.40 | 20 | ffs | na | |
| 5.9.41 | 40 | ffs | na | |
| 5.9.42 | 60 | ffs | na | |
| 5.9.43 | 80 | ffs | na | |
| 5.9.44 | 100 | ffs | na | |
| 5.9.45 | 120 | ffs | na | |

## 5.10 Optical splice

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| | Insertion loss (dB) (Note 9) | | | IEC 61300-3-4, IEC 61300-3-7 |
| 5.10.1 | Mechanical splice | 0.50 | na | |
| 5.10.2 | Fusion Splice (Active Alignment) | 0.30 | na | |
| 5.10.3 | Fusion Splice (Passive Alignment) | 0.50 | na | |
| | Reflectance (dB) | | | IEC 61300-3-6 |
| 5.10.4 | Mechanical splice | –40 | na | |
| 5.10.5 | Fusion splice | –70 | na | |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.10.6 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.10.7 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.10.8 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.10.9 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.10.10 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.10.11 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |

## 5.11 Optical switch

| Clause | Parameter | 1 × X switches | | 2 × 2 switches | | Test method |
|---|---|---|---|---|---|---|
| | | Max | Min | Max | Std | |
| 5.11.1 | Insertion loss (dB) | 2.5 \| $\log_2 X$ (Note 4) | na | ffs | na | IEC 61300-3-4, IEC 61300-3-7 |
| 5.11.2 | Reflectance (dB) | –40 | na | –40 | na | IEC 61300-3-6 |
| 5.11.3 | Operating wavelength range (nm) | ffs | ffs | ffs | ffs | IEC 61300-3-7 |
| 5.11.4 | Polarization dependent loss (PDL) (dB) | ffs \| 0.1 $(1 + \log_2 X)$ (Note 4) | na | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |

| Clause | Parameter | 1 × X switches | | 2 × 2 switches | | Test method |
|---|---|---|---|---|---|---|
| | | Max | Min | Max | Std | |
| 5.11.5 | Polarization dependent reflectance (dB) | ffs | na | ffs | na | IEC 61300-3-19 |
| 5.11.6 | Allowable input power (dBm) | ffs (Note 2) | na | ffs (Note 2) | na | ffs |
| 5.11.7 | Polarization mode dispersion (PMD) (ps) | ffs | na | ffs | na | G.650 (Note 3) |
| 5.11.8 | Switching time | 10 s \| 20 ms (Note 4) | na | ffs | na | ffs |
| 5.11.9 | Repeatability (dB) | 0.25 | na | ffs | na | ffs |
| 5.11.10 | Uniformity (dB) | ffs \| 0.4 $\log_2 X$ (Note 4) | na | ffs | na | ffs |
| 5.11.11 | Isolation (dB) | sba | na | sba | na | ffs |
| 5.11.12 | Directivity (dB) | na | 50 | na | ffs | ffs |
| NOTE – 2 × X switches are for future study. | | | | | | |

## 5.12 Optical termination

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.12.1 | Reflectance (dB) | –50 | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.12.2 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.12.3 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.12.4 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.12.5 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |

## 5.13 Tuneable filter

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| | Insertion loss (dB) | | | IEC 61300-3-4, IEC 61300-3-7 |
| 5.13.1 | Pass band | sba | sba | |
| 5.13.2 | Stop band | na | sba | |
| 5.13.3 | Reflectance (dB) | ffs | na | IEC 61300-3-6 |
| 5.13.4 | Operating wavelength range (nm) | sba | sba | IEC 61300-3-7 |
| 5.13.5 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.13.6 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.13.7 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.13.8 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.13.9 | 1 dB passband width (nm) | sba | sba | ffs |
| 5.13.10 | 3 dB passband width (nm) | sba | sba | ffs |
| 5.13.11 | Ripple (dB) | ffs | na | ffs |
| 5.13.12 | Reproducibility of passband setting (nm) | ffs | na | ffs |
| 5.13.13 | Tuning (settling) time (s) | sba | sba | ffs |
| 5.13.14 | Channel insertion loss deviation (dB) | ffs | ffs | ffs |

### 5.14 Optical wavelength MUX/DMUX

#### 5.14.1 Coarse WDM (CWDM) device

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.14.1.1 | Channel insertion loss (dB) | ffs | ffs | IEC 61300-3-4, IEC 61300-3-7 |
| 5.14.1.2 | Channel insertion loss deviation (dB) | ffs | ffs | ffs |
| 5.14.1.3 | Reflectance (dB) | ffs | na | IEC 61300-3-6 |
| 5.14.1.4 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.14.1.5 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.14.1.6 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.14.1.7 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.14.1.8 | Channel wavelength range (nm) | sba | sba | |
| 5.14.1.9 | Ripple (dB) | ffs | ffs | |
| 5.14.1.10 | Adjacent channel isolation (dB) | na | sba | |
| 5.14.1.11 | Non-adjacent channel isolation (dB) | na | sba | |
| 5.14.1.12 | Bidirectional (near-end) isolation (dB) | na | sba | |
| 5.14.1.13 | Unidirectional (far-end) crosstalk attenuation (dB) | na | sba | |
| 5.14.1.14 | Bidirectional (near-end) crosstalk attenuation (dB) | na | sba | |

### 5.14.2 Dense WDM (DWDM) device 1 × X

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.14.2.1 | Channel insertion loss (dB) | sba | sba | IEC 61300-3-4, IEC 61300-3-7 |
| 5.14.2.2 | Channel insertion loss deviation (dB) | ffs | ffs | ffs |
| 5.14.2.3 | Reflectance (dB) | ffs | na | IEC 61300-3-6 |
| 5.14.2.4 | Polarization dependent loss (PDL) (dB) | ffs | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.14.2.5 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.14.2.6 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.14.2.7 | Polarization mode dispersion (PMD) (ps) | ffs | na | G.650 (Note 3) |
| 5.14.2.8 | Channel frequency range (GHz) | sba | sba | ffs |
| 5.14.2.9 | Ripple (dB) | ffs | na | ffs |
| 5.14.2.10 | Adjacent channel isolation (dB) | na | sba | |
| 5.14.2.11 | Non-adjacent channel isolation (dB) | na | sba | ffs |
| 5.14.2.12 | Bidirectional (near-end) isolation (dB) | na | sba | ffs |
| 5.14.2.13 | Unidirectional (far-end) crosstalk attenuation (dB) | na | sba | ffs |
| 5.14.2.14 | Bidirectional (near-end) crosstalk attenuation (dB) | na | sba | ffs |

### 5.14.3 Wide WDM (WWDM) device 1 × X

| Clause | Parameter | Max | Min | Test method |
|---|---|---|---|---|
| 5.14.3.1 | Channel insertion loss (dB) | 1.5 $\log_2 X$ | ffs | IEC 61300-3-4, IEC 61300-3-7 |
| 5.14.3.2 | Channel insertion loss deviation (dB) | ffs | ffs | ffs |
| 5.14.3.3 | Reflectance (dB) | –40 | na | IEC 61300-3-6 |
| | Operating wavelength range (nm) (Note 1) | | | |
| 5.14.3.4 | 1310 nm window | 1360 | 1260 | IEC 61300-3-7 |
| 5.14.3.5 | 1550 nm window | 1580 | 1480 | IEC 61300-3-7 |
| 5.14.3.6 | Polarization dependent loss (PDL) (dB) | 0.1 (1 + $\log_2 X$) | na | IEC 61300-3-2, IEC 61300-3-12 |
| 5.14.3.7 | Polarization dependent reflectance (dB) | ffs | na | IEC 61300-3-19 |
| 5.14.3.8 | Allowable input power (dBm) | ffs (Note 2) | na | ffs |
| 5.14.3.9 | Polarization mode dispersion (PMD (ps) | ffs | na | G.650 (Note 3) |
| 5.14.3.10 | Unidirectional (far-end) isolation (dB) | na | sba | ffs |
| 5.14.3.11 | Bidirectional (near-end) isolation (dB) | na | sba | ffs |
| 5.14.3.12 | Unidirectional (far-end) crosstalk attenuation (dB) | na | sba | ffs |
| 5.14.3.13 | Bidirectional (near-end) crosstalk attenuation (dB) | na | sba | ffs |

# Appendix I

## Two-dimensional logarithmic transfer matrices of WDM devices

### I.1 Introduction

This appendix defines two-dimensional logarithmic transfer matrices for several specific WDM devices. The definitions apply to WDM devices for which the number of wavelength specific ports equals the number of wavelengths. Unidirectional MUX (M), unidirectional DMUX (D) and bidirectional MUX/DMUX (B) devices are considered.

The three-dimensional matrices described in the main body of this Recommendation are usable for all possible configurations of WDM Devices. The two-dimensional matrices presented in this appendix are valid only for $k \times 1$ MUX devices and $1 \times k$ DMUX devices having one wavelength per port.

The port numbering of the two-dimensional matrices is fixed, while the port numbering of the three-dimensional matrices contained in the main body of this Recommendation is allowed to be arbitrary.

The measured matrix elements for certain WDM devices are arranged more compactly and clearly in two, two-dimensional matrices which consist of fewer elements than the three-dimensional matrix A.

Clause 3.3.6 defines a three-dimensional ($n \times n \times k$) logarithmic transfer matrix A of a WDM device with general matrix elements $a_{srw}$. The three-dimensional matrix is presented by $k$ two-dimensional planes only to indicate the three-dimensionality in a drawing.

The two-dimensional logarithmic transfer matrices M, D and B use the matrix elements defined in 3.2:

$a_{ioc}$ = matrix element for channel insertion loss at channel wavelength $\lambda_c$ in MUX, DMUX or MUX-part of a bidirectional device (3.2.9 and 3.2.33);

$a_{doc}$ = matrix element for channel insertion loss at channel wavelength $\lambda_c$ in DMUX-part of a bidirectional device (3.2.6);

$a_{iox}$ = matrix element for unidirectional (far end) crosstalk attenuation at crosstalk (isolation) wavelength $\lambda_x$ in a DMUX (3.2.32 and 3.2.33);

$a_{mox}$ = matrix element for bidirectional (near end) crosstalk attenuation at crosstalk (isolation) wavelength $\lambda_x$ between MUX input port $m$ and DMUX output port $o$ of a bidirectional device (3.2.5 and 3.2.6).

The two-dimensional logarithmic transfer matrices Mr, Dr and Br for optical return losses use the matrix element:

$a_{iic}$ = matrix element for return loss of a WDM device, where $i$ is the input port number and $c$ the channel wavelength number (3.2.26, Note 1);

– The defined structures of the two, two-dimensional logarithmic transfer matrices per WDM device,

  e.g. M and Mr, D and Dr and B and Br with the above matrix elements, are given in I.2, for 4λ-MUX, 4λ-DMUX, 4λ-MUX/DMUX1 and 4λ-DMUX/MUX2.

## I.2 Definitions of two-dimensional logarithmic transfer matrices M, D, B, Mr, Dr and Br

The definitions of two-dimensional transfer matrices are based on the following assumptions:

- The two-dimensional logarithmic transfer matrices M, D, B, Mr, Dr and Br are based on the modified matrix elements $a_{iow}$ with input port number $i = 1, \ldots, k$ and output port number $o = 1$ for a MUX and with input port number $i = 1$ and output port number $o = 1, \ldots, k$ for a DMUX and with wavelength number $w = 1, \ldots, k$. $k$ is the total number of wavelengths. The assumption here is, that for a MUX the total number $k$ of input ports is equal to the total number $k$ of wavelengths, and for a DMUX the total number $k$ of output ports is equal to the total number $k$ of wavelengths.

  The corresponding definition for the three-dimensional transfer matrix A is given in 3.3.6.

- For each output port of a DMUX, there are assumed to be one channel wavelength $\lambda_c$ signal and $k$–1 crosstalk (isolation) wavelengths $\lambda_x$ ($\neq \lambda_c$) signals.

Arranging the various two-dimensional logarithmic transfer matrices M, D, B, Mr, Dr and Br with the matrix elements $a_{ioc}$, $a_{iox}$, $a_{doc}$, $a_{mox}$ and $a_{iic}$ results in each WDM-device being represented by two two-dimensional logarithmic transfer matrices:

– I.2.1 $k\lambda$-MUX by M and Mr;

– I.2.2 $k\lambda$-DMUX by D and Dr;

– I.2.3 4λ-MUX/DMUX1 by B1 and Br1; and

– I.2.4 4λ-DMUX/MUX2 by B2 and Br2.

### I.2.1 *k*λ-MUX

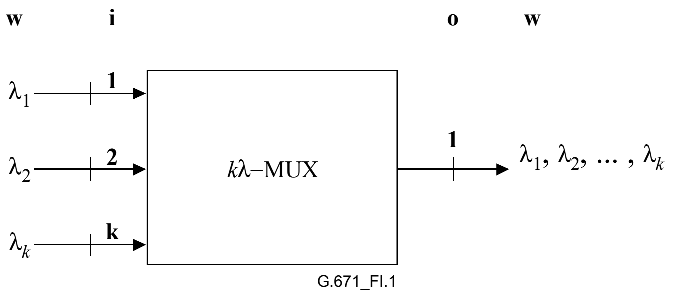


**Figure I.1/G.671 – *k*λ-MUX port numbering**

Figure I.1 illustrates the port numbering of a $k\lambda$-MUX device. The parameters of this device are represented as an ($i$,$w$)-matrix M with output port number $o$ = 1 as shown in Figure I.2 and an ($i$,$w$)-matrix Mr for return losses with output port number $o$ = 1 as shown in Figure I.3.

$$
M = \begin{array}{c}
\begin{array}{ccccc|c} 1 & 2 & 3 & . & k & i/w \end{array} \\
\begin{array}{c}
\begin{pmatrix}
a_{ioc} & . & . & . & . \\
. & a_{ioc} & . & . & . \\
. & . & a_{ioc} & . & . \\
. & . & . & . & . \\
. & . & . & . & a_{ioc}
\end{pmatrix}
\end{array}
\begin{array}{c} 1 \\ 2 \\ 3 \\ . \\ k \end{array}
\end{array}
$$

G.671_FI.2

**Figure I.2/G.671 – Matrix M for a *k*λ-MUX**

$$
\begin{array}{r c c}
 & \begin{array}{ccccc} 1 & 2 & 3 & . & k \end{array} & i/w \\
Mr = & \begin{pmatrix} a_{iic} & . & . & . & . \\ . & a_{iic} & . & . & . \\ . & . & a_{iic} & . & . \\ . & . & . & . & . \\ . & . & . & . & a_{iic} \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \\ . \\ k \end{array}
\end{array}
$$

G.671_FI.3

**Figure I.3/G.671 – Matrix Mr for a *k*λ-MUX**

## I.2.2 *k*λ-DMUX

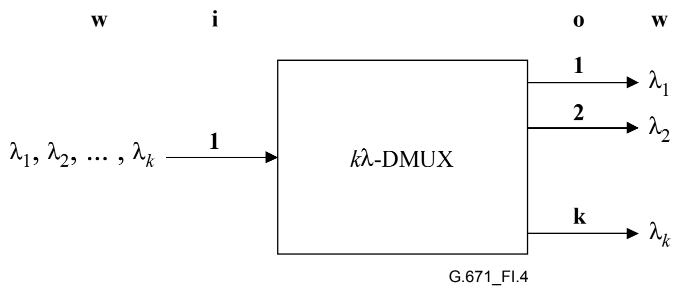


**Figure I.4/G.671 – *k*λ-DMUX port numbering**

Figure I.4 illustrates the port numbering of a *k*λ-DMUX device. The parameters of this device are represented as an $(o,w)$-matrix D with input port number $i = 1$ as shown in Figure I.5 and an $(o,w)$-matrix Dr for return losses with input port number $i = 1$ as shown in Figure I.6.

$$
\begin{array}{r c c}
 & \begin{array}{cccc} 1 & 2 & 3 & k \end{array} & o/w \\
D = & \begin{pmatrix} a_{ioc} & a_{iox} & a_{iox} & a_{iox} \\ a_{iox} & a_{ioc} & a_{iox} & a_{iox} \\ a_{iox} & a_{iox} & a_{ioc} & a_{iox} \\ a_{iox} & a_{iox} & a_{iox} & a_{ioc} \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \\ k \end{array}
\end{array}
$$

G.671_FI.5

**Figure I.5/G.671 – Matrix D for *k*λ-DMUX**

$$
\begin{array}{r c c}
 & \begin{array}{cccc} 1 & 2 & 3 & k \end{array} & o/w \\
Dr = & \begin{pmatrix} a_{iic} & . & . & . \\ . & a_{iic} & . & . \\ . & . & a_{iic} & . \\ . & . & . & a_{iic} \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \\ k \end{array}
\end{array}
$$

G.671_FI.6

**Figure I.6/G.671 – Matrix Dr for a *k*λ-DMUX**

### I.2.3 4λ-MUX/DMUX1

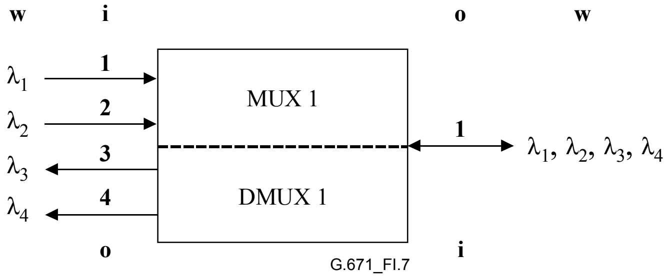


**Figure I.7/G.671 – 4λ-MUX/DMUX1 port numbering**

Figure I.7 illustrates the port numbering of a bidirectional 4λ-MUX/DMUX1. Signals with lower wavelengths $\lambda_1$ and $\lambda_2$ are at the inputs of MUX1. Signals with higher wavelengths $\lambda_3$ and $\lambda_4$ are at the outputs of DMUX1.

The parameters of a bidirectional 4λ-MUX/DMUX1 are represented by an $(i/o,w)$-matrix B1 as shown in Figure I.8 and an $(i/o,w)$ matrix Br1 for return losses as shown in Figure I.9.

$$
\begin{array}{cc}
 & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
B1 = & \begin{pmatrix} a_{ioc} & \cdot & \cdot & \cdot \\ \cdot & a_{ioc} & \cdot & \cdot \\ & & & \\ a_{mox} & a_{mox} & a_{doc} & a_{iox} \\ a_{mox} & a_{mox} & a_{iox} & a_{doc} \end{pmatrix}
\end{array}
\begin{array}{c} i/w \\ 1 \\ 2 \\ o/w \\ 3 \\ 4 \end{array}
$$

G.671_FI.8

**Figure I.8/G.671 – Matrix B1 for a 4λ-MUX/DMUX1**

$$
\begin{array}{cc}
 & \begin{array}{cccc} 1 & 2 & 3 & 4 \end{array} \\
Br1 = & \begin{pmatrix} a_{iic} & \cdot & \cdot & \cdot \\ \cdot & a_{iic} & \cdot & \cdot \\ & & & \\ \cdot & \cdot & a_{iic} & \cdot \\ \cdot & \cdot & \cdot & a_{iic} \end{pmatrix}
\end{array}
\begin{array}{c} i/w \\ 1 \\ 2 \\ o/w \\ 3 \\ 4 \end{array}
$$

G.671_FI.9

**Figure I.9/G.671 – Matrix Br1 for a 4λ-MUX/DMUX1**

### I.2.4 4λ-DMUX/MUX2

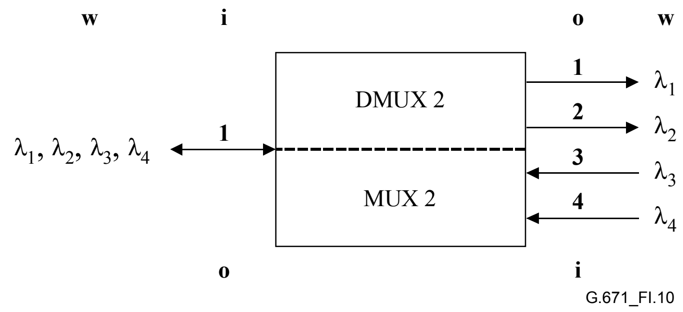


**Figure I.10/G.671 – 4λ-DMUX/MUX2 port numbering**

Figure I.10 illustrates the port numbering of a bidirectional 4λ-DMUX/MUX2. Signals with lower wavelengths $\lambda_1$ and $\lambda_2$ are at the outputs of DMUX2. Signals with higher wavelengths $\lambda_3$ and $\lambda_4$ are at the inputs of MUX2.

The parameters of a bidirectional 4λ-DMUX/MUX2 are represented by an (*o*/*i*,*w*)-matrix B2 as shown in Figure I.11 and an (*i*/*o*,*w*) matrix Br2 for return losses as shown in Figure I.12.

$$B2 = \begin{array}{cc} \begin{matrix} 1 & 2 & 3 & 4 \end{matrix} & o/w \\ \begin{pmatrix} a_{doc} & a_{iox} & a_{mox} & a_{mox} \\ a_{iox} & a_{doc} & a_{mox} & a_{mox} \\ & & & \\ . & . & a_{ioc} & . \\ . & . & . & a_{ioc} \end{pmatrix} & \begin{matrix} 1 \\ 2 \\ i/w \\ 3 \\ 4 \end{matrix} \end{array}$$

G.671_FI.11

**Figure I.11/G.671 – Matrix B2 for a 4λ-DMUX/MUX2**

$$Br2 = \begin{array}{cc} \begin{matrix} 1 & 2 & 3 & 4 \end{matrix} & o/w \\ \begin{pmatrix} a_{iic} & . & . & . \\ . & a_{iic} & . & . \\ & & & \\ . & . & a_{iic} & . \\ . & . & . & a_{iic} \end{pmatrix} & \begin{matrix} 1 \\ 2 \\ i/w \\ 3 \\ 4 \end{matrix} \end{array}$$

G.671_FI.12

**Figure I.12/G.671 – Matrix Br2 for a 4λ-DMUX/MUX2**

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