BS EN 61300-3-29:2014

BSI Standards Publication

Fibre optic interconnecting devices and passive components — Basic test and measurement procedures

Part 3-29: Examinations and measurements — Spectral transfer characteristics of DWDM devices

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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.

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Foreword

The text of document 86B/3718/FDIS, future edition 2 of IEC 61300-3-29, 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 61300-3-29:2014.

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)	2015-01-23
– latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2015-04-23

This document supersedes EN 61300-3-29:2006.

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Endorsement notice

The text of the International Standard IEC 61300-3-29:2014 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 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60050-731	-	International Electrotechnical Vocabulary (IEV) Chapter 731: Optical fibre communication	-	-
IEC 61300-3-2	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures Part 3-2: Examinations and measurements - Polarization dependent loss in a single-mode fibre optic device	EN 61300-3-2	-
IEC 61300-3-7	-	Fibre optic interconnecting devices and passive components - Basic test and measurement procedures Part 3-7: Examinations and measurements - Wavelength dependence of attenuation and return loss of single mode components	EN 61300-3-7	-
IEC 62074-1	-	Fibre optic interconnecting devices and passive components - Fibre optic WDM devices Part 1: Generic specification	EN 62074-1	-

CONTENTS

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES –

Part 3-29: Examinations and measurements – Spectral transfer characteristics of DWDM devices

1 Scope

This part of IEC 61300 identifies two basic measurement methods for characterizing the spectral transfer functions of DWDM devices.

The transfer functions are the functions of transmittance dependent of wavelengths. In this standard, optical attenuations are also used.

NOTE In this standard, transfer functions are expressed by $T(\lambda)$ and optical attenuations are expressed by $A(\lambda)$.

The transfer functions can be used to produce measurements of insertion loss (IL), polarization dependent loss (PDL), isolation, centre wavelength, bandwidth (BW) and other optical performances.

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

IEC 61300-3-2, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-2: Examinations and measurements – Polarization dependent loss in a single-mode fibre optic device*

IEC 61300-3-7, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-7: Examinations and measurements – Wavelength dependence of attenuation and return loss of single mode components*

IEC 62074-1, *Fibre optic interconnecting devices and passive components – Fibre optic WDM devices – Part 1: generic specification*

3 Terms, definitions, abbreviations and symbols

3.1 Terms and definitions

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

3.1.1
bandwidth
(linewidth)
BW
spectral width of a signal or filter

Note 1 to entry: In the case of a laser signal such as a tuneable narrowband light source, the term 'linewidth' is commonly preferred. Often defined by the width at a set power distance from the peak power level of the device (i.e. 3 dB BW or 1 dB BW). The bandwidth shall be defined as the distance between the closest crossings on either side of the centre wavelength in those cases where the spectral shape has more than 2 such points. The distance between the outermost crossings can be considered the full spectral width.

3.1.2
channel frequency range
(passband)
CFR
specified range of wavelengths (frequencies) from λ_{hmin} (f_{hmin}) to λ_{hmax} (f_{hmax}), centred about the nominal operating wavelength frequency), within which a WDM device operates to transmit less than or equal to the specified optical attenuation

Note 1 to entry: Passband is commonly used to convey the same meaning.

3.1.3
dense WDM
DWDM
WDM device intended to operate for channel spacing equal to or less than 1 000 GHz

3.1.4
polarization dependent loss
PDL
maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all SOP

3.1.5
state of polarization
SOP
distribution of light energy among the two linearly independent solutions of the wave equations for the electric field

3.1.6
source spontaneous emission
SSE
broadband emissions from a laser cavity that bear no phase relation to the cavity field

Note 1 to entry: These emissions can be seen as the baseline noise on an optical spectrum analyser (OSA)

3.1.7
wavelengths division multiplexer
WDM
term frequently used as a synonym for a wavelength-selective branching device

3.2 Symbols and abbreviations

3.2.1 Symbols

δ wavelength sampling increment during the measurement

λ_h centre channel or nominal operating wavelength for a component

3.2.2 Abbreviations

APC angled physical contact

ASE amplified spontaneous emission

BBD	broadband detector
BBS	broadband light source
BW	bandwidth
CFR	channel frequency range
DOP	degree of polarization
DUT	device under test
DWDM	dense wavelengths division multiplexer
FBG	fibre Bragg grating
IL	insertion loss
OPM	optical power meter
OSA	optical spectrum analyser
PC	polarization controller
PC	physical contact
PDCW	polarization dependent centre wavelength
PDL	polarization dependent loss
PSCS	polarization state change system
PL	polarizer
RBD	reference branching devices
S	light source
SD	standard deviation
SOP	state of polarization
SSE	source spontaneous emission
TF	tracking filter
TJ	temporary joint
TLS	tuneable laser source.
TND	tuneable narrowband detector
TNLS	tuneable narrowband light source
WDL	wavelength dependent loss
WDM	wavelength division multiplexer
WM	wavelength meter

4 General description

This standard is complementary to the wavelength dependence of attenuation, and return loss (IEC 61300-3-7), and polarization dependence of attenuation (IEC 61300-3-2) for DWDM devices which channel spacing is less than or equal to 1 000 GHz (8 nm at the wavelength band of 1 550 nm).

The transfer functions can be used to produce measurements of following performance parameters:

– insertion loss (IL);
– centre wavelength and centre wavelength deviation;
– *X* dB bandwidth;
– passband ripple;
– isolation;

– crosstalk;
– polarization dependent loss (PDL) and polarization dependent centre wavelength (PDCW) ;
– channel non-uniformity;
– out-of-band attenuation.

In general, the DWDM devices have channel bandwidths less than 1 nm, filter response slopes greater than 100 dB/nm, and out-of-band rejection extending over tens of nm.

The methods described in this standard will show how to obtain the transfer function from a single input to a single output port (single conducting path). For an *M* x *N* device, it will be required to repeat this procedure using all possible combinations of input and output ports.

The methods described in this standard are intended to be applicable to any wavelength band (C, L, S, O, etc.) although examples may be shown in the C-band for illustrative purposes.

The two methods contained in this standard differ mainly in the way in which the wavelength resolution is obtained. Method A uses a tuneable narrowband light source, while Method B used a broadband light source. Method A has two branching methods; Method A.1 and Method A.2. These three measurement methods are summarized in Table 1. Method A.2 shall be considered the reference test method for DWDM devices.

Table 1 – Test methods

Method	Names	Source	Detector	Examples	Remarks
A.1	TNLS in sweep mode + BBD	TNLS in sweep mode	BBD	TNLS + DUT + OPM	Alternative
A.2	TNLS in sweep mode + TND	TNLS in sweep mode	TND	TNLS + DUT + OSA	Reference
B	BBS + TND	BBS	TND	BBS + DUT + OSA	Alternative

This standard also includes annexes that illustrate the following:

Annex A: Reflection spectrum measurements;

Annex B: Determination of wavelength increment parameter;

Annex C: Determination of a mean value using the shorth function.

5 Apparatus

5.1 Measurement set-up

The basic measurement set-up for the characterization of DWDM devices is shown in Figure 1 below.

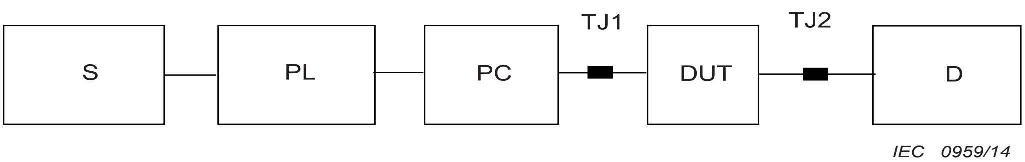


Figure 1 – Basic measurement set-up

This procedure contains three methods that differ fundamentally in the way in which the wavelength resolution is achieved. There are three key influences on the wavelength resolution: the linewidth of the source or bandwidth of the tuneable narrowband detector, the analogue bandwidth of the detection system and the rate of change of wavelength.

Having determined the wavelength resolution of the measurement, the wavelength sampling increment (δ) should be less than half the bandwidth of the system in order to accurately measure the average value of the optical attenuation.

The bandwidth of the system is determined by the convolution of the effective source bandwidth with the rate of change of wavelength over the time constant of the detector. Practical constraints may result in smaller or larger bandwidths than recommended. Two cautions should be noted with smaller bandwidths: first, coherent interference effects can lead to additional measurement errors, and second, under-sampling of the device could lead to misrepresentations of the reconstructed transfer function. If larger bandwidths are used, the reconstructed transfer function could smear out fine structures and distort response slopes. As the response slopes may exceed 100 dB/nm, small uncertainties in wavelength may result in large amplitude response errors. In general, the resolution bandwidth of the system needs to be chosen based on the device characteristics and noted in the details to be specified.

As explained in Table 1, there are three measurement methods. Figures 2, 3, and 4 show the typical set-ups for Methods A.1, A.2 and B.

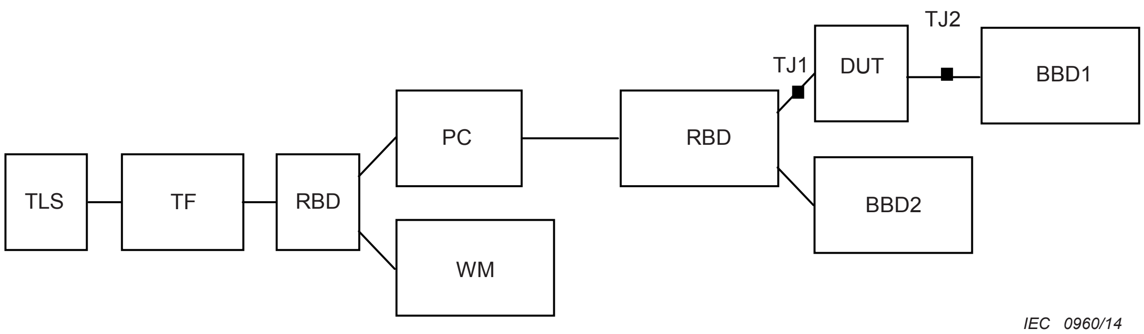


Figure 2 – Measurement set-up for tuneable narrowband light source (TNLS) system

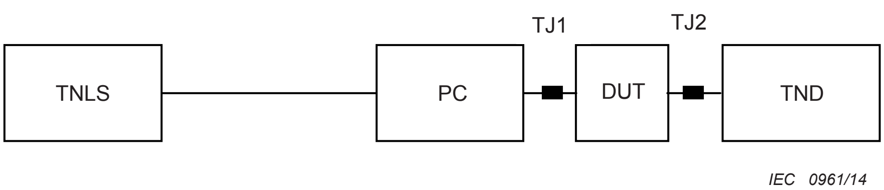


Figure 3 – Measurement set-up for TNLS and tuneable narrowband detector (TND) system

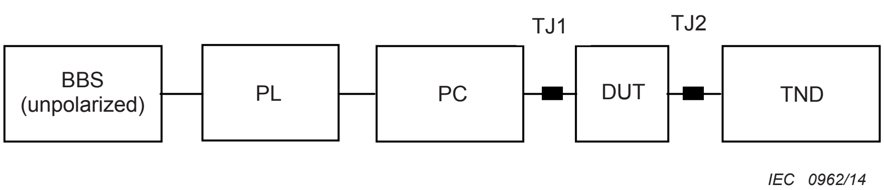


Figure 4 – Measurement set-up for BBS and tuneable narrowband detector (TND) system

5.2 Light source, S

5.2.1 Tuneable narrowband light source (TNLS) – Method A

This method uses a polarized tuneable narrowband light source (TNLS) that can select a specific output wavelength and can be tuned across a specified wavelength range. The "source" could also include a tracking filter, reference branching device (RBD), and wavelength monitor as shown in Figure 2. These additions are optional as they relate to the measurement requirements and the TLS specifications.

The power stability at any of the operating wavelengths shall be less than ±0,01 dB over the measuring period. This stability can be obtained using the optional detector BBD2 in Figure 2 as a reference detector. If BBD2 is synchronized with BBD1, then the variations in power can be cancelled. It should be noted that the dynamic response of the two power meters should have the same electrical bandwidth. The output power of the TLS shall be sufficient to provide the apparatus with an order of magnitude range more dynamic than the device exhibits (i.e. the measurement apparatus should be able to measure a 50 dB notch if the device is a 40 dB notch filter).

The wavelength uncertainty of the TLS shall be approximately an order of magnitude smaller than the step size for each point in the measuring range. This uncertainty may be obtained by having the wavelength monitor feedback to the TLS. The tuning range of the TLS shall cover the entire spectral region of the DWDM device and the source shall also be free of mode hopping over that tuning range.

The side mode suppression ratio and the SSE of the TLS should be sufficient to provide a signal to noise ratio one order of magnitude greater than is required for the measurement, or the use of a tracking filter shall be required for notch filter measurements. The SSE can be measured on an optical spectrum analyser using a 0,1 nm resolution bandwidth. The measured points should be taken at half the distance between possible DWDM channels (i.e. at 50 GHz from the centre frequency for a 100 GHz DWDM device). As an example, if the system needs to measure 50 dB of attenuation, the SSE should be –60 dB.

5.2.2 Broadband source (BBS) – Method B

This method uses an unpolarized broadband light source such as an LED or an amplified spontaneous emission (ASE) source. The source spectrum shall provide sufficient optical power over the full wavelength range of the DUT. This factor is especially important in the measurement of notch filters where the dynamic resolution of the system needs to be high (typically >50 dB) for accurate measurements.

The optical power of the light source shall either be stable over the duration of the test or normalized in a wavelength-specific fashion by means of a reference path (possibly consisting of a RBD and a synchronized TND).

5.3 Tracking filter (TF)

The tracking filter is required if the dynamic range of the TLS and the detector does not allow for measuring a depth of at least 10 dB greater than required due to the shape of the DUT and the broadband SSE of the TLS. The filter shall track the TLS so as to provide the maximum SSE suppression and the maximum transmitted power as the TLS is scanned across the measurement region. It should be noted that the spectral shape of the filter will affect the effective linewidth of the system.

5.4 Reference branching device (RBD)

The configuration of the RBD is 1 × 2 or 2 × 2. If its configuration is 2 × 2, one port of the RBD shall be terminated to have a back reflection of less than –50 dB. The splitting ratio of the RBD shall be stable with wavelength. It shall also be insensitive to polarization. The polarization sensitivity of transmission attenuation shall be less than one-tenth of the wavelength dependency of attenuation to be measured. The polarization mode dispersion of the RBD shall be less than one half of the coherence time of the source so as not to depolarize the input signal. The split ratio shall be sufficient to provide the dynamic range for the measurement of the transfer function and the power necessary for the wavelength meter to operate correctly.

5.5 Wavelength meter (WM)

In this test procedure, the wavelength uncertainty of the source needs to be extremely small and closely monitored. If the tuning uncertainty of the TLS is not sufficient for the measurement, the wavelength monitor shall be required. For this measurement method it is necessary to measure the spectral peak of any input signal within the device bandwidth to an uncertainty approximately one order of magnitude greater than the step size. Therefore, acceptable wavelength monitors include an optical wavelength meter or a gas absorption cell (such as an acetylene cell). If a gas absorption cell is used, the wavelength uncertainty of the TLS shall be sufficient to resolve the absorption lines.

Regarding the wavelength repeatability of the TLS and the monitor, it should be understood that if the test apparatus has 0,1 dB of ripple with a 30 pm period, then a random 3 pm wavelength variation from reference scan to device scan can result in as much as 0,03 dB of attenuation error.

5.6 Polarizer (PL)

For the BBS method (Method B), the polarizer shall be put after the BBS. A polarization extinction ratio of polarizer shall be more than or equal to 20 dB.

5.7 Polarization controller (PC)

The polarization controller is used to control the input state of polarization (SOP). The details of polarization controller are defined as PSCS in IEC 61300-3-2. That standard defines two types of PSCS, for all polarization methods and the Mueller matrix method. In the event of a polarization dependent measurement, the controller will be used to generate four known polarization states for testing purposes. The states shall be distinct and well known in order to achieve accurate PDL measurements. The return loss on the input to the controller shall be greater than 50 dB, so as not to return any polarized light back to the TLS cavity for Method A. This may also be achieved using an isolator to protect the TLS.

5.8 Device under test (DUT)

5.8.1 General

The device under test shall be DWDM devices. For the purposes of this standard, the test ports shall be a single “input-output” path. The method described herein can be extrapolated upon to obtain a single measurement system capable of handling even an M x N DWDM device. It is noted that these measurements are very sensitive to reflections, and that precautions shall be taken to ensure that reflection cavities are not introduced in the test set-up.

In many cases, the characteristics of DWDM devices are temperature dependent. This measurement procedure assumes that any such device is held at a constant temperature throughout the procedure. The absolute uncertainty of the measurement may be limited by the uncertainty of any heating or cooling device used to maintain a constant temperature. For example, if a device is known to have a temperature dependence of 0,01 nm/°C, and the temperature during the procedure is held to a set temperature ± 1 °C; then any spectral results obtained are known to have an uncertainty of 0,02 nm due to temperature.

5.8.2 Device input/output optics

If fibre connectors or fibre butt coupling are employed, use physical contact connectors or index matching fluid to avoid interference effects.

5.9 Detector (D)

5.9.1 Broadband detectors, BBD1, BBD2, Method A.1

The detectors used for this method consist of a broadband optical detector, the associated electronics and a means of connecting to an optical fibre. The optical connection may be a receptacle for an optical connector, a fibre pigtail, or a bare fibre adapter. The back reflection from detectors BBD1 and BBD2 should be minimized with any precautions available. The preferred options would be to use either an angled physical contact (APC) connector, or a physical contact (PC) connector in conjunction with an optical isolator. It should be noted that the use of an APC connector will contribute approximately 0,03 dB of PDL to the measurement uncertainty. The WDL and PDL for an optical isolator shall be less than 0,05 dB.

The dynamic range and sensitivity of the detectors should be sufficient to measure the noise floor required by the test system and the DUT. In general, it is required to have a dynamic range approximately 10 dB wider than the measurable isolation of the device, with a sensitivity at least 5 dB below the expected stop band attenuation at the test system power level. For instance if the maximum device isolation is 40 dB, the maximum device loss is 5 dB, and the test system optical power is –5 dBm, then the detectors would need to have a sensitivity of at least –55 dBm, and a dynamic range of at least 50 dB (i.e. should not saturate at –5 dBm).

The detectors should have a resolution of 0,001 dB and linearity better than 0,02 dB over the pass band wavelength range. The stability of the power detectors should exceed 0,01 dB over the measurement period in the pass band as well. For polarization dependent measurements, the polarization dependence of the detector should be less than 0,01 dB.

Where during the sequence of measurements a detector shall be disconnected and reconnected, the coupling efficiency for the two measurements shall be maintained. Use of a large area detector to capture all of the light emanating from the fibre is recommended, but care should be taken to ensure that the stability of the detector parameters are not affected by variations in detection uniformity over the active area of the detector. It is also recommended that the face of the detector be placed at an angle other than orthogonal to the incoming light source to reduce back reflections while ensuring that polarization effects are minimized.

Another important parameter for the detectors is the electrical bandwidth. As it is desired to make this measurement as quickly as possible, the response time of the detectors becomes a limiting factor in the amount of time spent on each step (or in the uncertainty of the reading for a swept system).

5.9.2 Tuneable narrowband detector (TND) – Method A.2 and Method B

This method measures the optical output of the DUT with a tuneable narrowband detector such as an optical spectrum analyser. The analyser can be a monochromator or a tuneable bandpass filter followed by a photodiode detector. The absolute wavelength of the optical spectral analyser, monochrometer, or tuneable filter shall be calibrated precisely before taking measurements.

As was stated in 5.3, it is also conceivable to use a tracking filter immediately after the broadband source (rather than in front of the detector) for this system with the caveats for effective source linewidth understood.

The detector shall have the same stability, dynamic range, sensitivity, resolution and linearity requirements as described in 5.2.1 for the tuneable laser method. One difference for this method is that the power density of the BBS over the optical bandwidth of the detector tends to have much lower powers than an equivalent laser based system, so the sensitivity needs to be much better to make the same measurement.

In the case of Method A.2, the bandpass of tuneable narrowband detector shall be wider than that of tuneable narrow light source.

5.10 Temporary joints (TJ)

Temporary joints are specified to connect all system components including the test sample. Examples of temporary joints are a connector, splice, vacuum chuck, or micromanipulator. The loss of the TJ shall be stable and should have a return loss at least 10 dB greater than the maximum return loss to be measured. In the event that connectors are used, it is preferred to use angled ones.

6 Procedure

6.1 General

The following subclauses will outline the measurement procedure whereby data can be collected and analysed on a DWDM device. Since these devices tend to be sensitive to polarization, all of the measurements shall be made using either the “all states method” or the “Mueller matrix method” in IEC 61300-3-2. These methods will be reiterated in this standard. Due to the number of data points typically required to characterize these devices, it is more practical to use the Mueller matrix method for this procedure. However, in the event of a controversy, the all states method (with sufficient coverage) shall be the reference. This procedure applies to both measurement systems as differences are highlighted in the text.

If polarization information is not required for the measurement (possibly for an incoming inspection test), it is acceptable to use Method B without the polarization controller. In this case, the measured unpolarized transfer function or reference is equivalent to the “average” transfer function or reference mentioned in the text.

In the interest of completeness, it is important to note that there are fibre components such as the fibre Bragg grating (FBG) that are used in DWDM devices. The main difference of these devices is that they can operate as a single port as opposed to the multi-port devices described in the standard. Annex A shows how this measurement technique can be expanded upon to handle single port components.

6.2 Preparation of DUTs

All the input and output optics shall be cleaned and inspected in accordance with standard industry practices or the recommendation of the device manufacturer.

6.3 System initialization

The test system will be set-up to sweep across the wavelength region of interest ($\lambda_{min} - \lambda_{max}$) or span in increments of δ, as determined by the specifications of the measurement. For reference purposes, Annex B shows how an appropriate step size can be determined using the desired wavelength uncertainty, the slope of the response curve at the crossing for the centre wavelength, and the maximum possible power error in the pass band measurement.

6.4 System reference measurement

6.4.1 General

In the determination of the transfer function, it will be necessary to measure the reference spectra of the test system itself. In the event of testing a multi-port device, it will not be necessary to repeat the reference step before each measurement.

6.4.2 Measurement of the reference spectra for Method A

Figure 5 shows the measurement set-up of reference spectra for Method A.1. TLS and TF are replaced by TNLS for Method A.2. The TLS shall then be scanned across the wavelength span taking wavelength measurements from the wavelength monitor, transmission measurements from BBD1 and source monitor measurements from BBD2. It is assumed that all powers are measured on a linear scale. The manner in which the polarization states are controlled during the sweep will vary based on the method used.

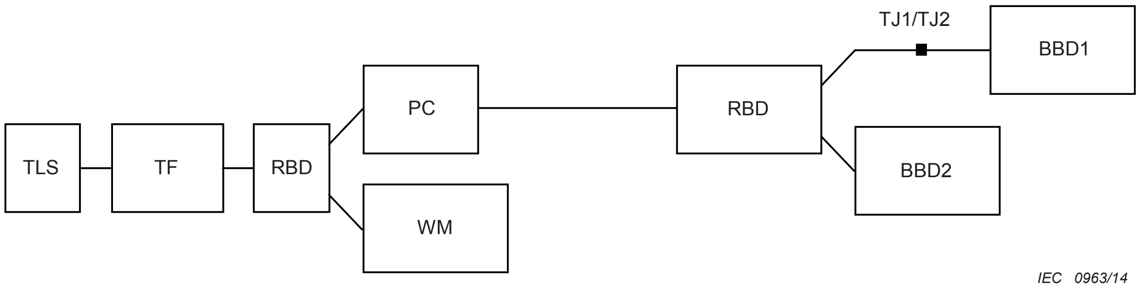


Figure 5 – System reference for transmission measurement

In the event that the all states method is used, the polarization shall be varied over all states for each step in the wavelength sweep. For each wavelength, it will be necessary to capture the maximum, minimum, and average values of the transmission power as well as the average value of the monitor power. This will result in matrixes for $t_{L\text{max}}(\lambda)$, $t_{L\text{min}}(\lambda)$, $t_{L\text{ave}}(\lambda)$, and $m_{\text{ave}}(\lambda)$. Care should be taken to ensure that enough time is spent at each polarization to get an accurate power reading.

In the event that the Mueller matrix method is used, it is more practical to complete a sweep at each of the four known SOPs. It is typical to use: A) linear horizontal, B) linear vertical, C) linear diagonal and D) right-hand circular. This will result in matrixes for $t_{L\text{A}}(\lambda)$, $t_{L\text{B}}(\lambda)$, $t_{L\text{C}}(\lambda)$, $t_{L\text{D}}(\lambda)$, $m_{\text{A}}(\lambda)$, $m_{\text{B}}(\lambda)$, $m_{\text{C}}(\lambda)$ and $m_{\text{D}}(\lambda)$. This can also be accomplished in a single sweep by varying the SOP at each wavelength increment, but it is less efficient in terms of time to complete the measurement.

6.4.3 Measurement of reference spectra for Method B

As in the above case, the DUT is removed from the test set-up (Figure 3). Here the output of the polarization controller is connected to the tuneable narrowband detector and the detector is swept across the entire measurement wavelength range. The readings from the detector shall supply the equivalent matrixes as in 6.4.2. If the measurement is made using unpolarized light, only the $t_{L\text{ave}}(\lambda)$ array is obtained.

6.5 Measurement of device spectra

With the device re-inserted in the test set-up, the measurement procedure outlined in 6.4.2 (or 6.4.3) shall be repeated. In this manner, the various transmission and source monitor spectra [$T_L(\lambda)$ and $M(\lambda)$] can be captured and stored.

7 Characterization of the device under test

7.1 Determination of transfer functions

7.1.1 General

After the measurement procedures outlined in Clause 6 are completed, the respective minimum, maximum and average transfer functions can be determined from the gathered data.

7.1.2 Accounting for the source variations

If the source monitor port is not used in the set-up, this subclause may be omitted. If it is used, the various transmission spectra should be recalculated for the Mueller matrix method as follows:

$$T_L'(\lambda) = T_L(\lambda)/M(\lambda) \text{ or } t_L'(\lambda) = t_L(\lambda)/m(\lambda) \quad (1)$$

For the all states method, this recalculation need only be made for the average power array since there is no way to correlate the maximum and minimum polarization states between the reference and the monitor paths without storing the results from each individual state.

It should be noted that for the remainder of the document *T'* may be substituted for *T* or *t*' for *t* in the equations. The prime factor is left off for convenience.

7.1.3 Calculations for the Mueller matrix method

If the Mueller matrix method is used, it is now necessary to translate the measurements from the known states into their approximate maximum, minimum and average values. That is done by establishing the Mueller matrix:

$$m_{11}(\lambda) = |\ ½ * [\ T_{LA}(\lambda)/t_{LA}(\lambda) + T_{LB}(\lambda)/t_{LB}(\lambda)\ ]\ | \quad (2)$$

$$m_{12}(\lambda) = |\ ½ * [\ T_{LA}(\lambda)/t_{LA}(\lambda) - T_{LB}(\lambda)/t_{LB}(\lambda)\ ]\ | \quad (3)$$

$$m_{13}(\lambda) = |\ T_{LC}(\lambda)/t_{LC}(\lambda) - m_{11}\ | \quad (4)$$

$$m_{14}(\lambda) = |\ T_{LD}(\lambda)/t_{LD}(\lambda) - m_{11}\ | \quad (5)$$

where measurements with subscript A were taken with linear horizontal, B with linear vertical, C with linear diagonal, and D with right-hand circular polarization in typical cases.

Maximum, minimum, and average transmissions can then be given as follows:

$$T_{L\max}(\lambda) = m_{11}(\lambda) + [m_{12}(\lambda)^2 + m_{13}(\lambda)^2 + m_{14}(\lambda)^2]^{1/2} \quad (6)$$

$$T_{L\min}(\lambda) = m_{11}(\lambda) - [m_{12}(\lambda)^2 + m_{13}(\lambda)^2 + m_{14}(\lambda)^2]^{1/2} \quad (7)$$

$$T_{L\text{ave}}(\lambda) = [T_{L\max}(\lambda) + T_{L\min}(\lambda)]/2 \quad (8)$$

7.2 Transmission ($T(\lambda)$) spectra measurements

7.2.1 General

As noted earlier, the transmission spectra around a passband (channel frequency range) for DWDM devices is same characteristics as that for optical filters which have one input port and one output port. In this clause, the measurement method is explained for bandpass filter and notch filter, instead of DWDM devices. A typical transfer function for a band pass filter is shown in Figure 6a, while a graph for a notch filter is shown in Figure 6b.

As shown in Figure 6, the transfer functions are usually plotted on a logarithmic scale so it is useful to convert the measurement arrays from Watts to decibels.

For the all states method (or unpolarized case), the transfer function is calculated as follows:

$$T_{\text{xxx}}\ (\lambda) = 10 \log \left[t_{L\text{xxx}}(\lambda) / T_{L\text{xxx}}(\lambda) \right] \text{ (dB)} \qquad (9)$$

where powers are measured in Watts.

If the Mueller matrix method is used, the transfer function is simply:

$$T_{\text{xxx}}\ (\lambda) = -10 \log \left[T_{L\text{xxx}}(\lambda) \right] \text{ (dB)} \qquad (10)$$

where the ‘xxx’ implies that the equation is valid for the average, minimum and maximum arrays.

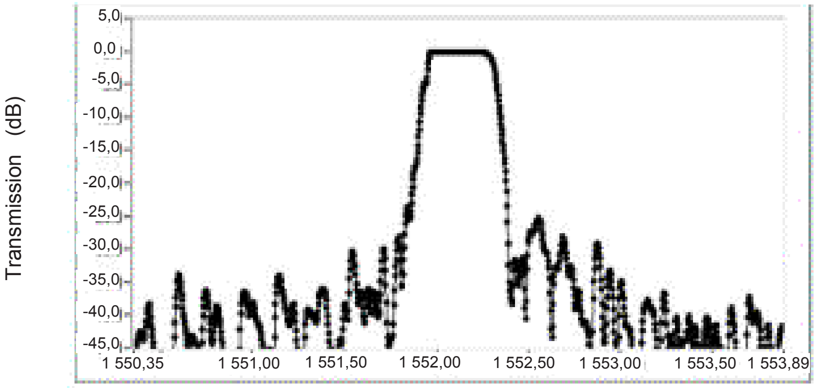
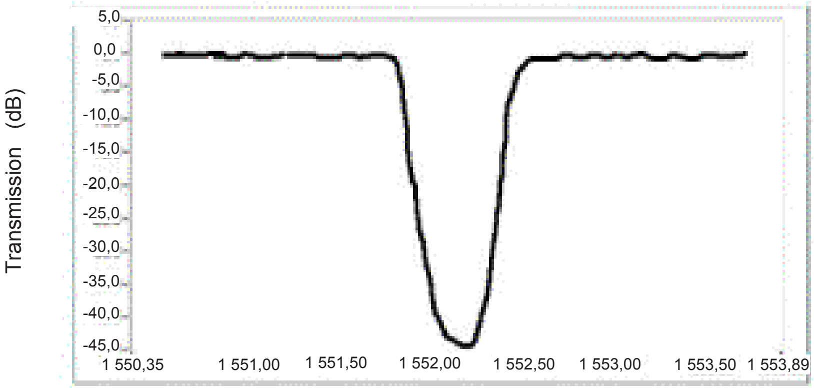


Figure 6a – Band pass filter

IEC 0964/14



Wavelength (nm)

Figure 6b – Notch filter

IEC 0965/14

Figure 6 – Normalized transfer functions

7.2.2 Peak power calculation

Nearly all of the spectral techniques described in this subclause shall be related to either the peak power of the pass band for band pass filters, or the peak power of the through channels for notch filters. In either case, the measured transfer function will not be flat across those regions, so it is necessary to understand how the peak is determined.

There are several common methods for selecting the peak power. A few of them are listed below:

$$T_{max} = \max\{T(\lambda)\} \quad (11)$$

$$T_{max} = \text{mean}\{T(\lambda_h - CFR/2),\ T(\lambda_h + CFR/2)\} \quad (12)$$

$$T_{max} = \text{shorth}\{T(\lambda_h -),\ T(\lambda_h +)\} \quad (13)$$

While the first two methods involve taking either the maximum or mean reading across a wavelength range, the third is less obvious and is explained in Annex C.

This standard does not recommend a preferred method, but the subtle differences shall be understood and noted in the measurement.

7.2.3 Normalization of the transfer function

The transfer functions are usually represented on a normalized, logarithmic scale (as seen in Figure 6) so the peak transmission as determined in 7.2.2 is at 0 dB. The plotted functions can be obtained as follows:

$$T_N(\lambda) = [T(\lambda) - T_{max}] \text{ (dB)} \quad (14)$$

Most of the measurements detailed in the following subclauses are based on the normalized transfer function.

7.3 Calculation of optical attenuation (A)

There are generally three types of optical attenuation (A) documented for DWDM devices. The first is the optical attenuation of the nominal channel of the device (([$A(\lambda_h)$). The second is the optical attenuation of the nearest neighbours or isolated channels ($A(\lambda_{i=h+1})$ and $A(\lambda_{g=h-1})$). The final optical attenuation is that of the other isolated channels ($A(\lambda_x)$, where x ≠ h, i, or g) termed the non-adjacent channel isolation.

In each of these cases, the insertion loss should be specified as a threshold throughout $\lambda = \lambda_h \pm$ CFR/2 where λ_h is the nominal wavelength for which the device is intended and CFR is the entire operating wavelength range specified for the device or respective channel.

For the all states method, optical attenuation is calculated as follows:

$$A(\lambda) = 10 \log [t_{Lave}(\lambda)/T_{Lave}(\lambda)] \text{ (dB)} \quad (15)$$

where powers are measured in Watts.

If the Mueller matrix method is used, the optical attenuation is simply:

$$A(\lambda) = -10 \log [T_{Lave}(\lambda)] \text{ (dB)} \quad (16)$$

In this case the reference sweep has already been accounted for in the matrix formulae.

As mentioned above the channel, nearest neighbour, and non-adjacent channel optical attenuation should be taken over the centre wavelength range of the device, leading to several different interpretations (minimum, maximum, mean) for each.

7.4 Insertion loss (IL)

Insertion loss is the optical attenuation for channel to transmit. Insertion loss is commonly defined as the maximum value of optical attenuation over the centre frequency range:

$$IL(\lambda_h) = \max (A(\lambda_h \pm CFR/2) \text{ (dB)} \quad (17)$$

Insertion loss expressed using transfer function is as follows:

$$IL(\lambda_h) = -10 \log [T_{Lmin}(\lambda_h \pm CFR/2)] \text{ (dB)} \quad (18)$$

Insertion loss is positive value in dB.

7.5 Bandwidth and full spectral width

7.5.1 General

Measurements of the pass band bandwidth (BW) are made relative to the peak of the spectral response of the normalized transfer function. An example of a reflectance spectrum for a FBG is shown in Figure 7 with the –1 dB BW highlighted. This presents an opportunity to show the difference between the BW and the full spectral width measurements, since the FBG has more than two –1 dB crossing points. In calculating the BW, it is necessary to use the closest crossing points on either side of the centre wavelength. In contrast, the full spectral width would use the furthest crossing points on either side of the centre wavelength.

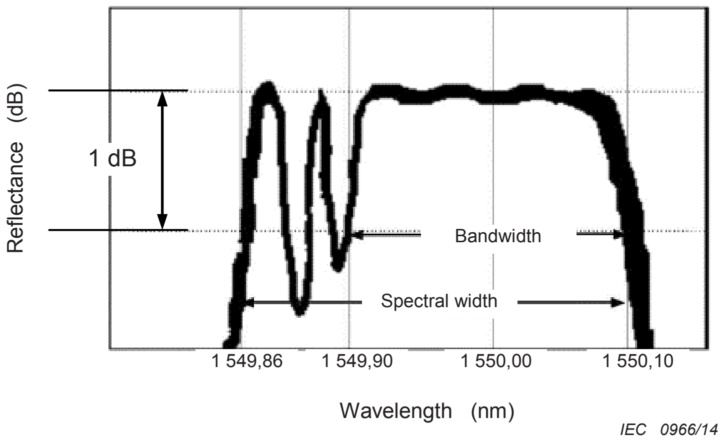


Figure 7 – BW and full spectral width for a fibre Bragg grating

In either case, it is unlikely that the actual crossing points of interest (T_x) will be one of the points in the measurement set. To determine the crossings in such a case, it is common to use a linear interpolation of the two points closest to the crossing. Thus, if the point just above the crossing is represented as (T_{x+}, λ_{x+}) and the point just below the crossing as (T_{x-}, λ_{x-}), the crossing wavelength λ_x is determined as follows:

$$\lambda_x = \left(\frac{\lambda_{x+} - \lambda_{x-}}{T_{x+} - T_{x-}}\right) * (T_x - T_{x-}) + \lambda_{x-} \qquad (19)$$

It is also acceptable to use the points just above or below the desired crossing for the respective BW calculations.

BW measurements should also include a spectral range over which the measurement should be limited. This is especially necessary for devices that exhibit a repeating structure or that have higher order modes.

For a notch filter (Figure 6b) the centre wavelength is located at the minimum of the spectral response curve, and the stop band is defined by the BW at a point relative to the top skirts of the filter (i.e. BW (–40 dB)).

7.5.2 Centre wavelength

The centre wavelength measurements for the purposes of this standard shall be based upon the X dB BW measurement. The centre shall be defined as the median of the two crossing points. For example, a device could have a –1 dB centre of 1 550,00 nm if its –1 dB crossings are at 1 549,90 nm and 1 550,10 nm, and an 1 dB band width of 0,20 nm.

The BW centre may differ from the nominal operating wavelength of the DUT as in practice the nominal centre may also incorporate other factors such as isolation, dispersion and/or polarization effects.

7.5.3 Centre wavelength deviation

The centre wavelength deviation is the difference between the centre wavelength and nominal wavelength of the specified channel for DWDM devices. Where centre wavelength is defined as the centre of the wavelength range which is *X* dB optical attenuation more than the minimum insertion loss (minimum optical attenuation) for the specified channel frequency range (passband).

NOTE 0,5, 1 or 3 are generally used for *X*.

7.5.4 *X* dB bandwidth

The *X* dB bandwidth is the minimum wavelength range at *X* dB increase from the minimum insertion loss. As shown in Figure 8, the centre wavelength can be shifted due to temperature dependence, polarization dependence and long-term aging. The *X* dB bandwidth includes this shift.

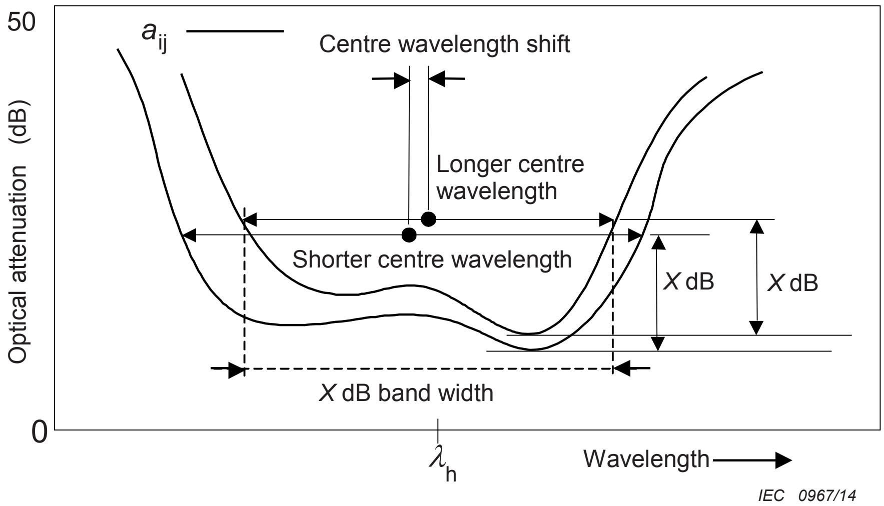


Figure 8 – *X* dB bandwidth

7.6 Passband ripple

Passband ripple is the maximum variation between the maximum and the minimum of the optical attenuation over the channel frequency range (passband).

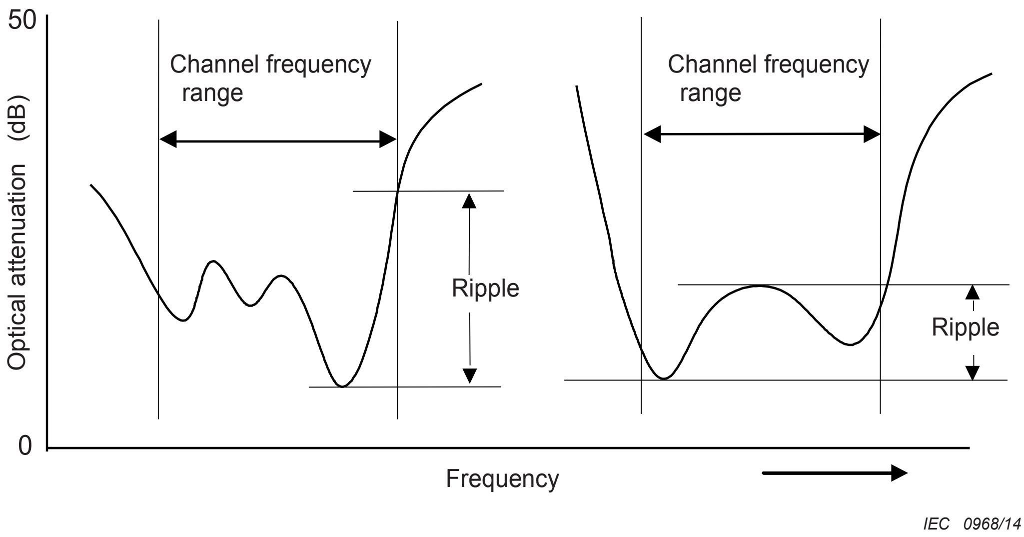


Figure 9 – Passband ripple

7.7 Isolation (I) and crosstalk (XT)

7.7.1 General

Isolation is a measure of the power from channels outside the channel frequency range leaking through a band pass filter relative to the input power. It is usually defined for the nearest neighbour and the non-adjacent cases. Figure 10 illustrates these concepts.

Crosstalk is different to isolation. The crosstalk is the ratio of undesired signal (or noise) power to the desired signal power.

Isolation is positive in dB, and crosstalk is negative in dB. In Figure 10, upwards pointing arrows show positive values and downward pointing arrows show negative values.

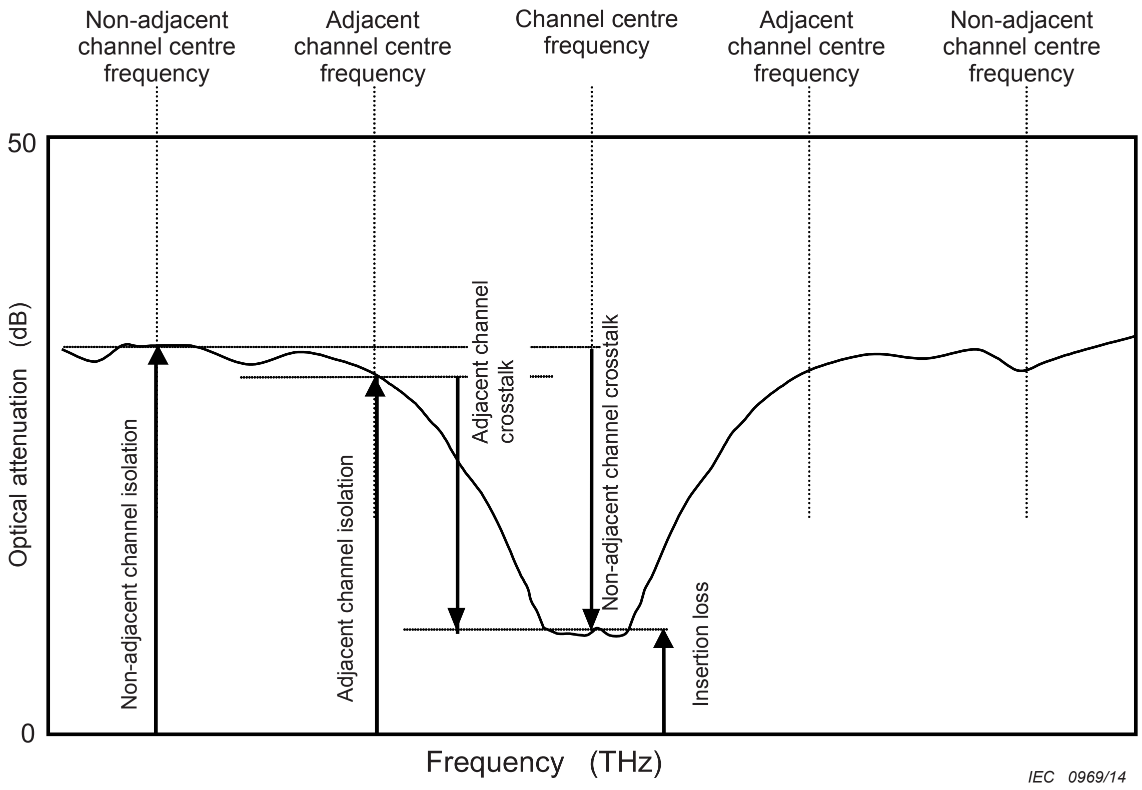


Figure 10 – Channel isolation and crosstalk

7.7.2 Channel isolation

The channel isolation at a particular wavelength [$I(\lambda_j)$, where j≠h] is the optical attenuation at that wavelength, λ_j. It is simply expressed as

$$I(\lambda_j) = A(\lambda_j) \text{ (dB)} \tag{20}$$

For using transfer function, it is expressed as

$$I(\lambda_j) = -10 \log [T(\lambda_j)] \text{ (dB)} \tag{21}$$

7.7.3 Channel crosstalk

The channel crosstalk at a particular wavelength is the ratio of the optical output power of the wavelength (λ_j, where j≠h) to the optical output power of the wavelength (λ_h). Crosstalk is calculated using optical attenuation, A as

$$XT(\lambda_j) = A(\lambda_h) - A(\lambda_j) \text{ (dB)} \tag{22}$$

As $A(\lambda_h)$ is generally smaller than $A(\lambda_j)$, the crosstalk is a negative value in dB.

NOTE As $A(\lambda_h)$ is the insertion loss and $A(\lambda_j)$ is the isolation, crosstalk is the subtraction of the isolation from the insertion loss.

7.7.4 Adjacent channel isolation

The adjacent channel isolation is the isolation coming from the adjacent ($\lambda_{j=h\pm1}$) transmission channel (λ_h).

NOTE There are two adjacent channel isolations, for the channels of g=h-1 and i=h+1, unless channel h is the shortest wavelength (highest frequency) or longest wavelength (lowest frequency) in all channels.

7.7.5 Adjacent channel crosstalk

The adjacent channel crosstalk is the crosstalk coming from the adjacent ($\lambda_{j=h\pm1}$) transmission channel (λ_h).

NOTE There are two adjacent channel crosstalks, for the channels of g=h-1 and i=h+1, unless channel h is the shortest wavelength (highest frequency) or longest wavelength (lowest frequency) in all channels.

7.7.6 Minimum adjacent channel isolation

The minimum adjacent channel isolation is the minimum value of the adjacent channel isolation over the channel frequency range (passband) of the adjacent channel, as shown in Figure 11.

7.7.7 Maximum adjacent channel crosstalk

The maximum adjacent channel crosstalk is the maximum value of the adjacent channel crosstalk over the channel frequency range (passband) for the channel h, g and i. It is calculated as the subtraction of the minimum optical attenuation of channel j (g and i; h±1) from the maximum optical attenuation of channel h, as:

$$XT_{adj}^{max}(\lambda_j) = \max[\ A(\lambda_h \pm CFR/2)\ ] - \min[\ A(\lambda_j \pm CFR/2)\ ]\ (\text{dB}) \qquad (23)$$

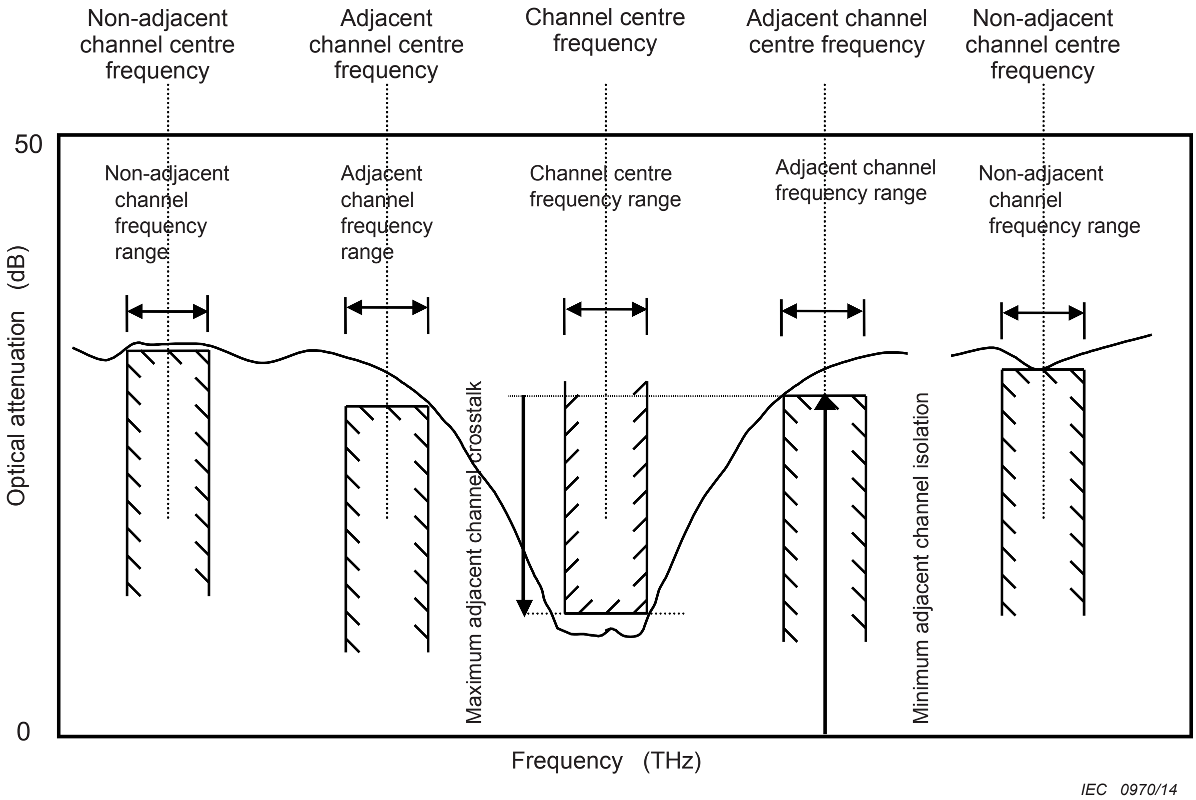


Figure 11 – Minimum adjacent channel isolation

7.7.8 Non-adjacent channel isolation

The non-adjacent channel isolation is the channel isolation which is not adjacent to the transmission channel. Refer to Figure 10.

7.7.9 Non-adjacent channel crosstalk

The non-adjacent channel crosstalk is the channel crosstalk which is not adjacent to the transmission channel. Refer to Figure 10.

7.7.10 Minimum non-adjacent channel isolation

The minimum non-adjacent channel isolation is the minimum value of the non-adjacent channel isolation over the channel frequency range (passband) of the non-adjacent channel, as shown in Figure 11.

7.7.11 Maximum non-adjacent channel crosstalk

The maximum non-adjacent channel crosstalk is the maximum value of the non-adjacent channel crosstalk over the channel frequency range (passband) for the channel h and all other channels j (j≠h, g and i). It is calculated as the subtraction of the minimum optical attenuation of channel j (j≠h, g and i) from the maximum optical attenuation of channel h, as:

$$XT_{\mathrm{nonadj}}^{\max}(\lambda_{\mathrm{j}}) = \max[\ A(\lambda_{\mathrm{h}} \pm CFR/2)\ ] - \min[\ A(\lambda_{\mathrm{j}} \pm CFR/2)\ ]\ \text{(dB)} \tag{24}$$

7.7.12 Total channel isolation

Total channel isolation is defined for 1xN DWDM devices when they are used for OMUX. It is calculated as the cumulative of the isolations for isolated channels. It is expressed using the transfer function as:

$$I_{\mathrm{tot}}(\lambda_{\mathrm{h}}) = -10\log\left(\sum_{i=1,\neq \mathrm{h}}^{N} T(\lambda_{\mathrm{i}})\right)\ \text{(dB)} \tag{25}$$

7.7.13 Total channel crosstalk

Total channel crosstalk is defined for 1xN DWDM devices when they are used for OMUX. It is the ratio of the cumulative optical output powers of the wavelength (λ_{j}, where j≠h) to the optical output power of the wavelength (λ_{h}). It is calculated as:

$$XT_{\mathrm{tot}}(\lambda_{\mathrm{h}}) = I_{\mathrm{tot}}(\lambda_{\mathrm{h}}) - IL(\lambda_{\mathrm{h}})\ \text{(dB)} \tag{26}$$

7.7.14 Minimum total channel isolation

Minimum total channel isolation is defined for 1xN DWDM devices when they are used for OMUX. It is calculated as the cumulative of the isolations for isolated channels over channel frequency range. It is expressed using transfer function as:

$$I_{\mathrm{tot}}^{\max}(\lambda_{\mathrm{h}}) = -10\log\left(\sum_{i=1,\neq \mathrm{h}}^{N} T(\lambda_{\mathrm{i}} \pm CFR/2)\right)\ \text{(dB)} \tag{27}$$

7.7.15 Maximum total channel crosstalk

Maximum total channel crosstalk is defined for 1xN DWDM devices when they are used for OMUX. It is the ratio of the cumulative optical output powers of the wavelength (λ_{j}, where j≠h) over channel frequency range to the optical output power of the wavelength (λ_{h}). It is calculated as:

$$XT_{tot}^{max}(\lambda_h) = I_{tot}^{max}(\lambda_h \pm CFR/2) - IL(\lambda_h \pm CFR/2) \text{ (dB)} \quad (28)$$

7.8 Polarization dependent loss (*PDL*(λ))

The PDL can be calculated for either the all states or the Mueller matrix method as follows:

$$PDL(\lambda) = T_{max}(\lambda) - T_{min}(\lambda) \text{ (dB)} \quad (29)$$

where the maximum and minimum transfer functions are in decibels. To obtain a spectrum of PDL, this measurement can be repeated for each point in the wavelength sweep of the process.

The main areas of interest for the PDL are in the CFRs of the nominal and the isolated channels. Clearly the PDL of the device will impact both the optical attenuation and the isolation parameters if the end application of the device is in a laser based system. However, the PDL will also affect the bandwidth and centre wavelength. Figure 12 is an example showing the transfer function of a DWDM passband using varying states of polarization.

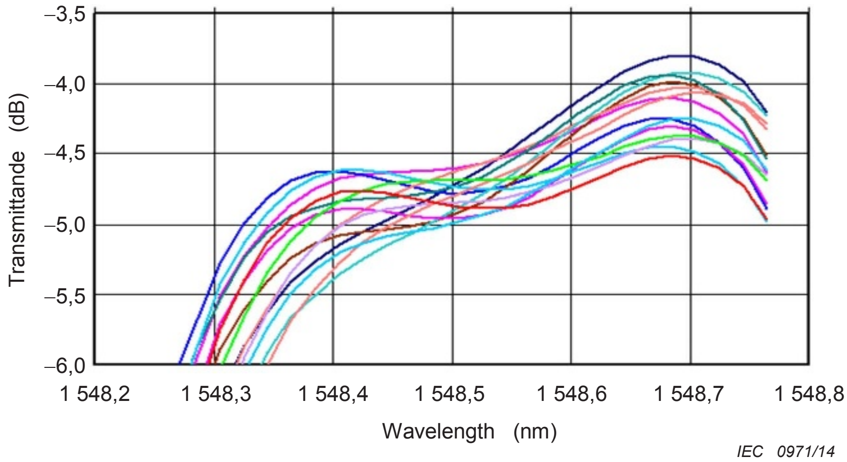


Figure 12 – Polarization dependence of the transfer function

7.9 Polarization dependent centre wavelength (PDCW)

The PDCW is the maximum variation of centre wavelength over all state of polarization (SOPs). Refer to Figure 13.

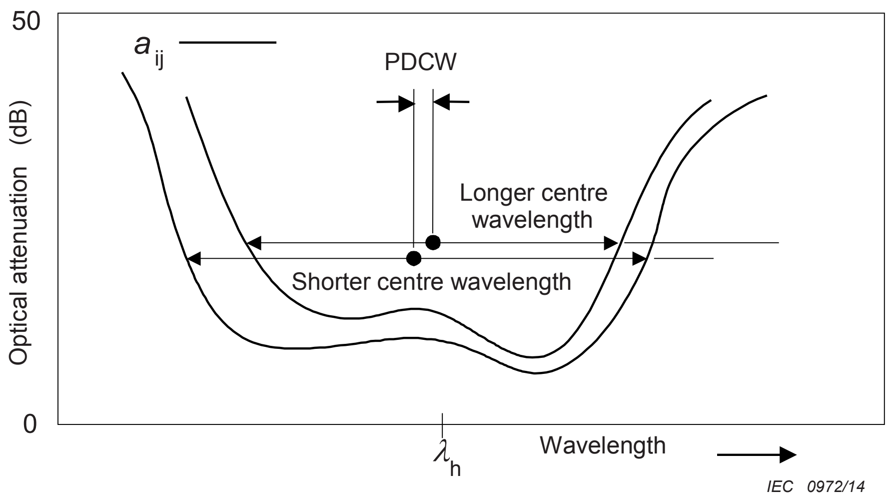


Figure 13 – Polarization dependent centre wavelength (PDCW)

7.10 Channel non-uniformity

The channel non-uniformity for 1 x *N* DWDM devices is the difference between the maximum and the minimum insertion loss for every channel from the common port. Channel non-uniformity is commonly defined as insertion loss at the nominal wavelength (frequency) for each channel. It is expressed as:

$$CNU = \max_{i=1-N}(IL(\lambda_i)) - \min_{j=1-N}(IL(\lambda_j)) \text{ (dB)} \quad (30)$$

7.11 Out-of-band attenuation

Out-of-band attenuation is the minimum optical attenuation of channels that fall outside of shortest channel wavelength range (highest channel frequency range) and longest channel wavelength range (lowest channel frequency range).

8 Details to be specified

8.1 Light source (S)

8.1.1 Tuneable narrowband light source (TNLS)

- Output power
- Output power uncertainty including setting accuracy, stability and repeatability
- Wavelength scanning range
- Wavelength uncertainty including setting accuracy, stability and repeatability
- Step resolution
- Scan time
- Effective source linewidth (laser linewidth or filter band width)
- Polarization extinction ratio

8.1.2 Broadband source (BBS) (unpolarized)

- Spectral power density
- Total power stability
- Wavelength bandwidth

- Degree of polarization

8.2 Polarization controller (PC)

- Scanning rate
- Insertion loss
- Insertion loss stability for polarization status

8.3 Polarizer (PL)

- Insertion loss
- Polarization extinction ratio

8.4 Tracking filter (TF)

- Tracking speed
- Bandwidth
- Insertion loss
- Insertion loss stability for tracking wavelength

8.5 Reference branching device (RBD)

- Power splitting ratio
- Directivity
- PDL
- Intrinsic loss
- Intrinsic return loss
- Wavelength monitor

8.6 Temporary joint (TJ)

- Type of optical connection
- Intrinsic loss
- Intrinsic return loss

8.7 Wavelength meter (WM)

- Wavelength uncertainty

8.8 Detector (D)

8.8.1 Broadband detector (BBD)

- Repeatability
- Dynamic range
- Power uncertainty including power linearity and polarization dependency
- Peak power reference (maximum, mean, or shorth)
- Intrinsic return loss

8.8.2 Tuneable narrowband detector (TNBD)

- Tuning speed
- Wavelength uncertainty
- Wavelength resolution
- Power uncertainty including power linearity and polarization dependency
- Dynamic range

8.9 DUT

- Type of technology
- Number of operating channels and channel spacing
- Values of the operating and isolation wavelengths
- Value of the operating wavelength range used in the equations
- Operating temperature during test
- Measurement uncertainty

Annex A
(informative)

Reflection spectrum measurements

A.1 General

The purpose of this annex is to describe a method for measuring the reflection spectrum of a DWDM device or single port filter device. An example of a single port filter device is a FBG that may be used in either a transmission or reflectance mode. In a transmission mode, the FBG acts as a notch filter and has a single input and single output port; however, in a reflectance mode the FBG acts as a passband filter but has a common input and output port. A FBG passband filter would always be used in a system with either a circulator or some other type of branching device (such as a passive coupler). The compound device (FBG + circulator) would fall under the definition of a DWDM devices as prescribed in the standard.

Either of the two methods described in this procedure can be used to make reflection measurements with only slight changes to the apparatus and the measurement procedure.

A.2 Apparatus

A.2.1 General

Starting with the apparatus shown in Figure A.1, the DUT can be measured in reflection mode by adding either a directional coupler or a circulator to the set-up to couple light into and out of the DUT, as shown in Figure A.1.

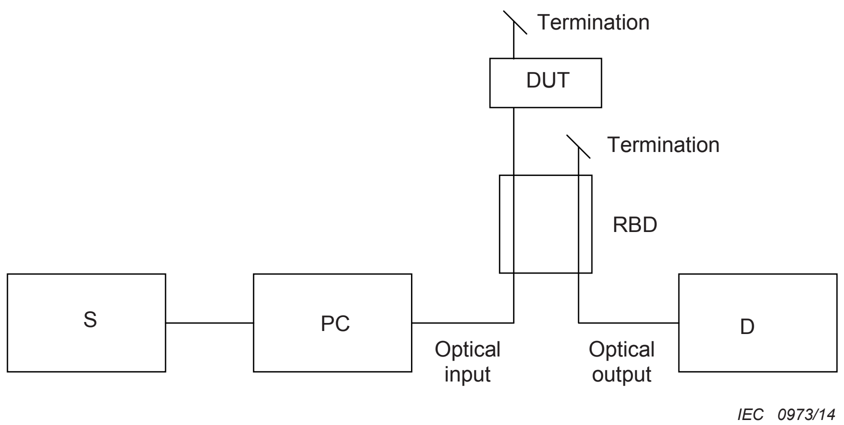


Figure A.1 – Measurement set-up for a single port device

A.2.2 Reference branching device

The RBD can be either an optical circulator or a directional coupler (shown). A circulator has three ports and serves to direct light from ports 1 and 2 to ports 2 and 3 respectively. Inputs to port 3 are dissipated. Each port shall have a return loss >50 dB, and port to port PDL should be less than 0,05 dB. The directivity between ports 1 and 3 should be >50 dB and between ports 3 and 1 should be >30 dB. It is also acceptable to use a passive 2 x 2 directional coupler in this arrangement in place of the circulator. In this case, care should be taken to properly terminate the unused leg of the coupler to reduce back reflections. The specification on the termination is in A.2.3.

A.2.3 Optical termination

In the event that optical terminations are required in either the measurement or reference set-up, the termination should provide a return loss >50 dB over the wavelength region of interest.

A.3 Measurement procedure

A.3.1 General

The reflection measurement procedure will be nearly identical to the transmission measurement procedure described in Clause 6. The main difference is that the two additional optical paths (source through RBD to DUT, and reflection from DUT through RBD to the detector) need to be calibrated out of the measurement. Although it will not be explicitly stated, this procedure implies that all the measurements are made at each polarization state as in the transmission measurement.

A.3.2 Determination of source reference spectrum

The first step is to calibrate the source for the loss in the RBD path connecting the source sub-system and the DUT. This is accomplished by removing the DUT from Figure A.1 and connecting the detector in its place as shown in Figure A.2. The unused RBD leg shall be properly terminated as well.

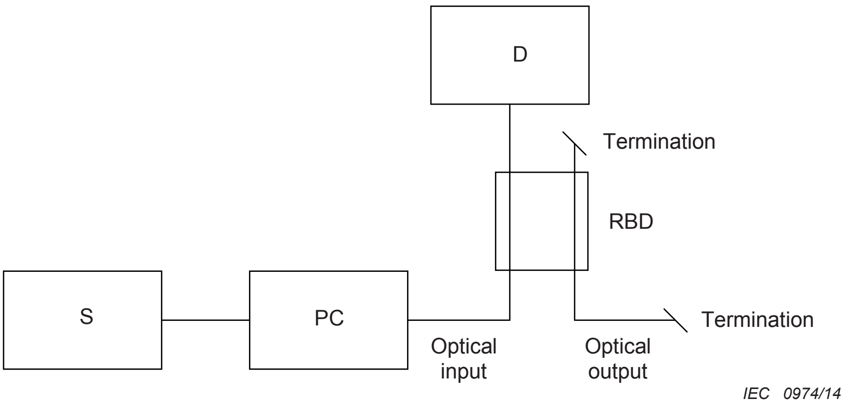


Figure A.2 – Source reference set-up

As the tuning system is scanned across the wavelength span, the source reference transmission spectrum [$t(\lambda)$] can be captured and stored by the detector.

A.3.3 Determination of system constant

The system constant, $G(\lambda)$, refers to the RBD path loss connecting the DUT and the detector. It can be obtained using the set-up in Figure A.3.

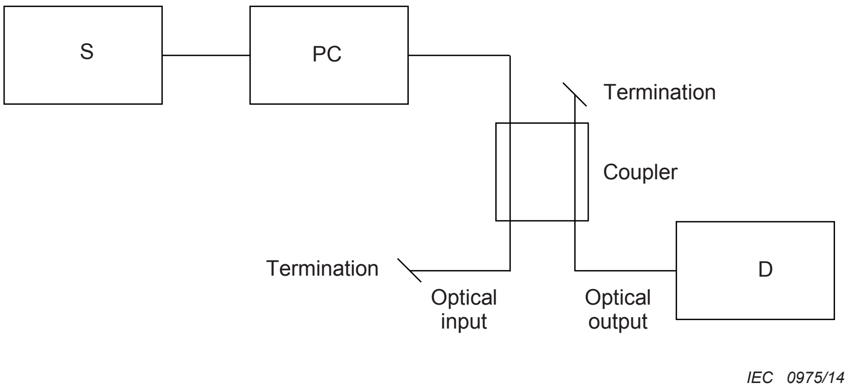


Figure A.3 – Set-up for measurement of system constant

As the tuning system is scanned across the wavelength span, measure and record the power at the detector as $Pb(\lambda)$.

Now connect the output of the polarization controller directly to the detector and measure and record the power as $Pb0(\lambda)$. The system constant, $G(\lambda)$, is calculated as follows:

$$G(\lambda) = -10 \log[Pb0(\lambda)/Pb(\lambda)] \text{ (dB)} \tag{A.1}$$

A.3.4 Determination of reference reflectance spectrum

With the DUT reinserted into Figure A.1, terminate the input fibre to the DUT by wrapping the fibre 5 turns around a 10 mm mandrel.

As the tuning system is scanned across the wavelength span, the reference reflectance spectrum [$r(\lambda)$] can be captured and stored by the detector. This is essentially the “system” back reflection.

A.3.5 Determination of device reflectance spectrum

Remove the mandrel wrap (or effective termination) from the test set-up.

With the test set-up as shown in Figure A.1, scan the system across the wavelength span and record the reflectance spectrum [$R(\lambda)$] from the detector.

A.3.6 Determination of optical attenuation

The reflected transfer function can now be characterized across the entire wavelength span of the system ($\lambda_{min} - \lambda_{max}$) as follows:

$$A(\lambda) = 10 \log [t(\lambda) / (R(\lambda) - r(\lambda))] + G(\lambda) \text{ (dB)} \tag{A.2}$$

with all powers measured in Watts, where $G(\lambda)$ is the system constant as obtained in A.3.2.

The various polarization states should be handled as specified for the all states or Mueller Matrix method (whichever is used) and the optical attenuation should be reported using the average polarization value.

A.4 Reflection [$R(\lambda)$] spectra measurements

Once the data for the reflectance spectra is obtained, all of the parameters and measurements that were shown in Clause 7 can be derived by using $R(\lambda)$ in place of the $T(\lambda)$ data and the optical attenuation as calculated in A.3.6.

Annex B
(informative)

Determination of the wavelength increment parameter

This annex describes a method for choosing an appropriate wavelength spacing for measuring a transmission or reflectance response curve.

Let $y_1, y_2, \cdots y_n$ (in dB) be the measured response values (hereafter "responses") in the nominally "flat", passband region of the transmission/reflectance curve, then the $-x$ dB value of the transmission/reflectance response y_{-x} is obtained as follows:

$$y_{-x} = \max(y_1, y_2, \cdots y_n) - x \tag{B.1}$$

If there are no outlying measurements, $\max(y_1, y_2, \cdots y_n)$ is the estimate of the "plateau" level of the curve. We can determine the proper sample size, hence the proper wavelength increment, based on the desired precision of this plateau estimate. If we assume y_i are independent and equally probable to lie anywhere between the values a and b (i.e. the maximum possible measurement error is $(b-a)$, then it can be shown [1][1] that the standard deviation (SD) of y_{-x} is given by

$$SD(y_{-x}) = \sqrt{\frac{n}{(n+2)\times(n+1)^2}}(b-a) \approx \frac{b-a}{n+2} \tag{B.2}$$

We can then equate this standard deviation to a threshold value to obtain the sample size required. For example, if we want to have an estimate of the $-x$ dB value of the transmission/reflectance response with a standard deviation less than one-tenth of the maximum error measurements (in the top "flat" region), we need to have at least eight measurements in that area.

Once we have a "good" estimate of the $-x$ dB transmission/reflectance response value, the lower and upper $-x$ dB wavelengths can be calculated. We consider only the lower $-x$ dB wavelength λ_L here. Let y^- and y^+ by the first two consecutive measured responses such that $y^- \le y_{-x} \le y^+$. The corresponding wavelengths for y^- and y^+ are λ_1 and $\lambda_1 + h\,(h > 0)$, respectively.

The lower $-x$ dB wavelength based on linear interpolation is given by

$$\lambda_L = \lambda_1 + \frac{y_{-x} - y^-}{y^+ - y^-}h \tag{B.3}$$

The maximum error of λ_L can be estimated by [2]:

$$\Delta\lambda_L \approx \frac{\Delta y}{dy / d\lambda_L} \tag{B.4}$$

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1 References in square brackets refer to the Bibliography.

where Δy is the maximum possible error in the transmission/reflectance measurements. An approximate value for $dy/d\lambda_L$ based on difference is $\left(y^+ - y^-\right)/h$, or

$$\Delta\lambda_L \approx \frac{\Delta y}{y^+ - y^-}h \tag{B.5}$$

An appropriate wavelength increment h can be obtained by requiring the maximum error of λ_L be less than a threshold value, say, ε, or

$$h \leq \frac{\varepsilon\left(y^+ - y^-\right)}{\Delta y} \tag{B.6}$$

The result in Formula (6) indicates that when the response curve is slow-varying in regions where y_{-x} is located ($y^+ - y^-$ is small), or Δy is large, we need a smaller increment.

Annex C
(informative)

Determination of a mean value using the shorth function

This annex describes a robust statistical method for determining the lower and upper $-x$ dB wavelengths of a transmission or reflectance curve.

When there are outlying measurements, it may be misleading to calculate the lower and upper $-x$ dB wavelengths with reference to the maximum value of the response curve according to

$$y_{-x} = \max(y_i, i = 1,2,\cdots) - x \qquad \text{(C.1)}$$

For example, the dotted vertical lines in Figure C.1 represent the lower and upper $-x$ dB wavelengths calculated using Equation (1). Obviously, the results reflect only the presence of the hump at the right side. Thus, we need a robust estimate of y_{-x} representing the plateau level of the transmission/reflectance curve.

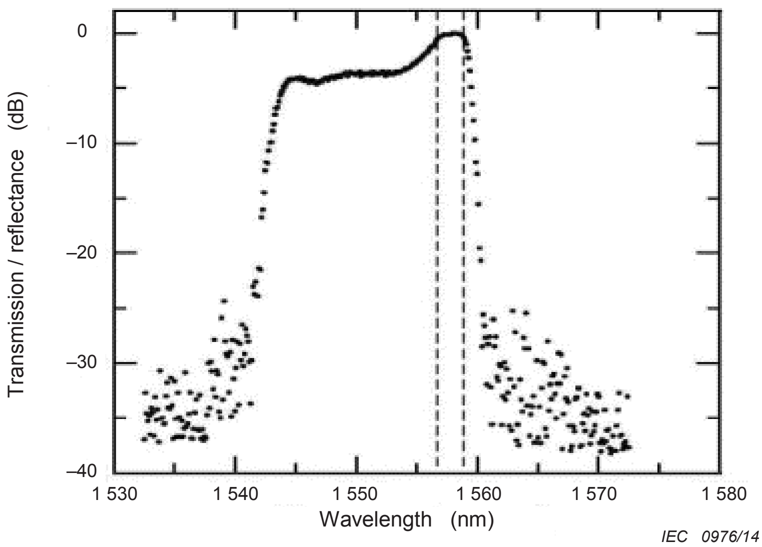

Figure C.1 – Example response and –*x* dB wavelengths

Let $y_1, y_2, \cdots y_n$ be the measured responses in the upper region of the transmission curve. This population can be obtained by accepting only the responses that are greater than a cut-off value. For the example in Figure C.1, we could use a cut-off value, say, –6 dB. It is not critical to use a particular cut-off value; any reasonable values will yield almost identical results because of the robustness of the procedure.

One might use $\bar{y} = \sum_{i=1}^{n} y_i / n$ to estimate the plateau level of the curve. The mean, however, is sensitive to outliers. We propose two alternatives. The first is the median of y_i. The second is a statistic, called *shorth*, which is similar to the median (in robustness) but has a convenient geometrical interpretation.

The shorth of y_i, $i = 1, 2, \cdots n$ is the midpoint of the shortest interval that includes half of y_i. This is done by finding the smallest of the values

$$y_k^* - y_1^*, y_{k+1}^* - y_2^*, \cdots, y_n^* - y_{n-k+1}^* \qquad \text{(C.2)}$$

where $k = \lfloor n/2 \rfloor + 1$, $\lfloor p \rfloor$ is the integer part of p, and $y_1^* \le y_2^* \le \cdots \le y_n^*$ are the ordered measurements of y_i. Then, the shorth simply equals the midpoint of the shortest interval. For example, let the ordered measurements of y_i, $i = 1, 2, \cdots 11$, be

$$1\ 3\ 4\ 7\ 8\ 14\ 15\ 16\ 17\ 27\ 100 \qquad \text{(C.3)}$$

Then $k = \lfloor 11/2 \rfloor + 1 = 6$ and the intervals that include half (6) of the measurements are

$$(1;\ 14),\ (3;\ 15),\ (4;\ 16),\ (7;\ 17),\ (8;\ 27),\ (14;\ 100) \qquad \text{(C.4)}$$

The shortest interval is (7, 17) and the shorth = (17 + 7)/2 = 12. Note that the median of the above 11 measurements is 14, while the mean is 19,3 (skewed by a single measurement).

If we fit a horizontal line to y_i, $i = 1, 2, \cdots n$ the mean of y_i is the line that minimizes the sum of the squared residuals (differences between the predicted and measured y_i). The shorth of y_i is the line that minimizes the median of the squared residuals. The median is not affected by the values of the outlying residuals and will not change unless more than half the residuals represent bad or spurious measurements. In short, the shorth is a robust estimate of the plateau level of the transmission/reflectance curve.

Figure C.2 displays the estimated plateau of the transmission/reflectance curve based on the mean (solid horizontal line) and the shorth (dotted horizontal line) of y_i. It also shows the –0,5 dB wavelengths based on the shorth (dotted vertical lines) and the mean (solid vertical lines).

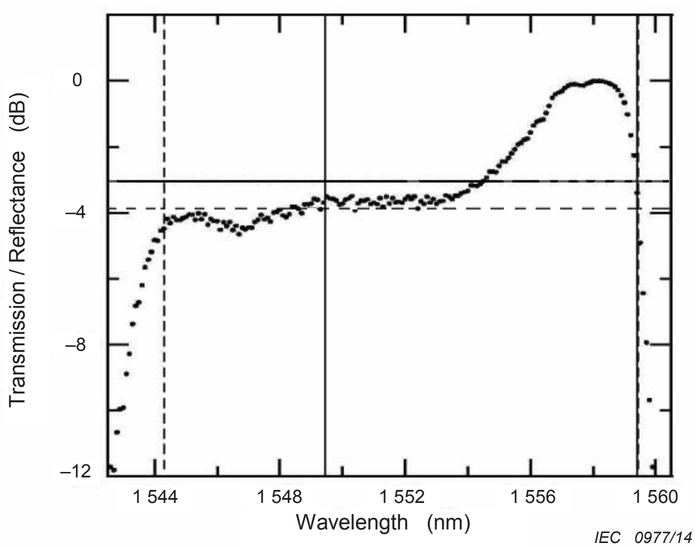

Figure C.2 – Example showing the –0,5 dB wavelengths based on the shorth (dotted vertical lines) and the mean (solid vertical lines)

Bibliography

[1] MOOD, A.M., GRAYBILL, F.A., and BOES, D.C. *Introduction to the Theory of Statistics*. McGraw-Hill, New York, p. 252, 1974.

[2] ABRAMOWITZ, M. and STEGUN, I.A., *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*. National Bureau of Standards, p. XII, 1964.

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