IEC/PAS 61300-3-29

Edition 1.0
2002-08

PRE-STANDARD

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

Part 3-29: Examinations and measurements – Measurement techniques for characterizing the amplitude of the spectral transfer function of DWDM components

PUBLICLY AVAILABLE SPECIFICATION

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Part 3-29: Examinations and measurements – Measurement techniques for characterizing the amplitude of the spectral transfer function of DWDM components

FOREWORD

A PAS is a technical specification not fulfilling the requirements for a standard, but made available to the public.

IEC-PAS 61300-3-29 has been processed by sub-committee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:
Draft PAS	**Report on voting**
86B/1699/PAS	86B/1748/RVD

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IEC 61300 consists of the following parts, under the general title: *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures:*

– Part 1: General and guidance

– Part 2: Tests

– Part 3: Examinations and measurements.

This PAS shall remain valid for no longer than 3 years starting from 2002-08. The validity may be extended for a single 3-year period, following which it shall be revised to become another type of normative document, or shall be withdrawn.

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

Part 3-29: Examinations and measurements – Measurement techniques for characterizing the amplitude of the spectral transfer function of DWDM components

1 Scope

The purpose of this document is to identify two basic measurement methods for characterising the spectral transfer functions of DWDM filter components as defined in IEC 62074-1. The transfer functions can be used to produce measurements of attenuation (A), polarisation dependent loss (PDL), isolation, centre wavelength, and bandwidth (BW).

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61300. All normative documents are subject to revision and parties to agreements based on this part of IEC 61300 are recommended to apply the most recent edition. A catalogue of current IEC and ISO standards can be found on http://www.iec.ch/ and http://www.iso.ch/ respectively.

IEC 62074-1: *Fibre Optic WDM devices – Part 1 Generic specification*

IEC 61300-3-2: *Fibre optic interconnecting devices and passive components – Polarisation dependence of attenuation for single mode fibre optic devices*

IEC 61300-3-5: *Fibre optic interconnecting devices and passive components – Wavelength dependence of attenuation*

IEC 61300-3-7: *Fibre optic interconnecting devices and passive components – Wavelength dependence of attenuation and return loss*

IEC 61300-3-12: *Fibre optic interconnecting devices and passive components – Polarisation of a single-mode fibre optic component: Matrix calculation method*

3 General description

This document is complementary to the wavelength dependence of attenuation (IEC 61300-3-5), the wavelength dependence of attenuation and return loss (IEC 61300-3-7), polarisation dependence of attenuation (IEC 61300-3-2), and the polarisation dependence of attenuation using matrix methods (IEC 61300-3-12) test procedures. It is meant to cover any DWDM devices described by IEC 62074-1. In general, these 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 procedure will show how to obtain the transfer function from a single input to a single output port (single conducting path). For an m × n device, it will be required to repeat this procedure using all possible combinations of input and output ports.

The methods described in this procedure 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 procedure differ mainly in the way in which the wavelength resolution is obtained. Method A uses a tuneable laser source and a broad band detector, while Method B uses a broad band source and a tuneable receiver. Method A shall be considered the reference test method for DWDM devices. This procedure also includes appendixes that illustrate the following:

A. Reflection spectrum measurements

B. Determination of wavelength increment parameter

C. Determination of a mean value using the shorth function

D. Precautions in using IEC 61300-3-7 for DWDM devices

3.1 Terms and abbreviations

Many of the terms and abbreviations in this document are described in the IEC generic standard 60050-731 and the IEC WDM component standard 62074-1. Some terms and abbreviations specific to this measurement technique are included below.

ASE Amplified spontaneous emissions

BW Bandwidth: The spectral width of a signal or filter. In case of a laser signal such as a tuneable laser 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). Must be defined as the distance between the closest crossings on either side of the centre wavelength in the cases where the spectral shape has more than 2 such points. The distance between the outermost crossings can be considered the full spectral width.

δ Wavelength sampling increment during the measurement.

λ_h Centre channel or nominal operating wavelength for a component

OWR Operating wavelength range. The specified range of wavelengths from λ_{hmin} to λ_{hmax} centred about the nominal operating wavelength, within which a WDM device operates.

SSE Source spontaneous emission: Broad band emissions from a laser cavity that bear no phase relation to the cavity field. These emissions can be seen as the baseline noise on an optical spectrum analyzer.

TLS Tuneable laser source.

4 Apparatus

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

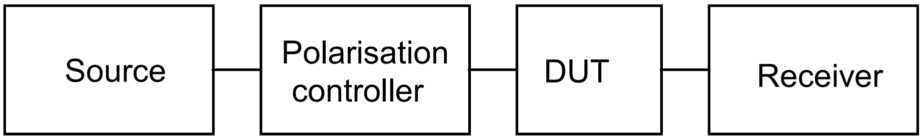

Figure 1 – Basic measurement apparatus

As mentioned in the general discussion, this procedure contains two distinct 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 receiver, 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 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 receiver. Practical constraints may result in smaller or larger bandwidths than recommended. Two cautions with smaller bandwidths; first, coherent interference effects can lead to additional measurement errors, and second undersampling 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.

A detailed explanation of the various components of this system and their functions is contained below. Apparatuses for both the Tuneable Laser and the Tuneable Receiver procedures are shown in Figures 2 and 3.

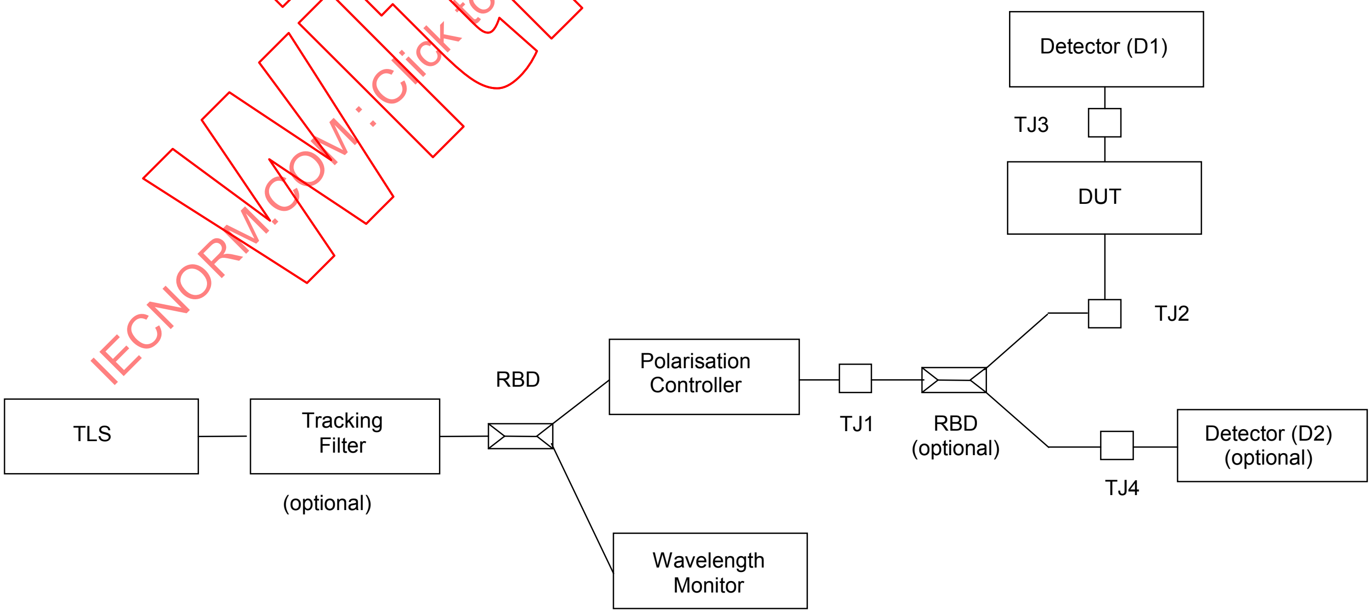

Figure 2 – Measurement apparatus for tuneable laser system

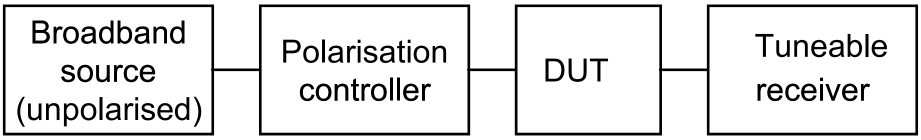

Figure 3 – Measurement apparatus for tuneable receiver system

4.1 Source

4.1.1 Tuneable laser, Method A

This method uses a polarised tuneable laser source (TLS) 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 better than +/– 0,01dB over the measuring period. This stability can be obtained using the optional detector D2 in Figure 2 as a reference detector. If D2 is synchronised with D1, 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 more dynamic range 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).

The wavelength accuracy of the TLS shall be approximately an order of magnitude better than the step size for each point in the measuring range. This accuracy 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 tuneable laser source should be sufficient to provide an order of magnitude greater signal to noise ratio 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 50GHz from 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 –60dBc.

4.1.1.1 Tracking filter

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 must 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.

4.1.1.2 Reference branching device (RBD)

The configuration of the RBD is 1x2 or 2x2. If its configuration is 2x2, one port of the RBD shall be terminated to have a back reflection <-50dB. The splitting ratio of the RBD shall be stable with wavelength. It shall also be insensitive to polarisation. The polarisation sensitivity of transmission attenuation shall be less than one tenth of the wavelength dependency of attenuation to be measured. The Polarisation Mode Dispersion of the RBD shall be less than ½ of the coherence time of the source so as not to depolarise 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.

4.1.1.3 Wavelength monitor

In this test procedure, the wavelength accuracy of the source needs to be extremely accurate and closely monitored. If the tuning accuracy 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 accuracy 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 accuracy of the TLS must be sufficient to resolve the absorption lines.

Regarding the wavelength repeatability of the TLS + 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.

4.1.2 Broad band source (BBS), Method B

This method uses an unpolarised broadband light source such as an LED or an amplified spontaneous emission (ASE) source. The source spectrum must 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 must 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 synchronised tuneable receiver).

The degree of polarization (DOP) of the source should be less than 10 percent to avoid biasing those measurements that require unpolarised light. Care should be taken to ensure that the narrow width of the tuneable filter does not increase the effective DOP beyond this limit.

In some instances, the tuneable filter used for this method could be placed after the BBS creating an unpolarised TLS. In this instance, the filter characteristics should be as described in the tuneable receiver section (2.4.2).

4.2 Polarisation controller

The polarisation controller is used to control the input state of polarisation (SOP). In the event of a polarisation dependent measurement, the controller will be used to generate four known polarisation states for testing purposes. The states must be distinct and well known in order to achieve accurate PDL measurements. The return loss on the input to the controller shall be >50dB, so as not to return any polarised light back to the TLS cavity for Method A.

For the BBS method (B), the controller is optional if polarisation dependent measurements are not required. If it is used in this set-up, it must provide an extinction ratio of at least 20 dB.

4.3 Device under test (DUT)

The device under test shall be a DWDM component as defined in IEC 62074-1. For the purposes of this document, 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 × n DWDM device. It is noted that these measurements are very sensitive to reflections, and that precautions must be taken to ensure that reflection cavities are not introduced in the test set-up.

In many cases, the characteristics of DWDM components are temperature dependent. This measurement procedure assumes that any such device is held at a constant temperature throughout the procedure. The absolute accuracy of the measurement may be limited by the accuracy 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 / ^{o}C, and the temperature during the procedure is held to a set temperature +/– 1 ^{o}C; then any spectral results obtained are known to have an uncertainty of 0,02 nm due to temperature.

4.3.1 Device input optics

Use an optical lens system or fibre pigtail to excite the test device. If a lens system is used, couple the power into the test device so it is insensitive to the position of the input end face. This can be done with a launch beam that spatially and angularly overfills the test port. In the case of fibre pigtailed devices, use a device that extracts cladding modes. The fibre coating will typically perform this function.

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

4.3.2 Device output optics

Use an optical lens system or fibre pigtail to couple light from the test device to the receiver. If fibre connectors or fibre butt coupling are employed, use physical contact connectors or index matching fluid to avoid interference effects.

4.4 Receiver system

4.4.1 Broad band detectors (D1,D2), Method A

The detectors used for this method consist of a broad band 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 D1 and D2 should be minimised with any precautions available. The preferred options would be to use either an APC connector, or a 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.

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 polarisation dependent measurements, the polarisation dependence of the detector should be < 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 polarisation effects are minimised.

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 accuracy of the reading for a swept system).

4.4.2 Tuneable receiver, Method B

This method measures the optical output of the DUT with a narrow-band tuneable receiver such as an optical spectrum analyser. The analyser can be a monochromator or a tuneable bandpass filter followed by a photodiode detector.

As was stated in 2.1.2, it is also conceivable to use a tuneable bandpass filter immediately after the broad band source (rather than in front of the detector) for this system with the caveats for effective source linewidth understood.

The receiver shall have the same stability, dynamic range, sensitivity, resolution, and linearity requirements as described in 2.4.1 for the tuneable laser method. One difference for this method is that the power density of the BBS over the optical bandwidth of the receiver 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.

4.5 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 20 dB greater than the maximum return loss to be measured. In the event that connectors are used, it is preferred to use angled ones.

5 Procedure

The following sections will outline the measurement procedure whereby data can be collected and analysed on a DWDM device. Since these devices tend to be sensitive to polarisation, all of the measurements shall be made using either the “all states method” 61300-3-2 or the “Mueller matrix method” as described in 61300-3-12. These methods will be reiterated in this document. Due to the number of data points typically required to characterise 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 shall be the reference. This procedure applies to both measurement systems as differences are highlighted in the text.

If polarisation information is not required for the measurement (possibly for an incoming inspection test), it is acceptable to use Method B without the polarisation controller. In this case the measured unpolarised 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 fibre Bragg gratings (FBG) that are used in DWDM devices but are not covered under IEC 62074-1. 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. To show how this measurement technique can be expanded upon to handle single port components, the reader is advised to see appendix A of this document.

5.1 Preparation of specimens

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

5.2 System initialisation

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 accuracy, the slope of the response curve at the crossing for the centre wavelength, and the maximum possible power error in the pass band measurement.

5.3 System reference measurement

In the determination of the transfer function, it will be necessary to reference out the effects 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.

5.3.1 Measurement of the reference spectra for method A

For this step, the DUT is removed from Figure 2 and the output of the polarisation controller is connected directly to the detector D1 as shown in Figure 4. The TLS shall then be scanned across the wavelength span taking wavelength measurements from the wavelength monitor, transmission measurements from D1, and source monitor measurements from D2. It should be noted that the document assumes all powers are measured on a linear scale. The manner in which the polarisation states are controlled during the sweep will vary based on the method used.

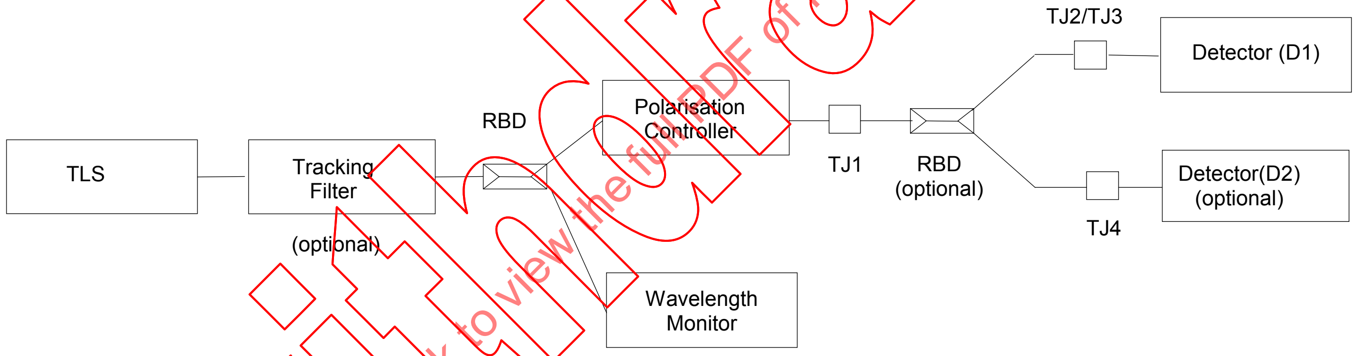

Figure 4 – System reference for transmission measurement

In the event that the all states method is used, for each step in the wavelength sweep the polarisation shall be varied over all states. 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 $t_{max}(\lambda)$,$t_{min}(\lambda)$, $t_{ave}(\lambda)$, and $m_{ave}(\lambda)$. Care should be taken to ensure that enough time is spent at each polarisation 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 states of polarisation (SOP). 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 $t_A(\lambda)$,$t_B(\lambda)$, $t_C(\lambda)$, $t_D(\lambda)$, $m_A(\lambda)$,$m_B(\lambda)$, $m_C(\lambda)$, and $m_D(\lambda)$. 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.

5.3.2 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 polarisation controller is connected to the tuneable receiver and the receiver is swept across the entire measurement wavelength range. The readings from the receiver shall supply the equivalent matrixes as in 3.3.1. If the measurement is done using unpolarised light, only the $t_{ave}(\lambda)$ array is obtained.

5.4 Measurement of device spectra

With the device re-inserted in the test set-up, the measurement procedure outlined in 3.3.1 (or 3.3.2) shall be repeated. In this manner the various transmission and source monitor spectra [$T(\lambda)$ and $M(\lambda)$] can be captured and stored.

6 Characterisation of the device under test

Once the measurement data has been collected, the amplitude characteristics of the devices can be fully documented. All general definitions and calculations from the experimental data should follow IEC 62074-1 and that document supersedes any of the below text.

6.1 Determination of transfer functions

After the measurement procedures outlined in section 3 are completed, the respective minimum, maximum, and average transfer functions can be determined from the gathered data.

6.1.1 Accounting for the source variations

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

$$T'(\lambda)=T(\lambda)/M(\lambda) \text{ or } t'(\lambda)=t(\lambda)/m(\lambda)$$

For the All States method, this recalculation need only be done for the average power array since there is no way to correlate the maximum and minimum polarisation 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.

6.1.2 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:

$$\begin{aligned}
m_{11}(\lambda) &= \left| \tfrac{1}{2} * [\, T_A(\lambda)/t_A(\lambda) + T_B(\lambda)/t_B(\lambda)\,] \right| \\
m_{12}(\lambda) &= \left| \tfrac{1}{2} * [\, T_A(\lambda)/t_A(\lambda) - T_B(\lambda)/t_B(\lambda)\,] \right| \\
m_{13}(\lambda) &= \left| T_C(\lambda)/t_C(\lambda) - m_{11} \right| \\
m_{14}(\lambda) &= \left| T_D(\lambda)/t_D(\lambda) - m_{11} \right|
\end{aligned}$$

where measurements with subscript of A were done with linear horizontal, B with linear vertical, C with linear diagonal, and D with right-hand circular polarisation in the typical case.

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

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

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

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

6.2 Calculation of attenuation (A)

There are generally three types of attenuation or insertion loss (IL) documented for DWDM components. The first is the attenuation of the nominal channel of the device [$A(\lambda_h)$]. The second is the attenuation of the nearest neighbours or isolated channels [$A(\lambda_i)$ & $A(\lambda_g)$]. The final attenuation is that of the other isolated channels [$A(\lambda_x)$, where $x \neq$ h, i, or g] termed the far end attenuation.

In any of these cases, the attenuation should be specified as a threshold throughout $\lambda = \lambda_h$ +/- OWR/2 where λ_h is the nominal wavelength for which the device is intended and OWR is the entire operating wavelength range specified for the device.

For the All States method (or unpolarised case), attenuation is calculated as:

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

where powers are measured in Watts.

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

$$A(\lambda) = 10 \log [\ T_{ave}(\lambda)] \text{ (dB)}$$

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

As mentioned above the channel, nearest neighbour, and far end attenuation should be taken over the OWR of the device, leading to several different interpretations (min, max, mean) for each. IEC 62074-1 fully defines these values.

6.3 Transmission [T(λ)] spectra measurements

As noted earlier DWDM components are optical filters, thus there are a number of important characteristics that are derived from the transfer functions of the device. This section shall focus on the description of both band pass and notch filters. A typical transfer function for a band pass filter is shown in Figure 5.a, while a graph for a notch filter is shown in Figure 5.b.

As shown in Figure 5, the transfer functions are usually plotted on a logarithmic scale so it is useful to convert the measurement arrays from Watts to decibels:

$$T_{xxx}(\lambda) = 10 \log [\ T_{xxx}(\lambda)] \text{ (dB)}$$

where the ‘xxx’ implies the equation is valid for the ave, min, and max arrays.

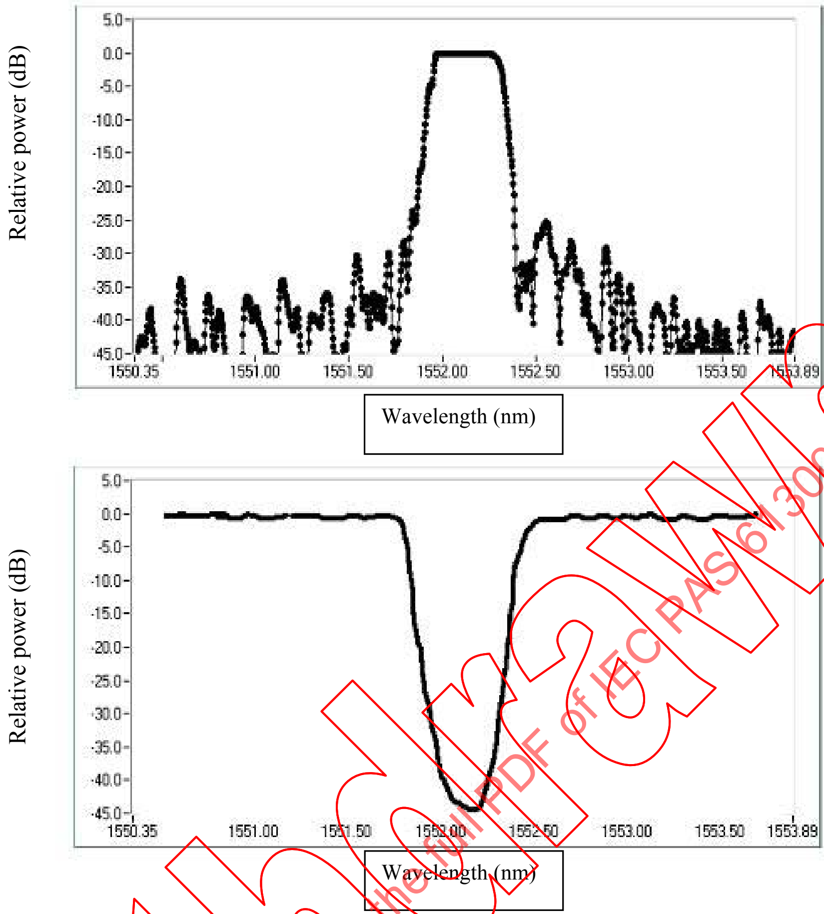

Figure 5 – Normalised transfer functions for a band pass filter (a) and a notch filter (b)

6.3.1 Peak power calculation

Nearly all of the spectral techniques described in this section shall be relational 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 tactics for selecting the peak power. A few of them are listed below:

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

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

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

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.

It is not meant for this document to select a method, but the subtle differences must be understood and noted in the measurement.

6.3.2 Normalisation of the transfer function

The transfer functions are usually represented on a normalised, logarithmic scale (as seen in Figure 5) so the peak transmission as determined in 6.3.1 is at 0 dB. The plotted functions can be obtained as:

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

Most of the measurements detailed in the following sections are based on the normalised transfer function.

6.3.3 Bandwidth and full spectral width

Measurements of the pass band bandwidth (BW) are done relative to the peak of the spectral response of the normalised transfer function. An example of a transmission spectra for a fibre Bragg grating (FBG) is shown in Figure 6 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.

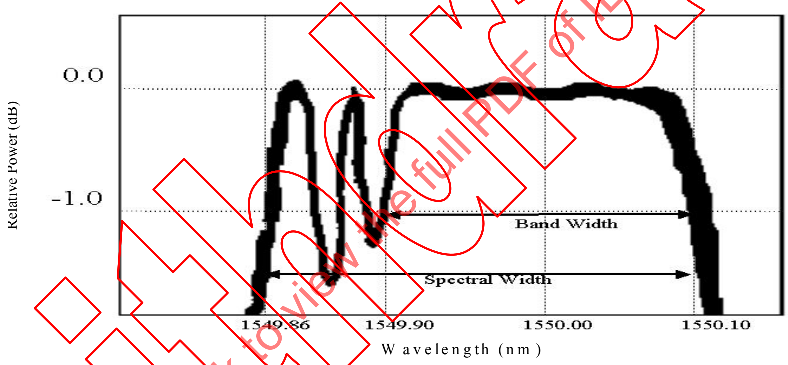

Figure 6 – BW and full spectral width for a fibre Bragg grating

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:

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

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 5.b) 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)).

6.3.4 Centre wavelength

The centre wavelength measurements for the purposes of this document 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 –1dB centre of 1550.00 nm if its –1 dB crossings are at 1549.90 nm and 1550.10 nm, and a bandwidth of 0.20 nm.

The reader should note that 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 polarisation effects.

6.3.5 Isolation

Isolation is a measure of the power from channels outside the nominal band leaking through a band pass filter relative to the signal power. It is usually defined for the nearest neighbour and the non-adjacent cases. Figure 7 illustrates these concepts.

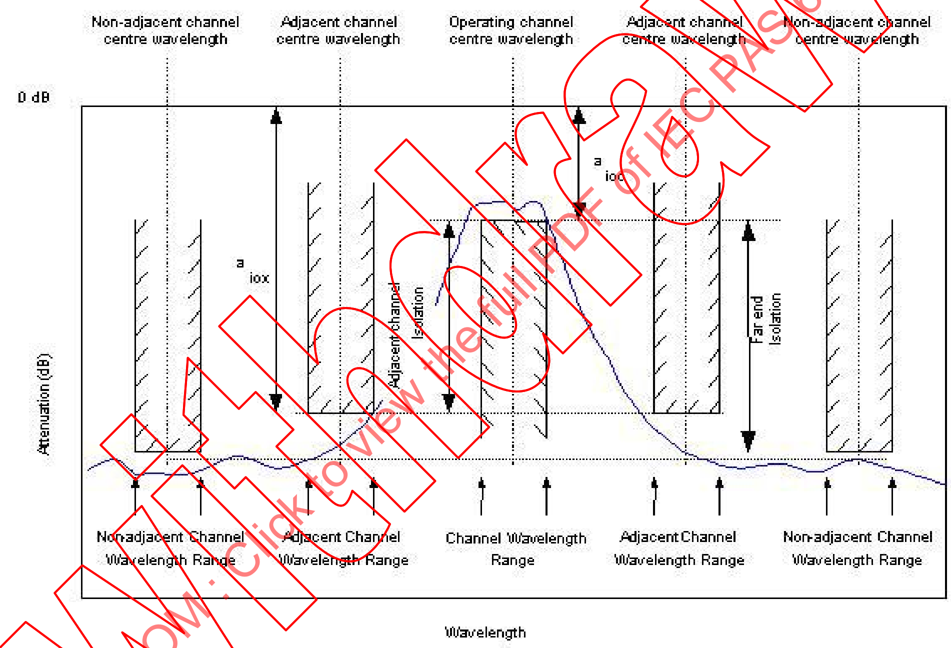

Figure 7 – Channel isolation

The reader is referred to IEC 62074-1 for full descriptions and definitions of the isolation terms of a DWDM device. Some sample calculations are included for interchannel and cumulative isolation. These are included for example purposes only.

6.3.5.1 Interchannel isolation

The interchannel isolation at a particular wavelength (I(λ)) is defined as the magnitude of the transfer function at that wavelength relative to the magnitude of the pass band. As in the attenuation measurement (4.2), there will be an interest to make this measurement across the device OWR. It is suggested that I(λ) be defined as follows:

$$I(\lambda) = [\ \min\{T_N(\lambda_h\text{-}OWR/2)\ ,\ T_N(\lambda_h\text{+}OWR/2)\}\ -\ \max\{T_N(\lambda\text{-}OWR/2)\ ,\ T_N(\lambda\text{+}OWR/2)\}\ ]$$

where all powers are in dB.

6.3.5.2 Cumulative interchannel isolation

The cumulative isolation (I_Σ) for a device can be defined as the sum of the power for every undesired channel in the system relative to the power of the desired channel.

$$I_\Sigma = -10\log\left(\frac{\min\{T(\lambda_h - OWR/2), T(\lambda_h + OWR/2)\}}{\sum_{i=1,\neq h}^{N}\max\{T(\lambda_i - OWR/2), T(\lambda_i + OWR/2)\}}\right)$$

where N is the total number of operating channels, λ_h is the nominal channel of interest, λ_i is any given isolated channel, OWR is the region of wavelengths in which a given channel may reside, and all powers are in Watts. The total isolation is expressed in decibels.

Note that it is easier to use the un-normalised transfer functions for these calculations.

6.4 Polarisation dependent losses (PDL(λ))

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

$$PDL(\lambda) = T_{max}(\lambda) - T_{min}(\lambda) \text{ [dB]}$$

where the max and min 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 OWR's of the nominal and the isolated channels. Clearly the PDL of the device will impact both the 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. For calculations that include the polarisation dependence the reader is again referred to IEC 62074-1. Figure 8 is an example showing the transfer function of a DWDM passband using varying states of polarisation.

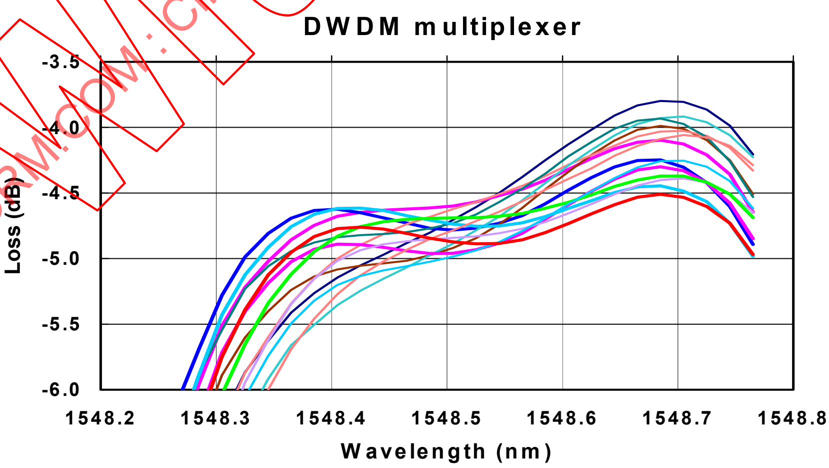

Figure 8 – Polarisation dependence of the transfer function

7 Details to be specified

7.1 Tuning sub-system

- Wavelength scanning range
- Wavelength accuracy
- Step size
- Scan time
- Effective source linewidth (laser linewidth or filter band width)

7.2 Power detector

- Repeatability
- Accuracy and linearity
- Peak power reference (max, mean, or shorth)

7.3 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

Annex A

Reflection spectrum measurements

A.1 General

The purpose of this section is to describe a method for measuring the reflection spectrum of a DWDM or single port filter device. An example of a single port filter device is a Fibre Bragg Grating (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. In alignment with IEC 62074-1, 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 component 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

Starting with the apparatus shown in Figure 1, the sample 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 A1.

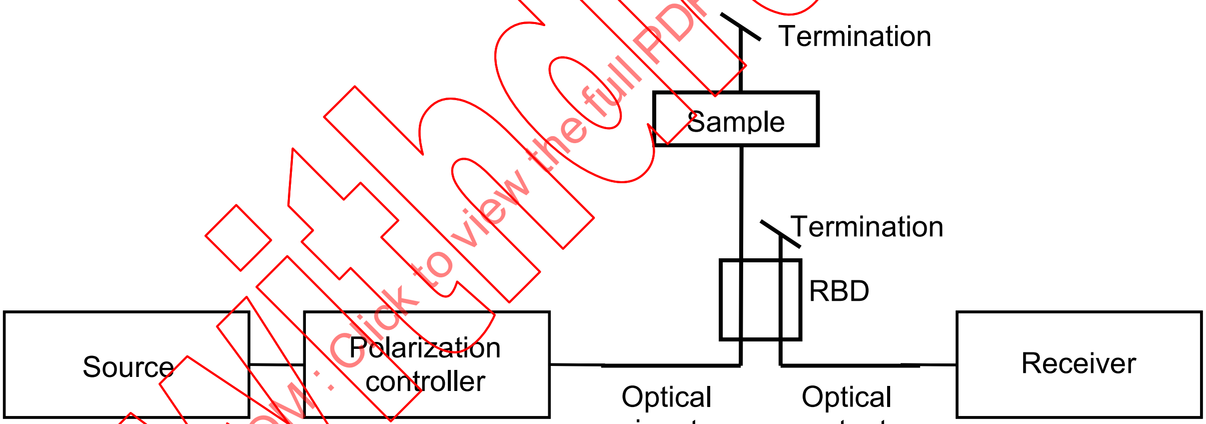

Figure A1 – Measurement apparatus for a single port device

A.2.1 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 must have a return loss >50 dB. The directivity between ports 1&3 should be >50dB and between ports 3&1 should be >30dB. It is also acceptable to use a passive 2x2 directional coupler in this arrangement in place of the circulator. In this case, care must be taken to properly terminate the unused leg of the coupler to reduce back reflections. The specification on the termination is in A.2.2.

A.2.2 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

The reflection measurement procedure will be nearly identical to the transmission measurement procedure described in section 3 of this document. The main difference is that the two additional optical paths (source through RBD to DUT, and reflection from DUT through RBD to the receiver) 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 polarisation state as in the transmission measurement.

A.3.1 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 A1 and connecting the receiver in its place as shown in Figure A2. The unused RBD leg must be properly terminated as well.

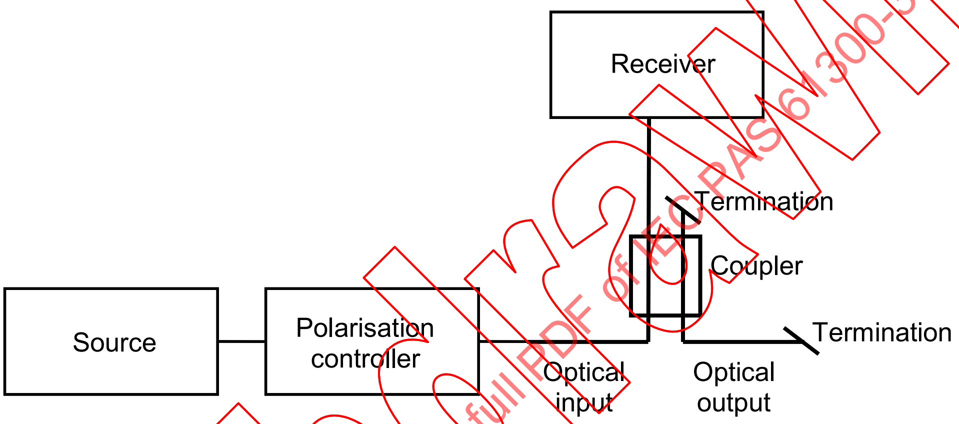

Figure A2 – Source reference set-up

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

A.3.2 Determination of system constant

The system constant, G(λ), refers to the RBD path loss connecting the DUT and the receiver. It can be obtained using the set-up in Figure A3.

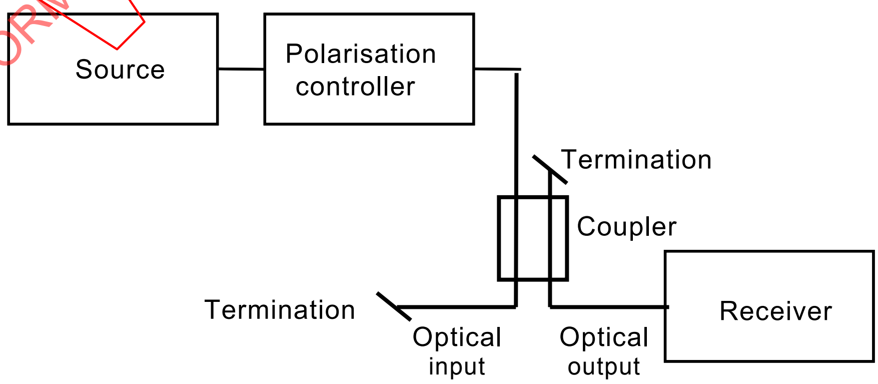

Figure A3 – Set-up for measurement of system constant

As the tuning system is scanned across the wavelength span, measure and record the power at the receiver as Pb(λ).

Now connect the output of the polarisation controller directly to the receiver and measure and record the power as Pb0(λ). The system constant, G(λ), is calculated as follows:

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

A.3.3 Determination of reference reflectance spectrum

With the DUT reinserted into Figure A1, 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(λ)] can be captured and stored by the receiver. This is essentially the “system” back reflection.

A.3.4 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 A1, scan the system across wavelength span and record the reflectance spectrum [R(λ)] from the receiver.

A.3.5 Determination of attenuation

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

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

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

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

A.4 Reflection [R(λ)] spectra measurements

Once the data for the reflectance spectra is obtained, all of the parameters and measurements that were shown in sections 4 of the main document can be derived by using R(λ) in place of the T(λ) data and the attenuation as calculated in A.3.5.

Annex B

Determination of the wavelength increment parameter

This appendix 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

$$y_{-x} = \max(y_1, y_2, \cdots y_n) - x \qquad \text{(B1)}$$

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] that the standard deviation (sd) of y_{-x} is given by

$$sd(y_{-x}) = \sqrt{\frac{n}{(n+2)\cdot(n+1)^2}}(b-a) \approx \frac{b-a}{n+2} \qquad \text{(B2)}$$

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 8 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

$$\lambda_L = \lambda_1 + \frac{y_{-x} - y^-}{y^+ - y^-} h\ . \qquad \text{(B3)}$$

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

$$\Delta\lambda_L \approx \frac{\Delta y}{dy / d\lambda_L} \qquad \text{(B4)}$$

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

$$\Delta\lambda_L \approx \frac{\Delta y}{y^+ - y^-} h\ . \qquad \text{(B5)}$$

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

$$h \leq \frac{\varepsilon\left(y^{+} - y^{-}\right)}{\Delta y} \qquad \text{(B6)}$$

The result in (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.

References

[1] Mood, A. M., Graybill, F. A., and Boes, D. C., *Introduction to the Theory of Statistics*. New York: McGraw-Hill, 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.