

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

Part 3-32: Examinations and measurements — Polarization mode dispersion measurement for passive optical components

The European Standard EN 61300-3-32:2006 has the status of a
British Standard

ICS 33.180.20

National foreword

This British Standard was published by BSI. It is the UK implementation of EN 61300-3-32:2006. It is identical with IEC 61300-3-32:2006.

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

A list of organizations represented on GEL/86/2 can be obtained on request to its secretary.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 October 2006

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ISBN 0 580 49480 2

Amendments issued since publication

Amd. No.	Date	Comments

**Fibre optic interconnecting devices and passive components -
Basic test and measurement procedures
Part 3-32: Examinations and measurements -
Polarization mode dispersion measurement
for passive optical components
(IEC 61300-3-32:2006)**

Dispositifs d'interconnexion et
composants passifs à fibres optiques -
Méthodes fondamentales d'essais
et de mesures
Partie 3-32: Examens et mesures -
Mesure de la dispersion de mode
de polarisation pour composants
optiques passifs
(CEI 61300-3-32:2006)

Lichtwellenleiter -
Verbindungselemente
und passive Bauteile -
Grundlegende Prüf- und Messverfahren
Teil 3-32: Untersuchungen
und Messungen -
Messung der
Polarisationsmodendispersion
für passive optische Bauteile
(IEC 61300-3-32:2006)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 86B/2325/FDIS, future edition 1 of IEC 61300-3-32, 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 was approved by CENELEC as EN 61300-3-32 on 2006-09-01.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2007-06-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2009-09-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61300-3-32:2006 was approved by CENELEC as a European Standard without any modification.

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

Part 3-32: Examinations and measurements – Polarization mode dispersion measurement for passive optical components

1 Scope

This part of IEC 61300 presents a number of alternative methods for measuring the polarization mode dispersion (PMD) of a passive fibre optic device under test (DUT). These methods typically measure PMD using either a frequency domain or time domain approach. In the frequency domain, the polarization properties of the DUT are analysed. In the time domain approach, the pulse delay or broadening is observed.

This procedure will cover measurements of both broadband, and narrowband dense wavelength division multiplexing (DWDM) passive fibre optic devices. Differences between measurement practices for these varied classes of passive fibre optic devices will be noted in the text.

This procedure can be applied to laboratory, factory and field measurements of PMD in passive fibre optic devices. Limitation of the application of some methods will be noted in the text when necessary.

This procedure can be applied to a transmissive or reflective DUT. In the latter case, the DUT connection is via a coupler or circulator, which should have a known very low PMD value.

2 Normative references

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

IEC 60793-1-48, *Optical fibres – Part 1-48: Measurement methods and test procedures – Polarisation mode dispersion*

IEC 61282-3, *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion*

IEC 61282-9, *Fibre optic communication system design guides – Part 9: Guidance on polarization mode dispersion measurements and theory*

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

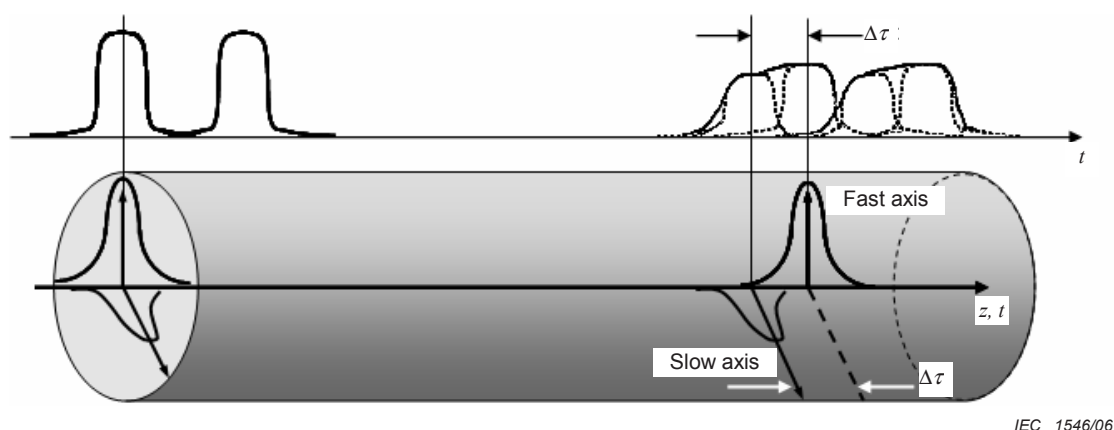
3 Abbreviations

ASE:	amplified spontaneous emission
DGD:	differential group delay
DOP:	degree of polarization
DUT:	device under test
DWDM:	dense wavelength division multiplexing
FA:	fixed analyser
FAFT:	fixed analyser Fourier transform
FAEC:	fixed analyser extrema counting
FWHM:	full width at half the maximum
INTY:	interferometry
ISI:	inter-symbol interference
JME:	Jones matrix eigenanalysis
MMA:	Mueller matrix analysis
MPS:	modulation phase shift
PDL:	polarization dependent loss
PMD:	polarization mode dispersion
PDV:	polarization dispersion vector
PPS:	polarization phase shift
PS:	Poincaré sphere
PSA:	Poincaré sphere analysis
PSP:	principal states of polarization
RBW:	resolution bandwidth
RMS:	root mean square
SOP:	state of polarization
SPE:	Stokes parameter evaluation
WDM:	wavelength division multiplexing

4 General description

PMD refers to the spreading of an optical pulse due to polarization-related anomalies. In optical communication systems, the spreading of a pulse leads to bit errors at the receiver due to inter-symbol interference (ISI) and consequently provides bandwidth limitation.

Each optical pulse is made up of a combination of two orthogonal SOPs called the principal SOPs (PSPs), due to birefringence possibly present in the DUT (see Figure 1). These different polarization components travel at different group velocities and will arrive at the output of the DUT at different times. PMD is related to the difference between the two PSP delays, the DGD $\Delta\tau$.



IEC 1546/06

Figure 1– Effect of PMD phenomenon on transmission of an information bit pulse in a device

4.1 Mode coupling

PMD in passive fibre optic devices is usually deterministic by nature meaning that the phenomenon is predictable and can be reproduced and controlled. However, it is important to understand how the polarization modes can couple together in the device, and in fact they can couple differently. In optical passive fibre optic devices, the mode coupling is typically referred to as negligible or no or negligible (including the cases of polarization maintaining fibres and short lengths of ordinary fibre) as opposed to random or strong mode coupling such as frequently seen in the case of long lengths of fibre. In no or negligible mode coupling, the axis of birefringence in the device is fixed and constant in only one section of birefringence and consequently the DGD is constant as a function of wavelength. In that case the PMD is equal to the DGD.

There can however be types of passive fibre optic devices exhibiting many sections of fixed birefringence with their axes not necessarily aligned with each other making the DGD randomly varying as a function of wavelength. In that case, the mode coupling is random. Even if the DGD varies, as a function of wavelength and the mode coupling is random, this variation will be constant from one measurement to another and it can still be predicted and the phenomenon is still deterministic. In that case, the PMD is the average value of the DGD spectral distribution (the root mean squared – RMS – value may also be used and is accepted).

There can also be intermediate cases where the passive fibre optic device has few birefringence sections and the DGD can vary less randomly such as a monotonous or sine wave variation as a function of wavelength. The PMD is still the average or RMS value of the DGD distribution and the phenomenon is still deterministic but the mode coupling is neither negligible nor random.

The mode coupling describes how the SOPs are maintained as energy traverses the device. Rather, each device is shown to have a polarization transfer function whereby the SOP at the input is mapped to a different SOP at the output as a function of wavelength. This transfer function is commonly represented using the Jones matrix and will be explained later in the document.

4.2 Narrowband devices

There are other cases of classification that are related to the PMD phenomenon and need to be taken into account. This includes narrowband devices. A narrowband device can have a small DGD distribution while experiencing a wide Fourier time spectrum

with a more complex spectrum in the time domain. Care will also have to be taken when making analysis of DGD in the time domain versus the spectral domain.

4.3 Polarization sensitivity

Another complicating factor is related to the presence of PDL in the DUT. Figure 1 illustrates such a case where at the output of the DUT the bits are not only broadened (in absence of PDL) but also distorted (in presence of PDL). In the case of PDL, the two PSPs are not necessarily orthogonal anymore (not anymore 180° apart on the Poincaré sphere). In this case, this test procedure will be restricted to devices with PDL equal to or less than 1 dB to allow the application of all suggested methods. This condition is typically met inside the passband of typical passive fibre optic devices used in DWDM systems.

PDL or polarization sensitivity may severely impact the correct determination of DUT DGD. PDL may be measured by using IEC 61300-3-2.

However, some possible exclusions or assumptions can be made to reduce the complexity of the situation. For example, a device with high PDL (>10 dB) will generally be used for single-polarization operation. It is therefore possible to argue that for such a device, PDL is the relevant parameter, not PMD.

Therefore with the above justification the scope of this document is restricted to exclude devices that have high (>10 dB) PDL. Such devices include polarizer, polarization sensitive splitters or modulators etc.

For devices with low PDL (<1 dB), which are the typical cases of DWDM devices, PDL generally presents little problem to the measurements of DGD, but will marginally increase uncertainty. As PDL rises, this uncertainty rises.

For devices with higher PDL (e.g. >10 dB) this error is likely to be unacceptably high.

4.4 Multiple path interference

Passive fibre optic devices may contain bulk optical elements, fibre-waveguide splices, and fibre-lens interfaces etc. that can give rise to reflections due to optical index mismatch between elements. The effect of these may be to induce multi-path dispersions that are either PMD-related (i.e. the path difference is polarization sensitive) or not (polarization insensitive path differences) [1]¹.

Reflections and multiple delay paths that are not polarization sensitive can be separately removed from DGD. Any kind of polarization-sensitive differential delay, however, will be recorded as DGD.

4.5 Fibre pigtails

Finally, the fibre pigtails will add PMD of their own, which will vary as the leads are bent, coiled or twisted.

¹ Figures in square brackets refer to the bibliography.

The pigtails into and out of the DUT (typically sealed into the DUT housing) will always contribute some PMD. Since the fibre leads are typically only a few metres long, the PMD in the leads is essentially deterministic, with little random coupling. Typical PMD values for a few metres of standard fibre are of the order of 1 fs/m or less. The PMD in the leads will partially add to, or partially subtract from, the DGD of the DUT itself according to the axial alignment of the lead birefringence and that of the DUT. This lead contribution represents a source of uncertainty in the DUT DGD determination. To avoid bending birefringence being introduced the pigtails should be kept as straight as possible with a bend radius greater than 50 mm. In addition, if required, the DGD measurements may be repeated many times with the leads re-configured each time to randomise the PMD contribution in the leads. The true device DGD will then be the average of the results taken. Care must be taken to ensure that the leads are arranged such that the full range of PMD variation is covered.

Components with PM pigtails are normally highly polarization sensitive or polarised sources and, as such, the polarization axis of the pigtail is aligned with the polarization axis of the device, and the relevant parameter is extinction ratio. Any misalignment will introduce significant PMD.

To summarize, the main features of passive fibre optic devices are as follows:

- discrete, deterministic birefringent element(s), possibly with mutually unaligned optical axes (low mode coupling);
- generally deterministic DGD properties, finite or low mode coupling, with fast and slow polarization modes that may be relatively independent of wavelength;
- PMD levels which can be low ($<0,1$ ps) to high (>2 ps);
- finite, often quite narrow wavelength transmission/reflection band;
- fibre pigtails which contribute a varying amount of PMD;
- possible reflections and other multi-path dispersion sources within the DUT;
- potentially large amounts of PDL (>1 dB to <10 dB).

4.6 Reference test methods

In this test procedure, the reference test method shall be a full polarimetric method based on the Stokes parameter evaluation. There are two practical analyses complying with this criterion that are in fact formalistically equivalent to each other [2][4]. Those are: the Jones Matrix Eigenanalysis (JME) and the Poincaré Sphere Analysis (PSA). All other test methods listed in this procedure shall be considered as alternative test methods. Except as indicated below, the JME and PSA procedures are identical to those described in IEC 60793-1-48.

4.7 Polarization mode dispersion coefficient

As the PMD phenomenon is deterministic in the case of passive fibre optic devices, the concept of PMD coefficient does not apply as it does in the case of short lengths or long lengths of fibre. The PMD of passive fibre optic devices will only be expressed in units of ps.

4.8 Analyses used in various test methods

The mathematical model on which the test method analyses are based can be found in IEC 61282-9.

4.9 Calculation of polarization mode dispersion

A mathematical development for calculating PMD can be found in IEC 61282-3.

4.10 Calibration

The equipment is calibrated by using a polarization maintaining fibre of known PMD, for the case of no or negligible mode coupling. For the case of random mode coupling, a certified randomly oriented stack of quarter wave plates is recommended. For large PMD values ($> 1\text{ps}$) representative of random mode coupling, there are no simple yet standardized calibration artifact and method.

5 Device under test

The DUT is typically a fibre-pigtailed discrete component, which is fusion spliced or connected via suitable patch cords, pigtails etc into the PMD test apparatus. The DUT may be in normal laboratory environments, or alternately as required the DUT may be placed in an environmental chamber to allow it to be subject to high or low temperature or humidity etc. during measurements.

- Ensure the DUT has less than 10 dB PDL, and that its approximate spectral bandwidth is known.

As the PMD measurement of an optical passive fibre optic device depends on the type of mode coupling the DUT experiences and consequently the number of birefringent sections of which it is composed, this document has grouped the DUTs into the following categories:

- negligible or no mode coupling;
- random mode coupling;
- intermediate mode coupling;
- narrowband DWDM.

Because of the sensitivity of the SOP to the measurement, it is also necessary to make note of the actual device configurations:

- fibre to fibre;
- plug to plug;
- receptacle to receptacle;
- receptacle to plug.

The key point to take into account is that any device with long fibre leads (longer than 1 km) will exhibit some degree of randomness in the measurement of DGD as a function of the length of the fibre. This is attributed to the random mode coupling properties of most fibre and consequently making PMD a stochastic phenomenon in that case. As the DUTs of interest use short fibre leads of much less than 1 km, this procedure will consequently assume that the PMD will be deterministic.

For the purposes of this procedure, the DUT has two optical ports that may be terminated with a bare fibre, plug, or receptacle. If the device is terminated with fibre, temporary splice joints can be used to connect the DUT to the input and output polarizers. In this case, care should be taken to ensure that interference effects due to reflections are avoided. The use of index matching materials is recommended.

In the event that a device has multiple ports, measurements will pertain to a single optical path, and the procedure should be repeated for all valid optical paths. In this case, the DGD or PMD for each optical path should be reported.

The DUT and pigtailed shall be fixed in position at a nominally constant temperature throughout the entire measurement to reduce uncertainties due to random mode coupling. Mechanical and temperature stability of the DUT may be observed by viewing the DUT output SOP on a Poincaré sphere display. In a time period corresponding to a measurement, the change in the output SOP should be small relative to the change produced by a wavelength increment.

When measuring PMD, or rather the DGD of passive fibre optic devices one needs to understand the class of devices being measured, as the techniques will vary slightly in specifications, performance, and accuracy.

For simple deterministic devices (negligible or no mode coupling), the DGD will be fairly constant with respect to wavelength. In these cases the output SOP will trace a near circle on the Poincaré sphere (see Figure 2). The angular velocity will be constant and the length of the PDV and consequently the DGD will be constant. The number and accuracy of wavelength points do not have to be very high in this case.

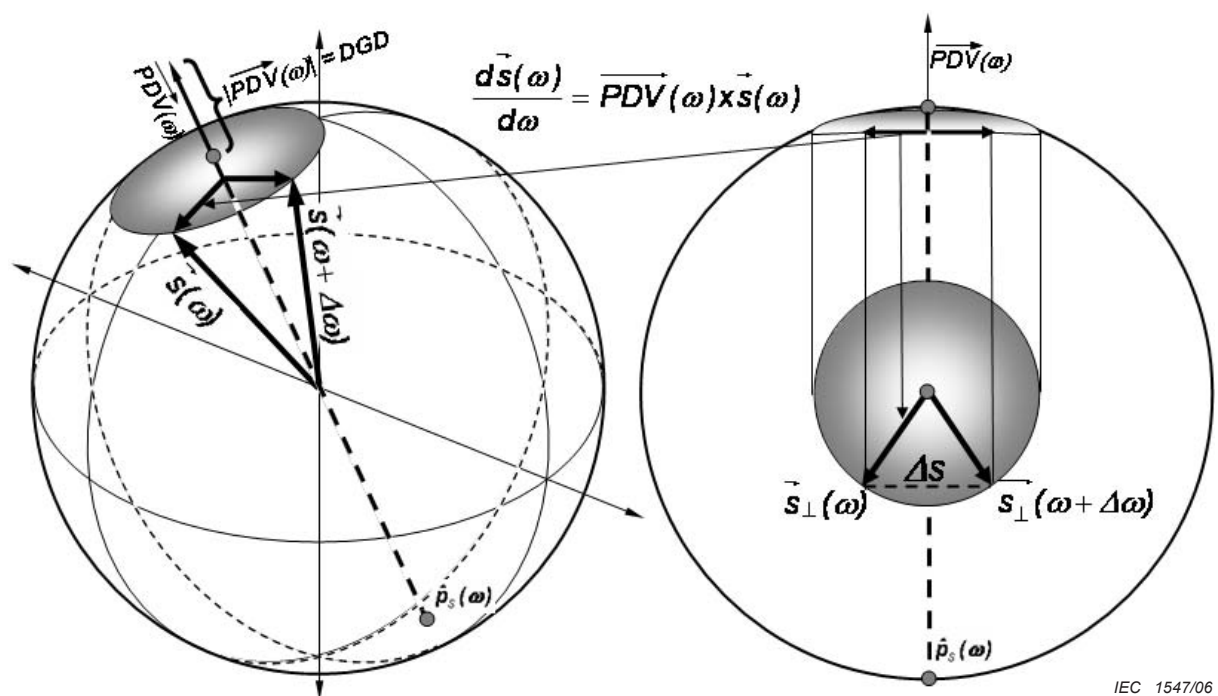


Figure 2 – Determination of polarization dispersion vector and principal states of polarization

There are however some DUTs, which could exhibit a varying angular velocity of their output SOP. With a DUT made of two sections of equal birefringence, the PSP is changing as a function of optical frequency (change of the PDV – its velocity – or its first order derivative as a function of optical frequency); but the DGD (the length of the PDV) remains constant. With three sections, both the length of the PDV (DGD) and its velocity are changing; but the DGD variation is monotonic and consequently the DGD experiences a kind of sine wave behaviour as a function of wavelength.

There could also be DUTs, exhibiting a large number of fixed changes of axis of birefringence (complex DUTs with many birefringence sections). The SOP will experience a rotation about a fixed axis of birefringence and around the fast axis PSP. But the axis of the PSP will also change and consequently the output SOP will also follow the displacement of the PSP axis on the Poincaré sphere. The rotation will not be monotonic anymore but rather complex. The DGD will experience a complex though predictable variation as a function of wavelength (random mode coupling). This case will happen when the DUT has a large number of sections of fixed birefringence. The PMD will still be the average value of that complex variation of the DGD as a function of wavelength.

DWDM devices are unique in that they will have very narrow bandwidth per channel and consequently will require a very high degree of spectral resolution in order to properly estimate the DGD as a function of wavelength and consequently the PMD. It is to be noted that in this case the Fourier spectrum of this narrowband device could give a very complex time spectrum. Care will have to be provided as the time spectrum could give questionable interpretation of time delays that might not be DGD. Provisions should also be taken in order to respect the Nyquist theorem (for instance, the source linewidth should be more than twice the step size of the wavelength scan).

Table 1 gives a summary of the test methods technical applicability to different DUT types.

Table 1 – Technical applicability of the various test methods to different DUT types

Test methods	FA		INTY		MPS	PPS	SPE	PS (arc)
	FAFT	FAEC	TINTY	GINTY				
Application to passive fibre optic devices								
Negligible or no mode coupling	(X)	N/A	(X)	X	X	X	X	X**
Random mode coupling	(X)	(X)	(X)	X	X	X	X	N/A
Intermediate mode coupling	N/A	N/A	N/A	X	X	X	X	N/A
Narrowband DWDM	N/A	N/A	N/A	X	X	X	X	X**
NOTE 1 Key: X Applicable. (X) Applicability is limited in scope, range or performance, or applicability not yet confirmed. ** Indicates that the PS arc method is only applicable to DUTs of the single element construction, where DGD is essentially constant over the wavelength range used (negligible mode coupling). N/A Not applicable NOTE 2 Key to PMD measurement methods: FAFT fixed analyser (Fourier analysis) method FAEC fixed analyser (extrema counting) method INTY interferometry method TINTY traditional analysis GINTY general analysis MPS modulation phase shift method PPS polarization phase shift SPE Stokes parameter evaluation method, including JME, PSA and MMA PS Poincaré sphere arc method								

6 Stokes parameter evaluation method

6.1 Apparatus

The basic set-up for the equivalent JME and PSA method for measuring PMD is shown in Figure 3. The various components of this system are described in the following subclauses.

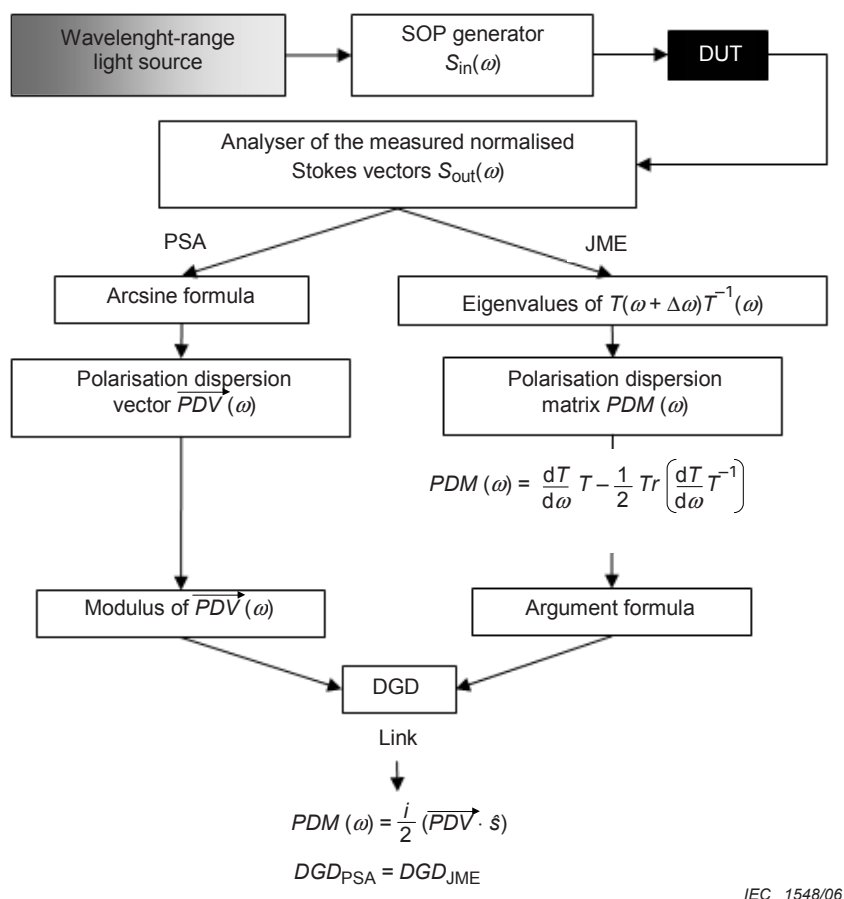
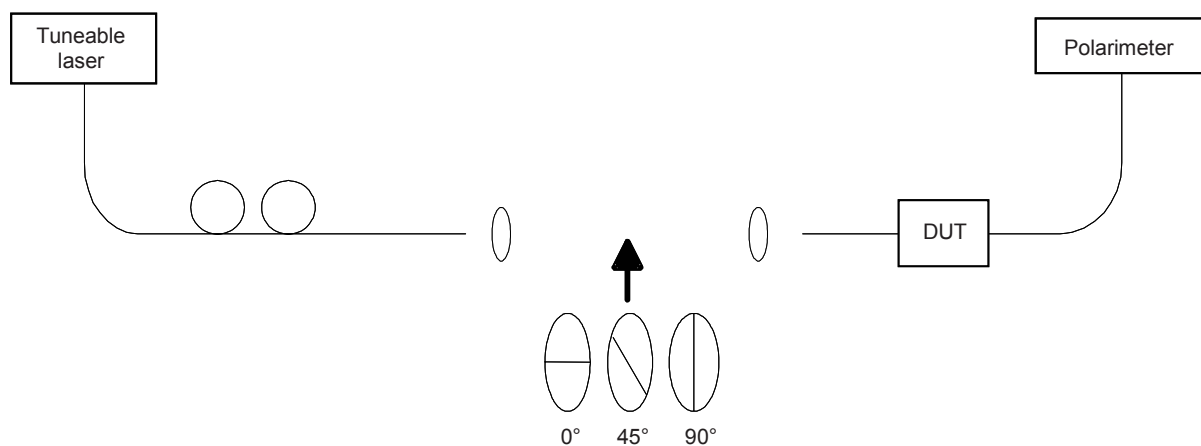


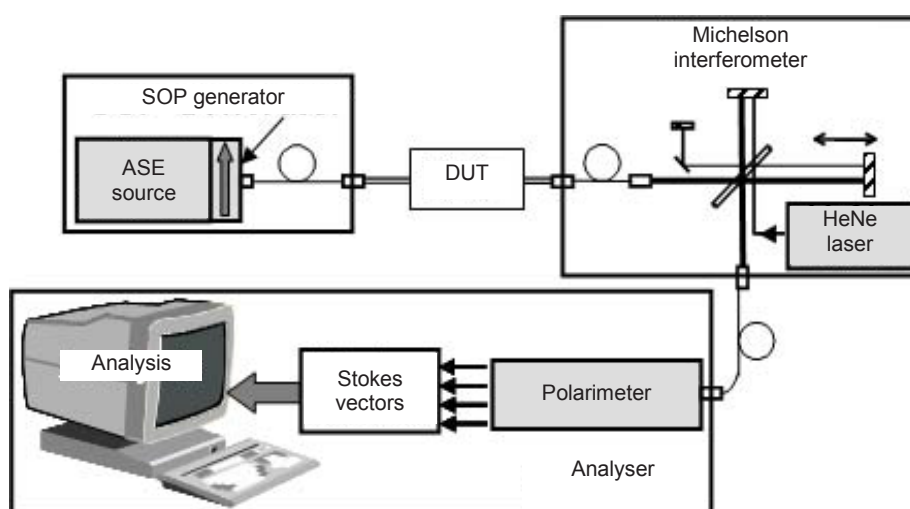
Figure 3 – Functional diagram of a generic measurement system based on Stokes parameter evaluation

Figure 4 illustrates two test set-ups for the Stokes parameter evaluation (SPE) method.



IEC 1549/06

a) Jones matrix eigenanalysis set-up



IEC 1550/06

b) Poincaré sphere analysis set-up

Figure 4 – Test set-ups for the Stokes parameter evaluation method

6.1.1 Light source

In all cases a polarised wavelength-range light source shall be used. In particular, two kinds of light source may be used depending on the type of analyser used. For instance, a narrowband source can be used with a polarimetric analyser while a broadband source can be used with a narrow band pass filtering analyser. The analyser can be an optical filter that may be placed before or after the DUT, an optical spectrum analyser or an interferometer used as a Fourier transform spectrum analyser and the polarimeter.

For the measurement of DWDM devices, the wavelength accuracy of the measurement system should be in accordance with the required accuracy to have meaningful and reliable results. The wavelength resolution should be set in accordance with the device bandwidth in order to follow the Nyquist theorem. This can be done by using a wavelength meter in the set-up procedure if necessary.

a) Narrowband source

A single-line laser or narrow band source shall be used which is tuneable across the intended measurement wavelength range. The spectral distribution shall be narrow enough so that light emerging from the DUT remains polarised under all conditions of the measurement, but not too narrow in order to avoid unnecessary noise, over-sampling and not respecting the Nyquist criterion. A degree of polarization (DOP) of 90 % or greater is preferred, although measurements may be performed with values as low as 25 % with reduced precision. For a given value of DGD, $\Delta\tau$, the lowest degree of polarization that can result is given by

$$DOP = 100 * e^{-\frac{1}{4\ln 2} \left(\frac{\pi c \Delta\tau \Delta\lambda_{FWHM}}{\lambda_0^2} \right)^2} \quad (1)$$

Assuming a Gaussian spectrum of width $\Delta\lambda_{FWHM}$ centred at λ_0 . DOP is expressed in percent.

b) Broadband source

The source can be an LED with at least 70 nm FWHM linewidth with a polarization extinction ratio of >20 dB. The filtering analyser should have a spectral width $\Delta\lambda_{FWHM}$ such that Equation (1) can be met with a DOP > 90 %.

6.1.2 State of polarization generator

A SOP generator is used for generating the input Stokes vectors $s_{in}(\omega)$. The SOP generator is composed of a polarization adjuster, a set of linear polarizers and suitable optics.

a) Polarization adjuster and linear polarizers

A polarization adjuster follows the light source and is set to provide roughly circularly polarised light to the polarizers, so that the polarizers never cross polarization with their input light.

- Adjust the polarization as follows.
- Make sure that the light source wavelength range is set to the centre of the range to be measured.
- Insert each of the three polarizers into the beam.
- Perform three corresponding power measurements at the output of the polarizer.
- Adjust the source polarization via the polarization adjuster such that the three powers fall within approximately a 3-dB range of one another.

In an open beam version of the set-up, a waveplate may perform the polarization adjustment.

In addition to the polarization adjuster, three linear polarizers, at relative angles of approximately 45°, are arranged for insertion into the light beam in turn. Alternatively, a rotating polarizer can be used. The actual relative angles do not need to be known but need to be distinct from each other.

b) Input optics

An optical lens system or single-mode fibre pigtail may be employed to excite the DUT.

If pigtails are used, interference effects due to reflections should be avoided. This may require index matching materials. The pigtails shall be single-mode. The pigtail should be kept as straight as possible and not touched in order to avoid macrobending or stress effects that would influence the test result.

If an optical lens system is used, some suitable means, such as a vacuum chuck, shall be used to provide a highly stable support to the input end of the DUT.

6.1.3 Analyser

- Couple all power emitted from the DUT to the analyser used for the measurement of the normalised Stokes vectors at the output of the DUT.

An optical lens system or a butt splice to a single-mode fibre pigtail, are examples of means that may be used.

- Measure the three output states of polarization corresponding to insertion of each of the three polarizers.

The wavelength range of the analyser shall include the wavelengths produced by the light source. Typically, the output will be in the form of Stokes parameters.

- Where a filter or spectral analyser is used, set the resolution bandwidth (RBW) in accordance with 6.2.

6.2 Procedure

This section outlines the data collection and calculation procedures of the SPE method for determining PMD.

- Couple the light source through the SOP generator (polarization adjuster to the polarizers).
- Couple the output of the SOP generator (polarizers) to the input of the DUT.
- Couple the output of the DUT to the input of the analyser.
- Select the wavelength range over which the Stokes parameters are to be measured.
- Set the wavelength step $\Delta\lambda$ (or frequency step $\Delta\nu$) of the tuneable light source or the analyser (used with the broadband source).

The maximum allowable value of $\Delta\lambda$ (around λ_0) or $\Delta\nu$ is set by the following requirement:

$$\Delta\tau_{\max} \Delta\lambda \leq \frac{\lambda_0^2}{2c} \quad (2)$$

$$\Delta\tau_{\max} \Delta\nu \leq \frac{1}{2}$$

where $\Delta\tau_{\max}$ is the maximum expected DGD within the measurement wavelength range.