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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical amplifiers – Test methods –
Part 11-1: Polarization mode dispersion parameter – Jones matrix eigenanalysis (JME)

Amplificateurs optiques – Méthodes d'essais –
Partie 11-1: Paramètre de dispersion du mode de polarisation – Analyse des vecteurs propres de la matrice de Jones (JME)

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FOREWORD

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International Standard IEC 61290-11-1 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition, published in 2003, and is a technical revision that specifically addresses additional types of optical amplifiers. It also includes updated references.

The text of this standard is based on the following documents:

CDV	Report on voting
86C/752/CDV	86C/786/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 61290 series, under the general title *Optical amplifiers – Test methods*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

OPTICAL AMPLIFIERS –
TEST METHODS –

Part 11-1: Polarization mode dispersion parameter – Jones matrix eigenanalysis (JME)

1 Scope and object

This part of IEC 61290 applies to all commercially available optical amplifiers (OAs), including optical fibre amplifiers (OFAs) using active fibres, semiconductor optical amplifiers (SOAs), and planar waveguide optical amplifiers (PWOAs).

Polarization-mode dispersion (PMD) causes an optical pulse to spread in the time domain. This dispersion could impair the performance of a telecommunications system. The effect can be related to differential group velocity and corresponding arrival times of different polarization components of the signal. For a narrowband source, the effect can be related to a differential group delay (DGD) between pairs of orthogonally polarized principal states of polarization (PSP). Other information about PMD may be found in IEC 61282-9 in general and in IEC 61292-5 on OAs in particular.

This test method describes a procedure for measuring the PMD of OAs. The measurement result is obtained from the measurement of the normalized Stokes parameters at two closely spaced wavelengths.

The test method described herein requires a polarized signal at the input of the polarimeter with a degree of polarization (DOP) of at least 25 %. Although the test source is highly polarized, the DOP at the output of the OA is reduced by amplified spontaneous emission (ASE). Annex A analyses the impact of ASE on the DOP. In order to assure an accurate measurement, the DOP is measured as part of the measurement procedure.

The method described herein has been shown to be immune to polarization-dependent gain (PDG) and polarization dependent loss (PDL) up to approximately 1 dB.

Although the Jones matrix eigenanalysis (JME) test method is in principle also applicable to unpumped (that is, unpowered) OAs, the JME technique in this standard applies to pumped (that is, powered) OAs only.

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

IEC/TR 61292-5, *Optical amplifiers – Part 5: Polarization mode dispersion parameter – General information*

3 Acronyms, symbols and abbreviations

$\Delta\lambda$	Wavelength interval
$\Delta\tau$	Differential group delay (DGD)
v	Optical frequency
ω	Angular optical frequency
F	OA noise factor
G	Gain
h	Plank's constant
$N(\gamma)$	Power spectral density of the ASE
P_s	Amplified signal power
ASE	Amplified spontaneous emission
DGD	Differential group delay
DOP	Degree of polarization
DUT	Device (optical amplifier) under test
JME	Jones matrix eigenanalysis
OA	Optical amplifier
OFA	Optical fibre amplifier
PDG	Polarization-dependent gain
PDL	Polarization-dependent loss
PMD	Polarization-mode dispersion
PWOA	Planar waveguide optical amplifier
PSP	Principal states of polarization
SOA	Semiconductor optical amplifier

4 Apparatus

4.1 General

Figure 1 provides a schematic diagram of the key components in a typical measurement system.

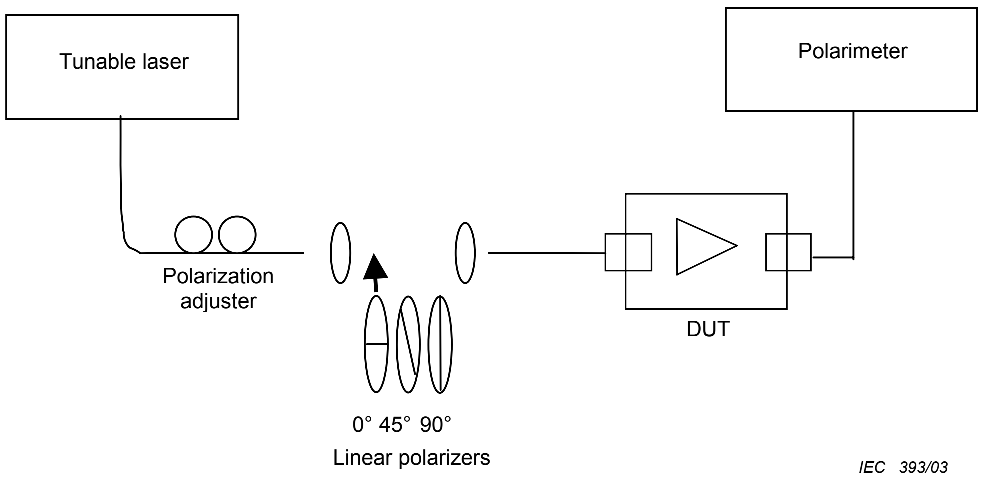


Figure 1 – Schematic diagram of equipment (typical)

4.2 Tuneable laser

Use single-line lasers or narrowband sources that can be varied or tuned across the intended measurement wavelength range. The spectral distribution shall be narrow enough so that light on the DUT remains polarized under all conditions of the measurement.

4.3 Polarization adjuster

If the source is polarized, a polarization adjuster follows the laser and is set to provide roughly circularly polarized light to the polarizers, so that the polarizers never cross polarization with the input light. If the source is unpolarized, this is not necessary. For the polarized source, adjust the polarization as follows.

a) Set the tuneable laser wavelength to the centre of the range to be measured.
b) Insert each of the three polarizers into the beam and perform three corresponding power measurements at the output of the polarizer.
c) Adjust the source polarization via the polarization adjuster in such a way that the three powers fall within approximately a 3-dB range of one another.

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

4.4 Polarizers

Three linear polarizers at relative angles of approximately 45 ° are arranged to be inserted into the light beam in turn. The actual relative angles shall be known.

4.5 Input optics

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

4.6 Fibre pigtail

If pigtails are used, interference effects due to reflections should be avoided. This may require index matching materials or angled cleaves. The pigtails shall be single-mode.

4.7 Optical lens system

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

4.8 Output optics

Couple all power emitted from the test fibre to the polarimeter. An optical lens system, a butt-splice to a single-mode fibre pigtail or an index-matched coupling made direct to the detector are examples of means that may be used.

4.9 Polarimeter

Use a polarimeter to measure the three output states of polarization corresponding to insertion of each of the three polarizers. The wavelength range of the polarimeter shall include the wavelengths produced by the light source.

5 Procedure

a) Couple the light source through the polarization adjuster to the polarizers.

b) Couple the output of the polarizers to the input of the DUT.

c) Couple the output of the DUT to the input of the polarimeter.

d) Select the wavelength interval $\Delta\lambda$ over which the normalized Stokes parameters are to be measured. The maximum allowable value of $\Delta\lambda$ (around the nominal wavelength λ_0) is set by the requirement

$$\Delta\tau_{max}\,\Delta\lambda \le \frac{\lambda_0^2}{2c} \tag{1}$$

where $\Delta\tau_{max}$ is the maximum expected DGD within $\lambda_0 \pm \Delta\lambda/2$. For example, the product of the maximum DGD and the wavelength interval shall remain less than 4 ps×nm at 1 550 nm and less than 2,8 ps×nm at 1 300 nm. This requirement ensures that from one test wavelength to the next, the output state of polarization rotates less than 180 ° about the principal states axis on the Poincaré sphere. If a rough estimate of $\Delta\tau_{max}$ cannot be made, perform a series of sample measurements across the wavelength range, each measurement using a closely spaced pair of wavelengths appropriate to the spectral width and minimum tuning step of the optical source. Multiply the maximum DGD measured in this way by a safety factor of 3, substitute this value for $\Delta\tau_{max}$ in the above expression and compute the value of $\Delta\lambda$ to be used in the actual measurement. If there is concern that the wavelength interval used for a measurement was too large, the measurement may be repeated with a smaller wavelength interval. If the shape of the curve of DGD versus wavelength and the mean DGD is essentially unchanged, the original wavelength interval was satisfactory.

e) Gather the measurement data. At the selected wavelengths, insert each of the polarizers and record the corresponding normalized Stokes parameters from the polarimeter.

f) Calculate the DOP from the measured normalized Stokes parameters to determine if the measurement is valid.

$$DOP = \sqrt{s_1^2 + s_2^2 + s_3^2} \tag{2}$$

If the DOP is greater than 25 %, the measurement is valid. If the DOP is less than 25 %, increase the tuneable laser power and repeat step e).

6 Calculations

6.1 Jones matrix eigenanalysis calculations

From the normalized Stokes parameters, compute the response Jones matrix at each wavelength. For each wavelength interval, compute the product of the Jones matrix $T(\omega+\Delta\omega)$ at the higher optical frequency and the inverse Jones matrix $T^{-1}(\omega)$ at the lower optical frequency. The radian optical frequency ω is expressed in radians per second and is related to the optical frequency v by $\omega = 2\pi v$.

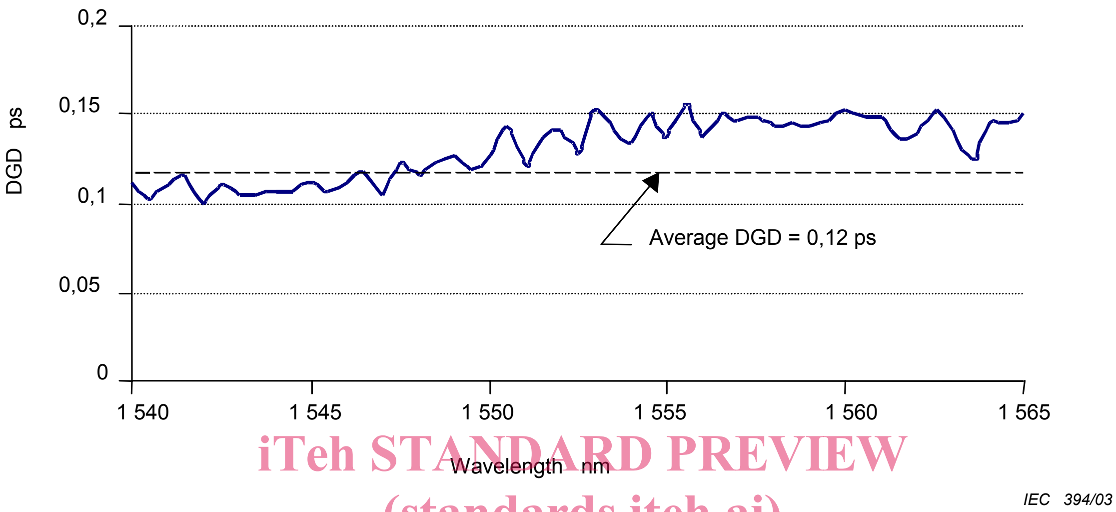
Find the DGD $\Delta\tau$ for the particular wavelength interval from the following expression:

$$\Delta\tau = \left| \frac{\text{Arg}\left(\frac{\rho_1}{\rho_2}\right)}{\Delta\omega} \right| \tag{3}$$

where ρ_1 and ρ_2 are the complex eigenvalues of $T(\omega+\Delta\omega)\ T^{-1}(\omega)$ and Arg denotes the argument function, that is Arg$(\eta e^{i\theta}) = \theta$. For the purposes of data analysis, each DGD value is taken to represent the differential group delay at the midpoint of the corresponding wavelength interval.

6.2 Display of DGD versus wavelength

Data arising from Jones matrix eigenanalysis calculations may be plotted in an x-y format with DGD on the vertical axis and wavelength on the horizontal axis as shown in Figure 2.



NOTE The DOP for this measurement ranges from 57 % to 79 %.

Figure 2 – Measurement example of the DGD for a typical optical amplifier

6.3 Average DGD

The expected PMD value of a single measurement is simply the average of the DGD measurement values corresponding to the wavelength intervals. If multiple measurements are performed under different conditions to increase the sample size, the ensemble average is used.

6.4 Maximum DGD

The maximum DGD is the maximum measured value over the wavelength range.

7 Test results

Report the following information for each test:

a) the wavelength range over which the measurement was performed, and the wavelength step size (nm);

b) the value of DGD at each wavelength (ps);

c) the average DGD across the specified wavelength range (ps);

d) the maximum DGD across the specified wavelength range (ps);

e) the minimum DOP across the wavelength range;

f) arrangement of the test set-up, including the type of tunable laser and its spectral linewidth;

g) an indication of the amplifier operating condition during measurement, for example, optical pump power (if applicable) for OFAs or electrical pump conditions (if applicable) for SOAs;

h) ambient temperature (if required).