TECHNICAL REPORT

IEC TR 61292-5

First edition
2004-07

Optical amplifiers –

Part 5: Polarization mode dispersion parameter – General information

Reference number
IEC/TR 61292-5:2004(E)

Publication numbering

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International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

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PRICE CODE M

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CONTENTS

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OPTICAL AMPLIFIERS –

Part 5: Polarization mode dispersion parameter – General information

FOREWORD

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IEC 61292-5, which is a Technical Report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
86C/579A/DTR	86C/608/RVC

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

IEC 61292 consists of the following parts, under the new general title *Optical amplifiers:*

Part 1: Parameters of amplifier components

Part 2: Theoretical background for noise figure evaluation using the electrical spectrum analyzer

Part 3: Classification, characteristics and applications.

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers[1)]

Part 5: Polarization mode dispersion parameter – General information

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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

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- withdrawn;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.

A bilingual version of this publication may be issued at a later date.

1) To be published.

OPTICAL AMPLIFIERS –

Part 5: Polarization mode dispersion parameter – General information

1 Scope

This part of IEC 61292, which is a Technical Report, applies to all commercially available optical amplifiers (OAs) including those using fibres (OFAs), semiconductors (SOAs), and waveguides (POWA), as classified in IEC 61292-3.

This Technical Report presents general information about polarization mode dispersion (PMD), related to the application of the two commonly used methods to test PMD in OAs, the Jones matrix eigenanalysis (JME) and the Poincaré sphere analysis (PSA), which have been demonstrated to be formalistically equivalent [4,5][2)].

This report is complementary to the International Standards describing the JME procedure (IEC 61290-11-1) and the PSA procedure (IEC 61290-11-2).

2 Normative references

The following referenced documents are indispensable for the understanding 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 61290-11-1, *Optical amplifier test methods – Part 11-1: Polarization mode dispersion – Jones matrix eigenanalysis method (JME)*

IEC 61290-11-2, *Optical fibre amplifier test methods – Part 11-2: Polarization mode dispersion – Poincaré sphere analysis method* [3)]

IEC 61292-3, *Optical amplifiers – Part 3: Classification, characteristics and applications*

3 Acronyms and abbreviations

ASE	amplified spontaneous emission
BBS	broadband source
DGD	differential group delay
DOP	degree of polarization
JME	Jones matrix eigenanalysis
OA	optical amplifier
OFA	optical fibre amplifier
OSA	optical spectrum analyser
PDG	polarization dependent gain
PDL	polarization dependent loss

2) Numbers in brackets refer to the Bibliography.

3) To be published.

PMD	polarisation mode dispersion
PMF	polarization-maintaining fibre
POWA	planar optical waveguide amplifier
PSA	Poincaré sphere analysis
PSP	principal states of polarization
RBW	resolution bandwidth
RMS	root mean square
SMSR	side mode suppression ratio
SOA	semiconductor optical amplifier
SOP	state of polarization
TLS	tuneable laser source

4 General Information

PMD refers to how the polarized light and in particular the principal states of polarization (PSPs) from a short pulse of a narrowband light source are modified when going through a device such as an OA. This process is mathematically explained by the concepts of polarization transfer function, the Jones vector and the polarization dispersion matrix, the Stokes vector and the Poincaré sphere, the PSPs and their mode coupling, the polarization dispersion vector and the differential group delay (DGD).

The following clauses will discuss some of these concepts as specifically applied to OAs.

4.1 Principal states of polarization and mode coupling

OAs are usually defined by a combination of optical components (passive or active gain medium); in some cases, an optical fibre is used as the active gain medium (see IEC 61292-3).

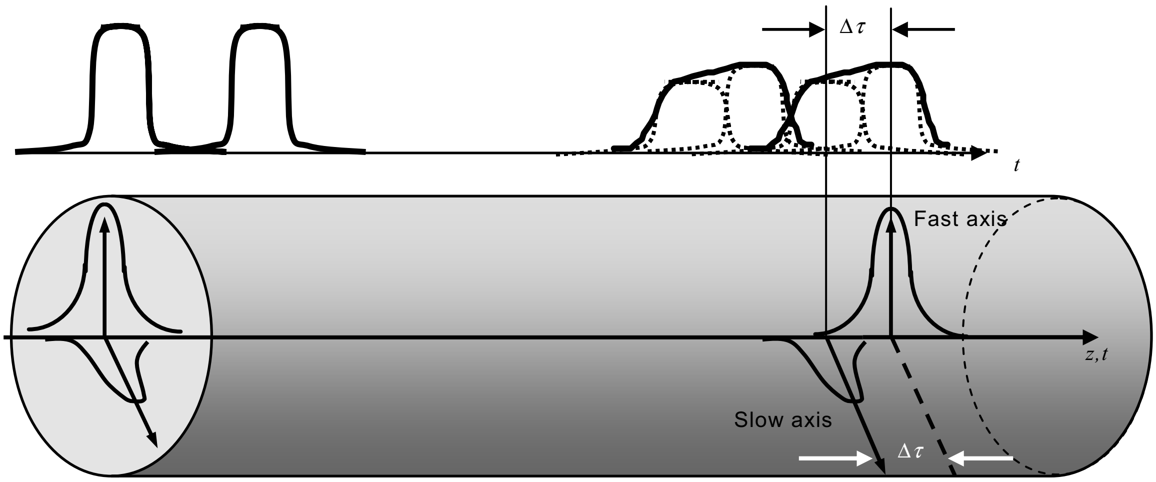
Some components have a deterministic behaviour while others behave stochastically, depending on their complexity and design. An optical fibre is deterministic if its length is short or if its birefringence axis is fixed, such as in the case of a polarization-maintaining fibre (PMF). The fibre will have a stochastic behaviour if it has a long length such as the fibre installed in cable plant. The length from which the fibre behaves stochastically is still under investigation.

Most OAs are expected to behave in semi-random mode coupling.

4.2 Differential group delay and polarization mode dispersion

In OAs, the DGD may vary as a function of wavelength (or frequency) even if this variation is smooth, small or sometimes predictable. In that case, the concept of PMD expressed as the RMS value or average value of the variation of the DGD as a function of wavelength (or optical frequency) and the concept of maximum value of that DGD variation can be used. For OAs the DGD and PMD are reported in ps.

In OAs, PMD together with polarization dependent loss (PDL) and polarization dependent gain (PDG) may introduce waveform distortion, leading to unacceptable bit error rate increase. Figure 1 illustrates the case where at the output of the DUT the bits are not only broadened (in absence of PDL/PDG) but also distorted (in presence of PDL/PDG). In presence of PDL, there is a loss of degree of polarization (DOP) for one PSP.



Key

t time

z direction of propogation along the fibre

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

5 Test method calculations

The mathematical formulation, as well as examples of calculation of JME and PSA, are found in IEC 61290-11-1 and IEC 61290-11-2, respectively.

6 Measurement issues

The following clauses pertain specifically to PMD measurement issues for OAs

6.1 Source degree of polarization and amplified spontaneous emission

The test methods require a polarized signal at the input of the polarimeter. Although the test source is highly polarized, the DOP at the output of the OA may be significantly reduced by the unpolarized amplified spontaneous emission (ASE).

The source DOP and measured signal DOP should be at least 25 % within the optical bandwidth of the SOP measurement. This is of particular concern when using a tuneable laser source (TLS) without a tracking optical filter at the OA output, because the total ASE power out of the OA, i.e. the ASE spectrum integrated over all wavelengths, impinges on the photodetectors whatever the selected wavelength. In this case, proper saturation conditions must be ensured in order for the DOP at the output port of the DUT to be high enough, e.g. >30 %, for accurate measurement.

Figure 2 shows a typical OFA output spectrum from a TLS input as viewed on an optical spectrum analyser (OSA) with a resolution bandwidth (RBW) of 0,5 nm (~65 GHz around 1 550 nm).

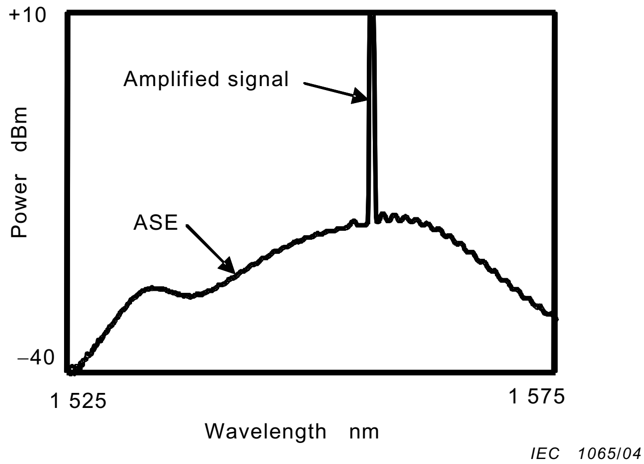


Figure 2 – Spectrum of optical fibre amplifier output

The source DOP requirement is less of a concern when using a BBS and spectral analysis (which acts as a narrowband filter centred about the selected wavelength, such as with a typical implementation of the PSA method shown in IEC 61290-11-2), or a TLS with a tracking narrowband filter at the output of the OA. In this case the ASE power, within the RBW of the spectral analysis, or output-filter bandwidth, remains low with respect to signal power for a broader range of saturation conditions.

Assuming that the signal is highly polarized and the ASE is unpolarized, the DOP is given by the following equation:

$$DOP = \frac{P_s}{P_s + \int N(\lambda) d\lambda} \quad (1)$$

where P_s is the amplified signal power and $N(\lambda)$ is the power spectral density of the ASE. The integral in the denominator is the total ASE power. For an OFA the value of N at the signal wavelength can be calculated as follows:

$$N = FGh\nu \quad (2)$$

where F is the OA noise factor, G is the gain, h is Plank's constant, and ν is the optical frequency. Typical values for a heavily saturated OA are:

F = 4 (6 dB)

G = 100 (20 dB)

P_s = 10 mW (+10 dBm)

For $h\nu$ = 1,28 x 10^{-19}, N is calculated as follows:

N = 4 x 100 x 1,28 x 10^{-19} = 5,12 x 10^{-17} W/Hz ~ 6,4 x 10^{-6} W/nm = –21,9 dBm/nm

Assuming a 30 nm bandwidth, the total ASE power is 0,19 mW = –7,2 dBm. Using Equation (1), DOP is calculated as 10/(10 + 0,19) = 98 %. This value is very adequate for making DGD measurements.

However, if the signal level is lowered, the ASE rises. Here are typical values for an OFA at a lower level of saturation:

F = 4 (6 dB)

G = 1 000 (30 dB)

P_s = 1 mW (0 dBm)

N = 4 x 1 000 x 1,28 x 10^{-19} = 5,12 x 10^{-16} W/Hz ~ 6,4 x 10^{-5} W/nm = –11,9 dBm/nm

Again, assuming a 30 nm bandwidth, the total ASE power is 1,9 mW = +2,8 dBm. Using Equation (1), DOP is calculated as 1/(1 + 1,9) = 34 %. This is marginally adequate for the JME method using a TLS.

In the case of JME, it is therefore critical to adequately saturate the OFA to obtain a sufficiently high DOP, e.g. >30 %, and a reliable measurement result.

6.2 The use of a broadband source

It is possible to characterize OAs with the use of BBS and tuneable optical filter (such as OSA). Some filters (analysers) have ≤10-pm RBW (<1,5 GHz around 1 550 nm). The difference here is the power measurement range. Strong ASE sources of ≥0 dBm/nm will give approximately –20 dBm (including filter loss) in a 20 pm window, whereas laser sources are generally more than 0 dBm, thus a 25-dB difference in measurement range. It is worth noting that some ASE sources can give more than +20 dBm/nm in some wavelength ranges. Nonetheless, if the sensitivity of the detectors is –80 dBm to –90 dBm, this still gives, in general, 60 dB to 70 dB of measurement range, sufficient for many measurement applications.

If a BBS is used together with a tuneable filter or OSA after or before the OA and the Fourier transform is performed on the OSA output signal, the interferogram or the time signature of the signal is obtained. This approach may be used for instance to perform PMD measurement using the PSA method (see IEC 61290-11-2). In that case, the RBW is the setting parameter. In fact any measure has a RBW, TLS included, which must be known, including the shape of the filter used, if the results need to be accurately determined and properly analysed.

In the case of the interferogram, the cut-off delay or the coherence time (in the time domain) or the RBW (in the frequency domain) must be specified. This corresponds to specifying the bandwidth of a filter, in order to properly reduce the noise level: the spectrum of the signal (the interferogram) is looked at and is cut-off from the point or area where there is excessive noise, spurious or non-interesting, irrelevant information. In fact the cut-off frequency of the filter (or its coherence time) is carefully selected by analysing the signal spectrum (the interferogram).

6.3 Coherence interference effects and multiple path interferences

These effects are also called Fabry-Perot effects or Fabry-Perot etalon effects.

OAs 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 transfer function measurements are sensitive to cavity effects if the lengths of these cavities are shorter than the coherence length of the TLS if a TLS is used. The longer the range between two reflections, the larger could be the instability of the transfer function measurements due to the fluctuation of the cavity effects. For instance, if two parasite reflections are separated by three metres of fibre, a fluctuation of a quarter of a wave of the cavity length will be enough to go from a maximum to a minimum in the transmission spectrum, approximately 0,25 µm in the fibre. A temperature fluctuation of the order of 0,01 °C may also be enough to generate such effects.

The effect of these reflections may also 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) [6].

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

Annex A
(informative)

Applicability of various PMD test methods to different applications

Table A.1 gives a summary of the technical applicability of the various PMD test methods to OA applications.

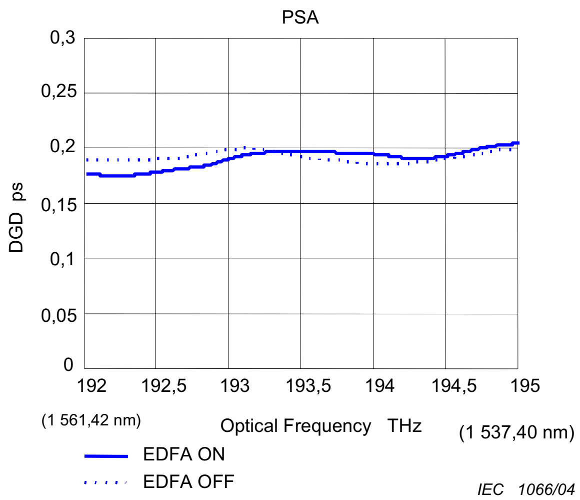
Table A.1 – Technical applicability of the various standardized PMD test methods for OAs

Applications	Test methods	
	JME	PSA
Pumped amplifiers (IEC 61290-11-1, 61290-11-2)	X[a]	X
Unpumped amplifiers	X[b]	X

[a] X = applicable.

[b] Applicability limited in scope, range or performance, or applicability not yet confirmed.

In the unpumped condition of an EDFA for example, the large ASE in the lower wavelength range will make the JME applicability limited compared to the applicability of the PSA implementation using BBS as shown in Figure A.1 below when comparing with the pumped condition.



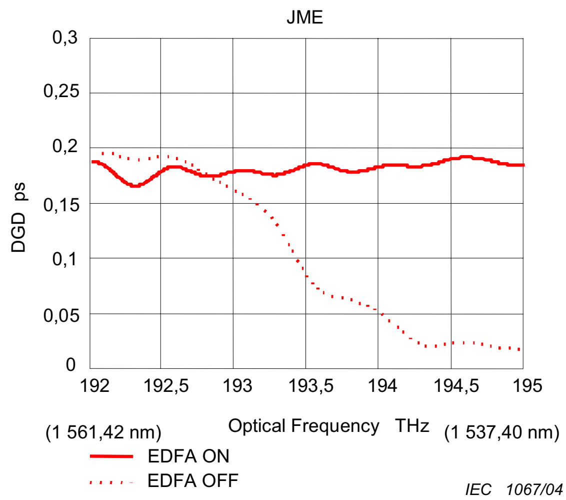


Figure A.1 – Applicability comparison of JME and PSA in pumped (EDFA ON) and unpumped (EDFA OFF) conditions

Other PMD test methods, such as the interferometric method, polarization phase shift method and modulation phase shift methods, although they have not yet been considered as test methods to be standardized, may be used for testing OAs. These methods have not been considered so far for various reasons, such as lack of experimental applications and validations, lack of availability up until now and lack of sufficient market attraction, even if for some of these methods their cost efficiency may have justified such interest.

Bibliography

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

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

[3] 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*

[4] CYR, N., GIRARD, A., and SCHINN, G.W. Stokes Parameter Analysis Method, the Consolidated Test Method for PMD Measurements. 15th National Fibre Optic Engineering Conference (NFOEC '99), Chicago Illinois, Sept. 1999, *Techn. Proc. II*, 280 (1999)

[5] CYR, N. Equivalence of Poincaré Sphere and Jones Matrix Analyses for Determination of PMD. 5th Optical Fibre Measurement Conference (OFMC '99), Nantes France, Sept. 1999, *Techn. Digest 41* (1999)

[6] CYR, N., BRETON, M., and SCHINN, G.W. PMD or Multipath Interference Dispersion: Which Measurement is of More Practical Importance?. 3rd Optical Fibre Measurement Conference (OFMC '97), Teddington UK, Sept.-Oct. 1997, *Techn. Digest* 130-135 (1997)

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Typeset and printed by the IEC Central Office
GENEVA, SWITZERLAND