

TECHNICAL REPORT

IEC TR 61282-9

First edition
2006-07

Fibre optic communication system design guides –

Part 9: Guidance on polarization mode dispersion measurements and theory

© IEC 2006 — Copyright - all rights reserved

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from the publisher.

International Electrotechnical Commission, 3, rue de Varembe, 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



Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE

XF

For price, see current catalogue

CONTENTS

FOREWORD.....	5
1 Scope.....	7
2 Normative references	7
3 Acronyms and abbreviations.....	8
4 General information	9
4.1 Polarization modes.....	9
4.2 Birefringence.....	11
4.3 Beat length.....	12
4.4 Polarization transfer function.....	12
4.5 Stokes parameters and the Poincaré sphere	13
4.6 Principal states of polarization.....	15
4.7 Differential group delay	15
4.8 Polarization mode dispersion.....	15
4.9 Polarization dispersion and birefringence vectors	16
4.10 Polarization mode coupling.....	18
4.11 Second-order polarization mode dispersion.....	23
5 Mathematical formulations of the polarization mode dispersion test methods.....	26
5.1 Stokes parameter evaluation	26
5.2 Modulation phase shift	39
5.3 Polarization phase shift	42
5.4 Fixed analyser.....	45
5.5 Interferometric method	59
5.6 Poincaré sphere arc method.....	84
5.7 Poole formula method	87
5.8 Single-end test methods.....	88
6 Measurement issues.....	95
6.1 Degree of polarization and amplified spontaneous emission.....	95
6.2 Suppression of amplified spontaneous emission using optical or electrical filtering ..	97
6.3 The use of a broadband source	98
6.4 The Nyquist theorem and optical measurements	99
6.5 Continuously swept tuneable laser source and sampling theory.....	106
6.6 Tuneable laser source and noise.....	107
6.7 The selection of the states of polarization.....	107
6.8 Coherence interference effects and multiple path interference.....	107
6.9 Fibre pigtails	108
6.10 Power measurement resolution and linearity	108
6.11 Calibration of test instruments	108
Annex A (informative) Summary of various PMD test methods found in IEC standards.....	109
Annex B (Informative) Summary of key definitions	111
Annex C (Informative) Calculation of polarization mode dispersion value	114
Annex D (informative) Generalised Parseval theorem	117
Annex E (informative) Open issues	119
Bibliography.....	125

Figure 1 – Two electric field vector polarizations of the HE_{11} mode in an optical fibre along the a) x-direction and b) y-direction	10
Figure 2 – Cartesian and elliptical representation of a state of polarization	12
Figure 3 – Poincaré sphere representation of states of polarization	14
Figure 4 – Effect of polarization mode dispersion on transmission of an information-bit pulse in a device.....	16
Figure 5 – Polarization dispersion vector and principal states of polarization	17
Figure 6 – No or negligible mode coupling	18
Figure 7 – Random mode coupling.....	19
Figure 8 – Statistics of differential group delay and related Maxwell distribution [15].....	22
Figure 9 – Polarization mode dispersion and differential group delay in negligible mode coupling	23
Figure 10 – Effects of first-order polarization mode dispersion (PMD_1) and second-order polarization mode dispersion (PMD_2) on the output state of polarization on the Poincaré sphere.....	24
Figure 11 – Rectangular system of co-ordinates defined by the response Stokes vectors, and direction angles of the polarization dispersion vector	29
Figure 12 – Arc of a circle described by the output state of polarization in the increment $[\omega, \omega+\Delta\omega]$	30
Figure 13 – Functional diagram of Stokes parameter evaluation	36
Figure 14 – a) Differential group delay (DGD) as a function of the optical frequency (f) obtained through Poincaré sphere analysis (PSA) and Jones matrix analysis (JME), and b) Difference of DGDs.....	38
Figure 15 – Trajectories of the principal states of polarization on the Poincaré sphere from a) Jones matrix eigenanalysis (JME) and b) Poincaré sphere analysis (PSA).....	39
Figure 16 – Mueller states on Poincaré sphere	40
Figure 17 – Example of random mode coupling result with fixed analyser using Fourier transform technique [15]	49
Figure 18 – Polarization mode dispersion by Fourier analysis	54
Figure 19 – Mean cross-correlation and autocorrelation functions.....	58
Figure 20 – Generic set-up for the measurement of polarization mode dispersion using the interferometric test method	59
Figure 21 – Schematic diagram for GINTY analysis using input/output state-of-polarization scrambling	65
Figure 22 – Comparison between single-scan and scrambling uncertainties	69
a) With a polarization maintaining fibre and one I/O SOP).....	70
b) With I/O-SOP scrambling ($L/h \ll 1$, $DGD = 0,732$ ps, $\sigma_A = 50$ fs, $DGD/\sigma_A \sim 14,7$).....	70
Figure 23 – Example of negligible-mode-coupling result using a) TINTY analysis and b) GINTY analysis.....	70
Figure 24 – Example of random-mode-coupling result using TINTY analysis.....	71
Figure 25 – Example of random-mode-coupling result using GINTY analysis with I/O-SOP scrambling.....	75
Figure 26 – Equivalence between a) Stokes parameter evaluation method PSA analysis and b) GINTY analysis	76
Figure 27 – Example of mixed-mode-coupling result using GINTY analysis.....	79
Figure 28 – Comparison between polarization mode dispersion results from TINTY and GINTY analyses.....	81
Figure 29 – Relationship between beat length and state of polarization	85

Figure 30 – Relationship between Stokes parameter and state of polarization on the Poincaré sphere.....	85
Figure 31 – Relationship between fixed analyser method with circular analyser (—) and Poincaré sphere arc method (---)	86
Figure 32 – Relationship of state of polarization (SOP) analysis to normalised Stokes s_3 parameter.....	87
a) For wide SOP-to-birefringence axis angle	93
b) For a small SOP-to-birefringence axis angle	93
Figure 33 – Backscattered state of polarization (SOP) for short and long pulses versus distance.....	93
Figure 34 – Degree of polarization (DOP) vs. distance for a concatenation of three 500-m fibres, with a centre fibre that exhibits a high h value	94
Figure 35 – Power spectrum of a typical optical fibre amplifier output showing the amplified signal, the amplified spontaneous emission (ASE), and the optical signal-to-noise ratio (OSNR)	95
Figure 36 – Power ratio of amplified signal to total amplified spontaneous emission (ASE) versus the optical signal-to-noise ratio (OSNR) in 0,1-nm resolution bandwidth (RBW).....	96
Figure 37 – Time varying signal	99
Figure 38 – Frequency spectrum of Figure 37 signal (its Fourier transform) a) in linear; b) in log scales	100
Figure 39 – Filtered signal with Nyquist-based defined bandwidth.....	101
Under-sampled signal (factor 2)	101
Figure 40 – Unfiltered signal with under-sampled (factor 2) defined bandwidth a	101
Figure 41 – Figure 37 signal with noise.....	102
Figure 42 – Frequency spectrum of Figure 41 signal.....	102
Figure 43 – Filtered noisy signal respecting the Nyquist theorem.....	103
Figure 44 – Un-filtered noisy signal spectrum not respecting the Nyquist theorem	103
Figure 45 – Signal frequency spectrum (of a filter as an example)	104
Figure 46 – Impulse response from Figure 45 signal.....	104
a) Signal frequency spectrum reconstructed following the Nyquist theorem.....	105
b) Under-sampled signal frequency spectrum	105
c) Under-sampled noisy signal spectrum.....	105
d) Reconstructed frequency spectrum of signal shown in (c).....	105
Figure 47 – Reconstructed signal based on Figure 45 a) following the Nyquist theorem; b) not following the Nyquist theorem; c) including noise; d) based on c).....	105
Table 1 – Example of Mueller set.....	41
Table 2 – Cosine Fourier transform calculations	57
Table 3 – Values of g_S for various types or degrees of coupling.....	80
Table 4 – Values of 45 ° power, Stokes parameters and SOP corresponding to Figure 29	85
Table A.1 – Applicability matrix for various polarization-mode-dispersion test methods.....	109
Table D.1 – Definition of the Fourier transform pairs	117

INTERNATIONAL ELECTROTECHNICAL COMMISSION

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

**Part 9: Guidance on polarization mode dispersion
measurements and theory**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61282-9, 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/696/DTR	86C/703/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.

This is a preview of "IEC/TR 61282-9 Ed. 1...". [Click here to purchase the full version from the ANSI store.](#)

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

A list of all parts of IEC 61282 series, published under the general title *Fibre optic communication system design guides*, 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.

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

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 9: Guidance on polarization mode dispersion measurements and theory

1 Scope

This technical report applies to all commercially available fibre optic products sensitive to polarization mode dispersion (PMD).

This report presents general information about PMD, the mathematical formulation related to the application of the generally accepted methods to test PMD, and some considerations related to the sampling theory regarding the use of different light sources and detection systems.

This report is complementary to the International Standards describing the PMD procedures (IEC 60793-1-48, IEC 61280-4-4, IEC 61290-11-1, IEC 61290-11-2 and IEC 61300-3-32) and other design guides on PMD (IEC 61282-3 and IEC 61292-5).

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 – Polarization mode dispersion*

IEC 61280-4-4: *Fibre optic communication subsystem test procedures – Part 4-4: Cable plants and links – Polarization mode dispersion measurement for installed links*

IEC 61290-11-1: *Optical fibre amplifier test methods – Part 11-1: Polarization mode dispersion – Jones matrix eigenanalysis method (JME)*

IEC 61290-11-2: *Optical amplifiers – Test methods – Part 11-2: Polarization mode dispersion parameter – Poincaré sphere analysis method*

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*

IEC 61300-3-32: *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-32: Examinations and measurements – Polarization mode dispersion for passive optical components*¹

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

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

¹ To be published