

This is a preview - click here to buy the full publication



IEC TR 61282-9

Edition 2.0 2016-03

TECHNICAL REPORT



Fibre optic communication system design guides – Part 9: Guidance on polarization mode dispersion measurements and theory

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.180.01

ISBN 978-2-8322-3236-1

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references.....	7
3 Terms, definitions, and abbreviations	7
3.1 Terms and definitions	7
3.2 Abbreviations	8
4 Theoretical framework	8
4.1 Limitations and outline	8
4.2 Optical field and state of polarization	8
4.3 SOP measurements, Stokes vectors, and Poincaré sphere rotations	11
4.4 First order polarization mode dispersion	14
4.5 Birefringence vector, concatenations, and mode coupling.....	16
4.6 The statistics of PMD and second order PMD	17
4.7 Managing time	20
5 Measurement methods.....	20
5.1 General.....	20
5.2 Stokes parameter evaluation	22
5.2.1 Equipment setup and procedure	22
5.2.2 Jones matrix eigenanalysis	23
5.2.3 Poincaré sphere analysis	24
5.2.4 One ended measurements based on SPE [3].....	26
5.3 Phase shift based measurement methods.....	27
5.3.1 General	27
5.3.2 Modulation phase shift – Full search.....	28
5.3.3 Modulation phase shift method – Mueller set analysis [4]	29
5.3.4 Polarization phase shift measurement method[5]	31
5.4 Interferometric measurement methods	33
5.4.1 General	33
5.4.2 Generalized interferometric method [6]	35
5.4.3 Traditional interferometric measurement method.....	40
5.5 Fixed analyser	41
5.5.1 General	41
5.5.2 Extrema counting	42
5.5.3 Fourier transform	43
5.5.4 Cosine Fourier transform.....	44
5.5.5 Spectral differentiation	45
5.6 Wavelength scanning OTDR and SOP analysis (WSOSA) method [7]	46
5.6.1 General	46
5.6.2 Continuous model	48
5.6.3 Large difference model.....	49
5.6.4 Scrambling factor derivation	50
6 Limitations.....	53
6.1 General.....	53
6.2 Amplified spontaneous emission and degree of polarization	53
6.3 Polarization dependent loss (or gain).....	53

6.4	Coherence effects and multiple path interference	54
6.5	Test lead fibres	54
6.6	Aerial cables testing	55
	Bibliography	56
	Figure 1 – Two electric field vector polarizations of the HE ₁₁ mode in a SMF.....	10
	Figure 2 – A rotation on the Poincaré sphere	13
	Figure 3 – Strong mode coupling – Frequency evolution of the SOP	16
	Figure 4 – Random DGD variation vs. wavelength	18
	Figure 5 – Histogram of DGD values from Figure 4	18
	Figure 6 – SPE equipment diagram	22
	Figure 7 – Relationship of orthogonal output SOPs to the PDV	24
	Figure 8 – Stokes vector rotation with frequency change.....	25
	Figure 9 – Setup for modulation phase shift.....	27
	Figure 10 – Setup for polarization phase shift.....	28
	Figure 11 – Output SOP relation to the PSP	30
	Figure 12 – Interferometric measurement setup.....	33
	Figure 13 – Interferogram relationships	35
	Figure 14 – Mean square envelopes.....	38
	Figure 15 – Fixed analyser setup	41
	Figure 16 – Fixed analyser ratio	42
	Figure 17 – Power spectrum	44
	Figure 18 – Fourier transform.....	44
	Figure 19 – WSOSA setup	46
	Figure 20 – Frequency grid	47
	Table 1 – Map of test methods and International Standards	22
	Table 2 – Mueller SOPs	29

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 itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 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 TR 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.

This second edition cancels and replaces the first edition published in 2006.

This second edition includes the following significant technical changes with respect to the previous edition:

- a) much of the theory has been condensed – focusing only on content that is needed to explain the test method;
- b) symbols have been removed, but abbreviations are retained;

- c) the material in the Clause 5 has been significantly reduced in an effort to avoid repeating what is already in the actual International Standards. Instead, the focus is on explaining the International Standards;
- d) measurement methods that are not found in International Standards have been removed;
- e) there are significant corrections to the modulation phase shift method, particularly in regard to the Mueller set technique;
- f) there are significant corrections to the polarization phase shift method;
- g) the proof of the GINTY interferometric method is presented. This proof also extends to the Fixed Analyser Cosine transfer technique;
- h) another Fixed Analyser method is suggested. This is based on the proof of the GINTY method and is called "spectral differentiation method";
- i) Clause 6 has been renamed "Limitations" and refocused on the limitations of the test methods. This Technical Report is not intended to be an engineering manual;
- j) the annexes have been removed;
- k) the bibliography has been much reduced in size;
- l) the introduction has been expanded to include some information on system impairments.

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

Enquiry draft	Report on voting
86C/1342/DTR	86C/1366/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 publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the 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 stability date indicated on the IEC website 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This Technical Report is complementary to the International Standards describing 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), as well as ITU-T Recommendation G.650.2.

The system power penalty associated with PMD varies depending on transmission format and bit rate. It also varies with optical frequency and state of polarization (SOP) of the light source. At the output of a link, the signal can shift from a maximum delay to a minimum delay as a result of using different SOPs at the source. The difference in these delays is called the differential group delay (DGD), which is associated with two extremes of input SOP. At these extremes, a signal in the form of a single pulse appears shifted up or down by half the DGD, about a midpoint, at the output. At intermediate SOPs, the single pulse appears as a weighted total of two pulses at the output, one shifted up by half the DGD and one shifted down by half the DGD. This weighted total of two shifted pulses is what causes signal distortion.

The system power penalty is partly defined in terms of a maximum allowed bit error rate and a minimum received power. In the absence of distortion, there is a minimum received power that will produce the maximum allowed bit error rate. In the presence of distortion, the received power should be increased to produce the maximum bit error rate. The magnitude of the required increase of received power is the power penalty of the distortion.

The term PMD is used to describe two distinctly different ideas.

One idea is associated with the signal distortion induced by transmission media for which the output SOP varies with optical frequency. This is the fundamental source of signal distortion.

The other idea is that of a number (value) associated with the measurement of a single-mode fibre transmission link or element of that link. There are several measurement methods with different strengths and capabilities. They are all based on quantifying the magnitude of possible variation in output SOP with optical frequency. The objective of this Technical Report is to explain the commonality of the different methods.

The DGD at the source's optical frequency is what controls the maximum penalty across all possible SOPs. However, in most links, the DGD varies randomly across optical frequency and time. The PMD value associated with measurements, and which is specified, is a statistical metric that describes the DGD distribution. There are two main metrics, linear average and root-mean square (RMS), that exist in the literature and in the measurement methods. For most situations, one metric can be calculated from the other using a conversion formula. The reason for the dual metrics is an accident of history. If history could be corrected, the RMS definition would be the most suitable.

For the non-return to zero transmission format, DGD equal to 0,3 of the bit period yields approximately 1 dB maximum penalty. Because DGD varies randomly, a rule of thumb emerged in the system standardization groups: keep PMD less than 0,1 of the bit period for less than 1 dB penalty. This assumes that DGD larger than three times the PMD, and that the source output SOP produces the worst case distortion, is not very likely. For 10 Gbit/s non-return to zero, this rule yields a design rule: keep the link PMD less than 10 ps. ITU-T G.sup.39 [1]¹ has more information on the relationship of PMD and system penalties.

¹ Numbers in square brackets refer to the Bibliography.

FIBRE OPTIC COMMUNICATION SYSTEM DESIGN GUIDES –

Part 9: Guidance on polarization mode dispersion measurements and theory

1 Scope

This part of IEC 61282, which is a Technical Report, describes effects and theory of polarization mode dispersion (PMD) and provides guidance on PMD measurements.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 amplifier – Test methods – Part 11-1: Polarization mode dispersion parameter – Jones matrix eigenanalysis (JME)*

IEC 61290-11-2, *Optical amplifier – Test methods – Part 11-1: Polarization mode dispersion parameter – Poincaré sphere analysis method*

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