IEC 60793-1-48

Edition 3.0 2017-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Optical fibres –
Part 1-48: Measurement methods and test procedures – Polarization mode dispersion

Fibres optiques –
Partie 1-48: Méthodes de mesure et procédures d'essai – Dispersion de mode de polarisation

IEC 60793-1-48:2017-08(en-fr)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

IEC 60793-1-48

Edition 3.0 2017-08

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Optical fibres – Part 1-48: Measurement methods and test procedures – Polarization mode dispersion

Fibres optiques – Partie 1-48: Méthodes de mesure et procédures d'essai – Dispersion de mode de polarisation

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 33.180.10 ISBN 978-2-8322-4686-3

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL FIBRES –

Part 1-48: Measurement methods and test procedures – Polarization mode dispersion

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.

International Standard IEC 60793-1-48 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 2007. It constitutes a technical revision. This edition includes the following significant technical change with respect to the previous edition:

a) removal of the SOP approach.

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

CDV	Report on voting
86A/1678/CDV	86A/1766/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.

This International Standard is to be read in conjunction with IEC 60793-1-1:2008. A list of all parts in the IEC 60793 series, published under the general title *Optical fibres,* 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 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.

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

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 phase and group velocities and corresponding arrival times $\delta\tau$ of different polarization components of the signal. For a sufficiently narrow band source, the effect can be related to a differential group delay (DGD), $\Delta\tau$, between pairs of orthogonally polarized principal states of polarization (PSP) at a given wavelength. For broadband transmission, the delays bifurcate and result in an output pulse that is spread out in the time domain. In this case, the spreading can be related to the average of DGD values.

In long fibre spans, DGD is random in both time and wavelength since it depends on the details of the birefringence along the entire fibre length. It is also sensitive to time-dependent temperature and mechanical perturbations on the fibre. For this reason, a useful way to characterize PMD in long fibres is in terms of an average DGD value over an appropriately large optical frequency range, either RMS $<\Delta\tau>$, the rms DGD over this frequency range, or MEAN $<\Delta\tau>$, the (linear) mean of the DGD over this same frequency range. In principle, the average DGD value (RMS $<\Delta\tau>$ or MEAN $<\Delta\tau>$) does not undergo large changes for a given fibre from day to day or from source to source, unlike the parameters $\delta\tau$ or $\Delta\tau$. In addition, the average DGD value is a useful predictor of lightwave system performance.

The term "PMD" is used both in the general sense of two polarization modes having different group velocities, and in the specific sense of the average DGD value (RMS $<\Delta\tau>$ or MEAN $<\Delta\tau>$). Although the DGD $\Delta\tau$ or pulse broadening $\Delta\delta$ is preferably averaged over frequency, for certain situations it may be averaged over time, or temperature.

The coupling length l_c is the length of fibre or cable at which appreciable coupling between the two polarization states begins to occur. If the fibre length L satisfies the condition $L << l_c$, mode coupling is negligible, and $<\Delta\tau>$ scales with fibre length. The corresponding PMD coefficient is

$$\text{short-length PMD coefficient} = <\Delta\tau>/L.$$

Fibres in practical systems nearly always have fibre lengths much greater than the coupling length and random mode coupling. When mode coupling is random, $<\Delta\tau>$ scales with the square root of fibre length, and

$$\text{long-length PMD coefficient} = <\Delta\tau>/\sqrt{L}\ .$$

OPTICAL FIBRES –

Part 1-48: Measurement methods and test procedures – Polarization mode dispersion

1 Scope

This part of IEC 60793 applies to three methods of measuring polarization mode dispersion (PMD), which are described in Clause 4. It establishes uniform requirements for measuring the PMD of single-mode optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60793-1-1, *Optical fibres - Part 1-1: Measurement methods and test procedures - General and guidance*

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

ITU-T Recommendation G.650.2, *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ITU-T Recommendation G.650.2 apply.

NOTE Further explanation of their use in this document is provided in IEC TR 61282-9.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Symbols and abbreviated terms

Arg	Argument function
ASE	Amplified spontaneous emission
BBS	Broadband source
CFT	Cosine Fourier transform
c/c_0	Velocity of light in vacuum/in free space
DGD	Differential group delay
DGD_{max}	Maximum DGD value

DOP	Degree of polarization
E	Number of extrema in $R(\lambda)$ (method A)
EC	Extrema counting
$f(\Delta\tau)$	Maxwell probability distribution
FA	Fixed analyser (method A)
FCFT	Fast cosine Fourier transform
FT	Fourier transform
FUT	Fibre under test
GINTY	General analysis for method C
INTY	Interferometry method (method C)
I/O	Input/output
JME	Jones matrix eigenanalysis (method B)
k	Mode coupling factor
l_c	Coupling length
L	Length of fibre/fibre cable test sample
LED	Light emitting diode
N	Total number of measurements/population of mode-coupled fibres/wavelength intervals
$P_A(\lambda)$	Optical power recorded with analyser in place (method A)
P_F	Probability of exceeding DGD_{max}
$P_B(\lambda)$	Optical power recorded with analyser rotated 90 ° (method A)
$P_{TOT}(\lambda)$	Optical power recorded with analyser removed (method A)
$P_x(\tau)/P_x(\tau)$	Received power in the two orthogonal SOP axes corresponding to the fringes in method C
PBS	Polarization beam splitter
PDL	Polarization dependent loss
PDV	Polarization dispersion vector
PMD	Polarization mode dispersion
PMD_Q	Link design PMD value
PSA	Poincaré sphere analysis (method B)
PSP	Principle states of polarization
$R(\lambda)$	Output ratio from PMD measurement system (method A)
RBW	Resolution bandwidth
RTM	Reference test method
s	Normalized output Stokes vectors
SOP	State of polarization
SPE	Stokes parameter evaluation (method B)
T	Jones matrix
T^{-1}	Inverse of the Jones matrix
t_c	Optical source coherence time (method C)
TINTY	Traditional analysis for method C
α	Single parameter which specifies a Maxwell distribution
X^2	Chi-squared variable

$\Delta\hat{h}/\Delta\hat{v}/\Delta\hat{q}/\Delta\hat{c}$	Finite differences computed from the Stokes vectors
$\delta\lambda$	Wavelength step size
$\Delta\lambda$	Optical source spectral width (full width half maximum (FWHM) unless otherwise noted)
$\delta\nu$	Optical frequency step size
$\Delta\theta$	Rotation angle on Poincaré sphere
$\delta\tau$	Arrival time of different polarization components of a signal or pulse broadening
$\Delta\delta\tau_{max}$	Maximum $\delta\tau$ value that can be measured
$\Delta\delta\tau_{min}$	Minimum $\delta\tau$ value that can be measured
$\Delta\tau$	DGD value
$\Delta\tau_{max}$	Maximum DGD
$<\Delta\tau>$	Average DGD over wavelength scan range or PMD value
$\sqrt{<\Delta\tau^2>}$	r.m.s. DGD over wavelength scan range or PMD value (method C)
$<\Delta\tau>_0$	Maximum PMD specification that each fibre shall meet in a population of mode-coupled fibres
$<\Delta\tau>_t$	Average DGD over time
$<\Delta\tau>_T$	Average DGD over temperature
$<\Delta\tau>_\lambda$	Average DGD over wavelength
$\Delta\omega$	Angular frequency variation in method B
λ	Test wavelength used to measure PMD
λ_0	Central wavelength of the light source
λ_1/λ_2	First/last wavelength in set of test wavelengths (or position of first/last maximum or minimum in $R(\lambda)$ in method A)
ν	Optical light frequency
ρ_1/ρ_2	Complex eigenvalues of $T(\omega+\Delta\omega)T^{-1}(\omega)$
σ	One-standard-deviation uncertainty
σ_0	r.m.s. width of the squared envelope of the autocorrelation interferogram (method C, GINTY)
σ_A	r.m.s. width of the autocorrelation envelope (method C)
σ_R	Second moment of FT data (method A)
σ_x	r.m.s. width of the squared envelope of the cross-correlation interferogram (method C, GINTY)
σ_ε	r.m.s. width of the cross-correlation envelope (method C, TINTY)
ω	Angular optical frequency
Ω	PDV

4 General

4.1 Methods for measuring PMD

Three methods are described for measuring PMD (see Annexes A, B and C for more details). The methods are listed below in the order of their introduction. For some methods, multiple approaches of analysing the measured results are also provided.

a) Method A
   1) Fixed analyser (FA)
   2) Extrema counting (EC)
   3) Fourier transform (FT)
   4) Cosine Fourier transform (CFT)
b) Method B
   1) Stokes parameter evaluation (SPE)
   2) Jones matrix eigenanalysis (JME)
   3) Poincaré sphere analysis (PSA)
c) Method C
   1) Interferometry (INTY)
   2) Traditional analysis (TINTY)
   3) General analysis (GINTY)

The PMD value is defined in terms of the differential group delay (DGD), $\Delta\tau$, which usually varies randomly with wavelength, and is reported as one or another statistical metric. Equation (1) is a linear average value of the DGD values and is used for the specification of optical fibre cable. Equation (2) is the root mean square value which is reported by some methods. Equation (3) can be used to convert one value to the other if the DGDs are assumed to follow a Maxwell random distribution.

$$PMD_{\mathrm{AVG}} = \langle \Delta\tau \rangle \tag{1}$$

$$PMD_{\mathrm{RMS}} = \sqrt{\langle \Delta\tau^2 \rangle} \tag{2}$$

$$\langle \Delta\tau \rangle = \left(\frac{8}{3\pi} \right)^{1/2} \sqrt{\langle \Delta\tau \rangle} \tag{3}$$

Equation (3) applies only when the distribution of DGDs is Maxwellian, for instance when the fibre is randomly mode coupled. The generalized use of Equation (3) can be verified by statistical analysis. A Maxwell distribution may not be the case if there are point sources of elevated birefringence (relative to the rest of the fibre), such as a tight bend, or other phenomena that reduce the mode coupling, such as a continual reduced bend radius with fibre in tension. In these cases, the distribution of the DGDs will begin to resemble the square root of a non-central Chi-square distribution with three degrees of freedom. For these cases, the PMD_{RMS} value will generally be larger relative to the PMD_{MEAN} that is indicated in Equation (3). Time domain methods such as method C and method A, cosine Fourier transform, which are based on PMD_{RMS}, can use Equation (3) to convert to PMD_{MEAN}. If mode coupling is reduced, the resulting reported PMD value from these methods can exceed those that can be reported by the frequency domain measurements that report PMD_{MEAN}, such as method B.

The PMD coefficient is the PMD value normalized to the fibre length. For normal transmission fibre, for which random mode coupling occurs and for which the DGDs are distributed as Maxwell random variables, the PMD value is divided by the square root of the length, and the PMD coefficient is reported in units of $\mathrm{ps}/\sqrt{\mathrm{km}}$. For some fibres with negligible mode coupling, such as polarization maintaining fibre, the PMD value is divided by the length, and the PMD coefficient is reported in units of ps/km.

All methods are suitable for laboratory measurements of factory lengths of optical fibre and optical fibre cable. For all methods, changes in the deployment of the specimen can alter the results. For installed lengths of optical fibre cable that may be moving or vibrating, either method C or method B is appropriate (in an implementation capable of millisecond measurement time scales).

All methods require light sources that are controlled at one or more states of polarization (SOPs). All methods require injecting light across a broad spectral region (i.e. 50 nm to 200 nm wide) to obtain a PMD value that is characteristic of the region (i.e. 1 300 nm or 1 550 nm). The methods differ in:

a) the wavelength characteristics of the source;

b) the physical characteristics that are actually measured;

c) the analysis methods.

Method A measures PMD by measuring a response to a change of narrowband light across a wavelength range. At the source, the light is linearly polarized at one or more SOPs. For each SOP, the change in output power that is filtered through a fixed polarization analyser, relative to the power detected without the analyser, is measured as a function of wavelength. The resulting measured function can be analysed in one of three ways:

a) by counting the number of peaks and valleys (EC) of the curve and application of a formula that has been shown [1][1] to agree with the average of DGD values, when the DGDs are distributed as Maxwellian. This analysis is considered as a frequency domain approach;

b) by taking the FT of the measured function. This FT is equivalent to the pulse spreading obtained by the broadband transmission of method C. Appropriate characterisation of the width of the FT function agrees with the average of DGD values, when the DGDs are distributed as Maxwellian;

c) by taking the CFT of the difference of the normalized spectra from two orthogonal analyser settings and calculating the r.m.s. of the squared envelope. The PMDRMS value is reported. This is equivalent to simulating the fringe pattern of the cross-correlation function that would result from interferometric measurements.

Method B measures $\Delta\tau(\omega)$ by measuring a response to a change of narrowband light across a wavelength range. At the source, the light is linearly polarized at one or more SOPs. The Stokes vector of the output light is measured for each wavelength. The change of these Stokes vectors with angular optical frequency, ω, and with the (optional) change in input SOP yields the DGD as a function of wavelength through relationships that are based on the following definitions:

$$\frac{ds(\omega)}{d\omega} = \Omega(\omega) \times s(\omega) \tag{4}$$

$$\Delta\tau(\omega) = \left|\Omega(\omega)\right| \tag{5}$$

where

s is the normalized output Stokes vector;

Ω is the polarization dispersion vector (PDV) in the direction of the PSPs;

$\Delta\tau$ is the DGD.

For both the JME and PSA analysis approaches, three linear SOPs at nominally 0 °, 45 °, and 90 ° (orthogonal on the Poincaré sphere) shall be launched for each wavelength.

[1] Numbers in square brackets refer to the Bibliography

The JME approach is completed by transforming the output Stokes vectors to Jones matrices [2], appropriately combining the matrices at adjacent wavelengths and by a calculation using the eigenvalues of the result to obtain the DGD, by application of an argument formula, at the base frequency.

The PSA approach is completed by doing matrix algebra on the normalized output Stokes vectors to infer the rotation of the output Stokes vector on the Poincaré sphere at two adjacent wavelengths, using the application of an arcsine formula to obtain the DGD. The JME and PSA approaches are mathematically equivalent for common assumptions (see IEC TR 61282-9).

Method C is based on a broadband light source that is linearly polarized. The cross-correlation of the emerging electromagnetic field is determined by the interference pattern of output light, i.e. the interferogram. The determination of the PMD delay for the wavelength range associated with the source spectrum is based on the envelope of the fringe pattern of the interferogram. Two analyses are available to obtain the PMD delay (see IEC TR 61282-9), both of which measure the PMD_{RMS} value:

a) TINTY uses a set of specific operating conditions for its successful applications and a basic setup;
b) GINTY uses no limiting operating conditions but, in addition to the same basic set-up as TINTY, it uses a modified setup.

The analysis approaches represent an evolution of the understanding of PMD. The GINTY is, for example, more complete than TINTY. The reproducibility of PMD depends on the PMD level and the wavelength range of the measurement [3]. Better relative reproducibility is achieved for broader wavelength ranges and higher PMD values for a given range. For measurements of higher PMD values, for example 0,5 ps, the differences in the analysis methods are less important than for the measurements of low PMD values.

Information common to all three methods is contained in Clauses 4 to 10, and requirements pertaining to each individual method appear in Annexes A, B, and C, respectively. IEC TR 61282-9 provides the mathematical formulations for all methods.

4.2 Reference test method

Method B is the reference test method (RTM), which shall be the one used to settle disputes.

4.3 Applicability

PMD in fibre is a statistical parameter. IEC 60794-3 includes a statistical requirement on PMD, called PMD_{Q} or link design value that is based on sampled measurements of optical fibre cable and calculations for concatenated links. The PMD of a cabled fibre can vary from the PMD of the uncabled fibre due to effects of cable construction and processing. A limit on the PMD_{Q} of the uncabled fibre is, however, required to limit the PMD_{Q} on cabled fibre. Uncabled fibre PMD_{Q} less than half the cabled fibre PMD_{Q} limit is generally considered as a conservative rule. Alternative limits may be determined for particular constructions and stable cable processes.

The fibre or cable deployment should be selected so that externally induced mode coupling is minimized. Sources of such external mode coupling can be:

a) excessive tension;
b) excessive bending induced from
    1) fibre cross-overs on a shipping reel;
    2) crimping of fibre within a cable on a spool that is too small;
    3) too small a bend radius.
c) excessive twist.