

Optical fibres —

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

The European Standard EN 60793-1-48:2003 has the status of a British Standard

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National foreword

This British Standard is the official English language version of EN 60793-1-48:2003. It is identical with IEC 60793-1-48:2003.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/1, Optical fibres and cables, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Foreword

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Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, annexes A, B, C and ZA are normative and annexes D to K are informative.

Annex ZA has been added by CENELEC.

EN 60793-1-4X consists of the following parts, under the general title: Optical fibres:

- Part 1-40: Measurement methods and test procedures – Attenuation
- Part 1-41: Measurement methods and test procedures – Bandwidth
- Part 1-42: Measurement methods and test procedures – Chromatic dispersion
- Part 1-43: Measurement methods and test procedures – Numerical aperture
- Part 1-44: Measurement methods and test procedures – Cut-off wavelength
- Part 1-45: Measurement methods and test procedures – Mode field diameter
- Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance
- Part 1-47: Measurement methods and test procedures – Macrobending loss
- Part 1-48: Measurement methods and test procedures – Polarization mode dispersion
- Part 1-49: Measurement methods and test procedures – Differential mode delay

Endorsement notice

The text of the International Standard IEC 60793-1-48:2003 was approved by CENELEC as a European Standard without any modification.

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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 the expected value, $\langle\Delta\tau\rangle$, or the mean DGD over wavelength. In principle, the expected value $\langle\Delta\tau\rangle$ 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, $\langle\Delta\tau\rangle$ 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 expected value $\langle\Delta\tau\rangle$. The DGD $\Delta\tau$ or pulse broadening $\delta\tau$ can be averaged over wavelength, yielding $\langle\Delta\tau\rangle_\lambda$, or time, yielding $\langle\Delta\tau\rangle_t$, or temperature, yielding $\langle\Delta\tau\rangle_T$. For most purposes, it is not necessary to distinguish between these various options for obtaining $\langle\Delta\tau\rangle$.

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

$$\text{“short-length” PMD coefficient} = \langle\Delta\tau\rangle/L. \quad (1)$$

Fibres in practical systems are nearly always in the $L \gg l_c$, regime and mode-coupling is random. If mode-coupling is found to be random, $\langle\Delta\tau\rangle$ scales with the square root of fibre length, and

$$\text{“long-length” PMD coefficient} = \langle\Delta\tau\rangle/\sqrt{L} \quad (2)$$

The text provides means for deciding when it is appropriate to use Equations (1) or (2) to calculate the PMD coefficient. Typical units are ps for $\Delta\tau$, km for L , ps/km for short-length PMD, and ps/ $\sqrt{\text{km}}$ for long-length PMD. See 5.1 and Annex H for more details on determining the mode-coupling regime.

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 PMD, which are described in Clause 3. It establishes uniform requirements for measuring the PMD of optical fibre, thereby assisting in the inspection of fibres and cables for commercial purposes.

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 60793-1-1, *Optical fibres – Part 1-1: Generic specification – General*

IEC 60793-1-44:2001, *Optical fibres – Part 1-44: Measurement methods and test procedures – Cut-off wavelength*

IEC 60793-1-50:2001, *Optical fibres – Part 1-50: Measurement methods and test procedures – Damp heat (steady state)*

IEC 60793-2-50:2002, *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres*

IEC 60794-3:2001, *Optical fibre cables – Part 3: Sectional specification – Outdoor cables*

IEC 61280 (all parts), *Fibre optic communication subsystem basic test procedures*

IEC 61282-3:2002, *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion in fibre optic systems*

3 General

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.

Method A **Fixed analyser**

Extrema counting (EC)

Fourier transform (FT)

Method B Stokes parameter evaluation

Jones matrix eigenanalysis (JME)

Poincaré sphere analysis (PSA)

State of polarization (SOP)

Method C Interferometry

Negligible mode-coupling

Random mode-coupling

All these 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, only Method C is appropriate for measurements of installed optical fibre cable that may be moving or vibrating.

All methods require light sources that are controlled at one or more 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. 1300 nm or 1550 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 states of polarization. For each state, 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 two ways.

- By counting the number of peaks and valleys (extrema counting) of the curve and application of a formula that has been shown [1]³ to agree with the average of DGD values. This analysis is considered as a frequency domain approach.
- By taking the Fourier transform of the measured function. This transform is equivalent to the pulse spreading obtained by the broadband transmission of Method C. Appropriate characterization of the width of the transform function agrees with the average of DGD values.

Method B 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 states of polarization. The Stokes vector of the output light is measured for each wavelength. The change of these Stokes vectors with angular optical frequency (wavelength), ω and with the (optional) change in input state of polarization yields the DGD as a function of wavelength through relationships that are based on the following definitions:

$$\frac{ds(\omega)}{d\omega} = \Omega(\omega) \times s(\omega) \quad (3a)$$

³ Figures in square brackets refer to the bibliography.

$$\Delta\tau(\omega) = \|\Omega(\omega)\| \quad (3b)$$

where

$\mathbf{s}$ is the output Stokes vector;

Ω is the polarization dispersion vector 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) must be launched for each wavelength. For the SOP analysis, only one input state is required.

The JME approach is completed by transforming the output Stokes vectors to Jones matrices [2], appropriate combination of the matrices at adjacent wavelengths, and 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 output Stokes vector associated with circular birefringence at two adjacent wavelengths, followed by the application of an arcsine formula to obtain the DGD.

The SOP approach is based on a piecewise evaluation of Equation (3a) using the normalized measured Stokes vectors.

The JME and PSA approaches are mathematically equivalent for common assumptions. The SOP approach yields valid results when the transit of the output Stokes vector is well-behaved (negligible mode-coupling) but can produce incorrect results when the output Stokes vector changes rapidly and randomly. The extra measurement time required for the three input states of polarization for JME and PSA result in a more robust measurement.

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 the output light. The characterization of this pattern is either done by computing the r.m.s width for randomly mode-coupled specimens or by evaluation of the most extreme interferogram “spike” for specimens with negligible mode-coupling. For random mode-coupled specimens, the r.m.s width relates to the average DGD (PMD).

Information common to all three methods is contained in Clauses 3 to 9, and requirements pertaining to each individual method appear in Annexes A, B, and C, respectively.

3.1 Reference test method

Method B, Stokes parameter evaluation (only JME and PSA approaches), is the reference test method (RTM), which shall be the one used to settle disputes.

3.2 Applicability

PMD in fibre is a statistical parameter. IEC 60794-3 includes a statistical requirement on PMD that is based on sampled measurements of optical fibre cable and calculations for concatenated links. IEC 60793-2-50 includes an optional maximum for individual uncabled fibres for support of cabled results – provided that the relationship of measurements on uncabled fibre and cabled fibre have been demonstrated to be stable for a given cable construction.

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

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

Reproducibility of individual measurements should be evaluated after perturbing the fibre to allow sampling the full range of mode-coupling combinations. This can be done by, for example, changing the temperature slightly or making small adjustments in the deployment. Annex D includes information on the inter-comparison of the methods based on round-robin studies. Gisin [3] reported a fundamental reproducibility limit for measurements showing that the reproducibility increases as the PMD increases and as the spectral width of the source increases. Annex E includes information on approaches to improving the precision.

Guidelines for the calculation of PMD for systems that include other components such as dispersion compensators or optical amplifiers are given in IEC 61282-3. Test methods for optical amplifiers are given in IEC 61280.

4 Apparatus

The following apparatus is common to all three measurement methods. Annexes A, B, and C include layout drawings and other equipment requirements for each of the three methods, respectively.

4.1 Light source and polarizers

See Annexes A, B, and C for detailed options of the spectral characteristics of the light source. The source shall produce sufficient radiation at the intended wavelength(s) and be stable in intensity over a time period sufficient to perform the measurement.

For all methods, the polarization of the light is required to be linearly polarized before it is injected into the fibre. Use a polarization adjuster to transform the source light to a state that is roughly circular for the centre of the wavelength range being used. Use a polarizer to transform this light to linear polarization at one or more states. The polarizer can be one of a set of three oriented at 0°, 45°, and 90°. In an open-beam set-up, a wave plate may perform the polarization adjustment. The polarization adjuster set-up can be verified by measuring the output power at the three linear polarizations. If the output powers are within 3 dB of one another, the adjuster set-up is suitable.

For Methods A and B, the effective spectral width of the source, $\Delta\lambda$, shall be narrow enough so that light emerging from the fibre remains polarized under all conditions of measurement. A degree of polarization (DOP) of 90 % or greater is preferred, although measurements may be performed with values as low as 25 % with reduced precision. For a given value of DGD, $\Delta\tau$, the lowest DOP which can result is given by

$$DOP(\%) = 100 \exp \left[-\frac{1}{4 \ln(2)} \left(\frac{\pi c \Delta\tau \Delta\lambda}{\lambda_0^2} \right)^2 \right] \quad (4)$$

assuming a Gaussian spectrum width (full-width half-max) centred at λ_0 (c is the speed of light in vacuum.)

For Method C, the polarizer extinction ratio over the source spectral width shall be >20 dB.

For Method B, the SOP approach, the polarization controller is set to optimize the conditions for the determination of the rotation angle on the Poincaré sphere, if necessary, by selecting an input state for which the variation in the output Stokes vectors with wavelength is maximal.

4.2 Input optics

An optical lens system or fibre pigtail may be employed to excite the specimen. It is recommended that the power coupled into the specimen be relatively insensitive to the position of its input end face. This can be accomplished by using a launch beam that spatially and angularly overfills the input end face.

If using a butt splice, employ index-matching material between the fibre pigtail and the specimen to avoid interference effects. The coupling shall be stable for the duration of the measurement.

4.3 Input positioner

Provide means of positioning the input end of the specimen to the light source. Examples include the use of x-y-z micropositioner stages, or mechanical coupling devices such as connectors, vacuum splices, three-rod splices, etc. The position of the fibre shall remain stable over the duration of the measurement.

4.4 Cladding mode stripper

Use a device that extracts cladding modes. In some circumstances, the fibre coating will perform this function.

4.5 High-order mode filter

Use a means to remove high-order propagating modes in the desired wavelength range that is greater than, or equal to, the cut-off wavelength (see IEC 60793-1-44) of the specimen. For example, a one-turn bend of radius = 30 mm on the fibre is generally sufficient.

4.6 Output positioner

Provide a suitable means for aligning the fibre output end face to the output optics. Such coupling may include the use of lenses or may be a mechanical connector to a detector pigtail.

Provide means such as a side-viewing microscope or camera with a cross-hair to locate the fibre at a fixed distance from the output optics. It may be sufficient to provide only longitudinal adjustment if the fibre is constrained in the lateral plane by a device such as a vacuum chuck.

4.7 Output optics

See Annex A, B, or C, as appropriate.

4.8 Detector

For signal detection, an optical detector is used which is linear and stable over the range of intensities and measurement times that are encountered in performing the measurement. A typical system might include synchronous detection by a chopper/lock-in amplifier, an optical power meter, optical spectrum analyser, or a polarimeter. To use the entire spectral range of the source, the detection system must have a wavelength range which includes the wavelengths produced by the light source. See Annex A, B, or C, as appropriate, for additional details.

4.9 Computer

Use a computer to perform operations such as controlling the apparatus, taking intensity measurements, and processing the data to obtain the final results.

5 Sampling and specimens

A specimen is a known length of single-mode optical fibre (IEC 60793-2-50) which may or may not be cabled. The sample and pigtails must be fixed in position at a nominally constant temperature throughout the measurement. Standard ambient conditions shall be employed unless otherwise specified. In the case of installed fibres and cables, prevailing deployment conditions may be used.

Mechanical and temperature stability of the test device may be observed by the following procedures. For Method A, the output power from the fibre at a fixed wavelength is measured with the output analyser in place. In a time period corresponding to a typical complete measurement, the output power change should be small relative to the changes produced by a wavelength increment. For Method B, the output state of polarization of the test fibre on a Poincaré sphere display is viewed. In a time period corresponding to an adjacent pair of Jones matrix measurements, the output polarization change should be small relative to the change produced by a wavelength increment. Method C is normally robust with regard to slight temperature change or fibre movements.

End faces for the input and output ends of the test sample must be prepared as appropriate for the requirements of the apparatus and procedure. Precautions shall be taken to avoid any reflections.

5.1 Specimen length

The specimen length is dictated by three factors:

- a) minimum desired PMD coefficient;
- b) mode-coupling regime;
- c) signal-to-noise ratio.

Each test method and implementation is limited to a minimum PMD value (ps) that can be measured. In many cases, this minimum can be determined on the basis of theory. It can also be determined experimentally by examining the measured distribution. For fibres in the high mode-coupling regime, the minimum PMD coefficient is determined by dividing the PMD value by the square root of the fibre length (km). For the negligible mode-coupling case, the division is by the length. The length that is measured and the minimum measurable PMD value will therefore determine the minimum measurable PMD coefficient. Fibres or cables with lengths sufficient to achieve this minimum can be selected for measurement. Alternatively, specimens can be cut to a length that is satisfactory. The minimum measurable PMD value shall be documented. The length of the individual specimens shall be recorded.

NOTE The length may also be limited by the deployment method (see 5.2) and instrument dynamic range.

The values specified in IEC 60794-3 and IEC 60793-1-50 express the PMD coefficient in terms of $\text{ps}/\sqrt{\text{km}}$ – in effect, these documents assume that the length measured is sufficient to induce the randomly mode-coupled regime. For a given fibre type or cable construction, this can be confirmed by doing a cut-back experiment in which the PMD value is measured on a specimen at each of several lengths – achieved by cutting the specimen back between measurements. Lengths above which there is a square-root dependence of the PMD value on length may be considered as randomly mode-coupled. Annex H provides additional information on the confirmation of the randomly mode-coupled assumptions.

The dynamic range is limited by the method, the source power, and the overall loss of the specimen, which is affected by length. This limit must generally be determined on the basis of specific implementations by experimental means. This limit shall be documented.

5.2 Deployment

The deployment of the fibre or cable can influence the result. For normal measurements to be used in specification conformance evaluation, the following requirements apply.

5.2.1 Uncabled fibre

The fibre shall be kept at minimal tension either by loosely wrapping it on a spool with a smooth surface or by deploying in loops on a flat smooth surface (smoothness equivalent or better than paper of grade 88 g/m^2).

In either case, the fibre shall be deployed without crossing over itself and with bend radii in excess of 15 cm. Any pigtails to which the fibre is connected shall also have bend radii in excess of 15 cm.

For the most accurate measurements of specimens with low PMD, use the Stokes parameter evaluation method. For optical fibre and cable, PMD measurements have an inherent sampling variability that increases as the PMD value decreases or as the wavelength window that is sampled in the measurement decreases [3]. When PMD measurements are combined

to evaluate the statistical specification of optical fibre cable (see IEC 60794-3), this variability leads to a possible overstatement of the link design value (PMD_Q). For experiments in which precise PMD values are needed, the procedures of Annex E are recommended. This annex calls for retests following multiple perturbations of the individual specimens.

NOTE Alternative deployments may be used if applicability to values measured on cabled fibres or other deployment conditions are demonstrated.

5.2.2 Optical fibre cable

PMD measurements on fibres in cables wound on shipping drums may not always reflect the functionally relevant PMD values for fibres in the installed cable deployment configuration. Consequently, to demonstrate compliance with the cabled-fibre PMD specification, alternative deployment configurations or mapping functions relating on-drum PMD value to off-drum PMD value may be used. The exact deployment configuration shall be agreed upon between the supplier and the customer.

6 Procedure

- 6.1 Deploy the fibre or cable and prepare the ends.
- 6.2 Attach the ends to the input and output optics.
- 6.3 Engage the computer to complete the scans and measurements found in Annexes A, B, and C for the three measurement methods.
- 6.4 Complete documentation.

7 Calculation or interpretation of results

Equations (1) and (2) provide the calculation of the PMD coefficient from the PMD value that is measured. Subclause 5.1 and Annex H provide information on how to determine which formula to use. For fibre and cable in excess of 1 km, random mode-coupling is normally observed.

Annexes A, B, and C provide calculations to convert the measured data into PMD values.

IEC 60794-3 and IEC 61282-3 provide calculations for computing the link design value, PMD_Q, the maximum differential group delay DGD_{max} and the probability of exceeding it, P_F . IEC 61282-3 also provides calculations to combine these values with the PMD values of other network elements.

8 Documentation

8.1 Information required for each measurement

- a) Specimen identification
- b) Testing date
- c) Specimen length
- d) PMD coefficient and its units (ps/√km or ps/km)
- e) Wavelength region (for example, 1 300 nm or 1 550 nm)

8.2 Information to be available

- a) Measurement method used
- b) Calculation approach used
- c) Description of the deployment method (including any fibre support mechanism)
- d) Wavelength range
- e) For Methods A and B, the number of wavelengths sampled
- f) For Method C, the type of fringe-detection technique
- g) Description of the equipment
- h) Date of latest calibration
- i) Evidence supporting the mode-coupling regime (indicated by units of the PMD coefficient)
- j) For Method B with narrowband source, the wavelength range resolution and number of wavelengths
- k) For Method B with broadband source, the centre wavelength and -3 dB linewidth

9 Specification information

- a) Type of fibre or cable
- b) Failure or acceptance criteria
- c) Wavelength region
- d) Any deviations from this procedure

Annex A (normative)

Fixed analyser measurement method

This annex contains requirements specific to Method A.

A.1 Apparatus

Figure A.1 shows possible block diagrams.

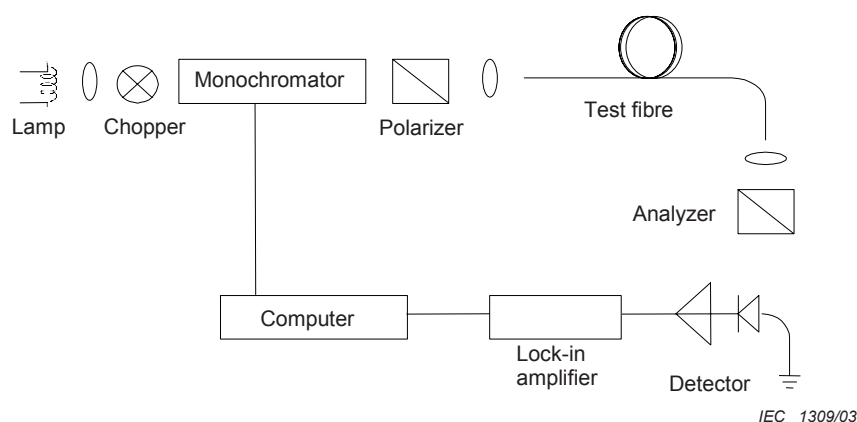


Figure A.1a – Narrowband source

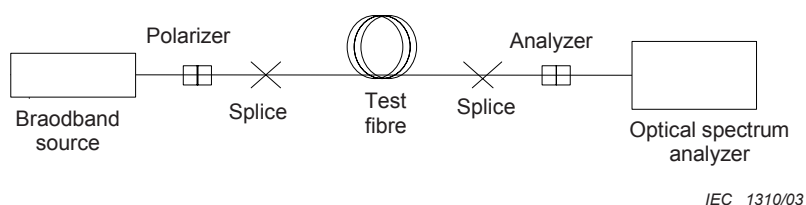


Figure A.1b – Broadband source

Figure A.1 – Block diagrams for fixed analyser

A.1.1 Light source

In all cases, two kinds of light sources may be used, depending on the type of analyser. A narrowband source, such as the broadband lamp and monochromator combination shown in Figure A.1a, can be used with a polarization analyser. A broadband source as shown in Figure A.1b can be used with a narrow bandpass filtering analyser such as an optical spectrum analyser or an interferometer used as a Fourier transform spectrum analyser placed before the analyser. In the case of a broadband source, the width of the filter is taken as the spectral width for the purpose of calculations.

In both cases, the spectral width shall be sufficiently small to maintain the desired degree of polarization (see 4.1). In both cases, the range of wavelengths shall be sufficient to provide a PMD measurement of sufficient precision at the specified wavelength region (see Clause A.3).

To insure that all features in the optical spectrum are adequately resolved, the spectral width should satisfy

$$\Delta\lambda / \lambda_0 < (8\nu\Delta\tau_{\max})^{-1} \quad (\text{A.1})$$

where

$\nu = c/\lambda$ is the optical frequency;

$\Delta\lambda$ is the spectral width;

$\Delta\tau_{\max}$ is the maximum anticipated DGD.

For λ in the vicinity of 1 550 nm, Equation (A.1) reduces to the condition that $\Delta\lambda$ (nm) should be less than the reciprocal of $\Delta\tau$ (ps).

A.1.2 Analyser

The angular orientation of the analyser is not critical but should remain fixed throughout the measurement. With negligible mode-coupling or low PMD values, some adjustment of the analyser may be helpful in maximizing the amplitude of the oscillations in Figure A.2 – which can also be achieved by rotating the fibre at splices or connectors.

NOTE The analyser can be replaced by a polarimeter.

A.2 Procedure

A.2.1 Wavelength range and increment

The procedure requires measuring the power as a function of wavelengths (or optical frequencies) over a range at a defined wavelength increment once with the analyser in the optical path and once without. The wavelength range can influence the precision of the result (see Clause A.3). The wavelength increment should be selected to satisfy Equation (A.1), with the wavelength increment replacing $\Delta\lambda$.

If the Fourier transform method is used, the step size should ideally be uniform in optical frequency and the number of steps should be a power of 2. The monochromator step-size, expressed in optical frequency, $\delta\nu$, must be a factor of two smaller than the “oscillation frequency” corresponding to the maximum DGD measured. Because of the large amount of power outside the second moment for randomly mode-coupled fibres, the Nyquist condition must be at least three times the frequency of the second moment for the maximum anticipated DGD. That is:

$$\frac{1}{6\delta\nu} > \Delta\tau_{\max} \quad (\text{A.2})$$

NOTE 1 If, from the Fourier transform, it is evident that there is significant energy near $\Delta\tau_{\max}$, the measurement should be repeated with a reduced increment.

NOTE 2 The source spectral width is generally equal to, or less than, the smallest wavelength increment. For example, for $\Delta\tau_{\max} = 0,67$ ps, a monochromator spectral width of 2 nm at 1 550 nm ($\delta\nu = 249$ GHz) is typical.

A.2.2 Complete the scans

Complete the scan with the analyser in the light path. Record the received power as $P_A(\lambda)$.

Remove the analyser from the light path and repeat the scan. Record the received power as $P_{\text{Tot}}(\lambda)$.

Calculate the power ratio, $R(\lambda)$ as follows. Figure A.2 shows an example of both negligibly and randomly mode-coupled results.

$$R(\lambda) = \frac{P_A(\lambda)}{P_{\text{Tot}}(\lambda)} \quad (\text{A.3})$$

An alternative procedure is to leave the analyser in place on the second scan but rotate it 90° . Record the power as $P_B(\lambda)$. The formula for the power ratio is then:

$$R(\lambda) = \frac{P_A(\lambda)}{P_A(\lambda) + P_B(\lambda)} \quad (\text{A.4})$$

NOTE 1 The ratio, P_A/P_B , could also be used when extrema counting is used.

NOTE 2 If a polarimeter is used as the detection element, the normalized Stokes parameters are measured versus wavelength. The three spectral functions (one per vector element) are independent of received power and correspond to three independent power ratio functions that can be analysed in the same way.

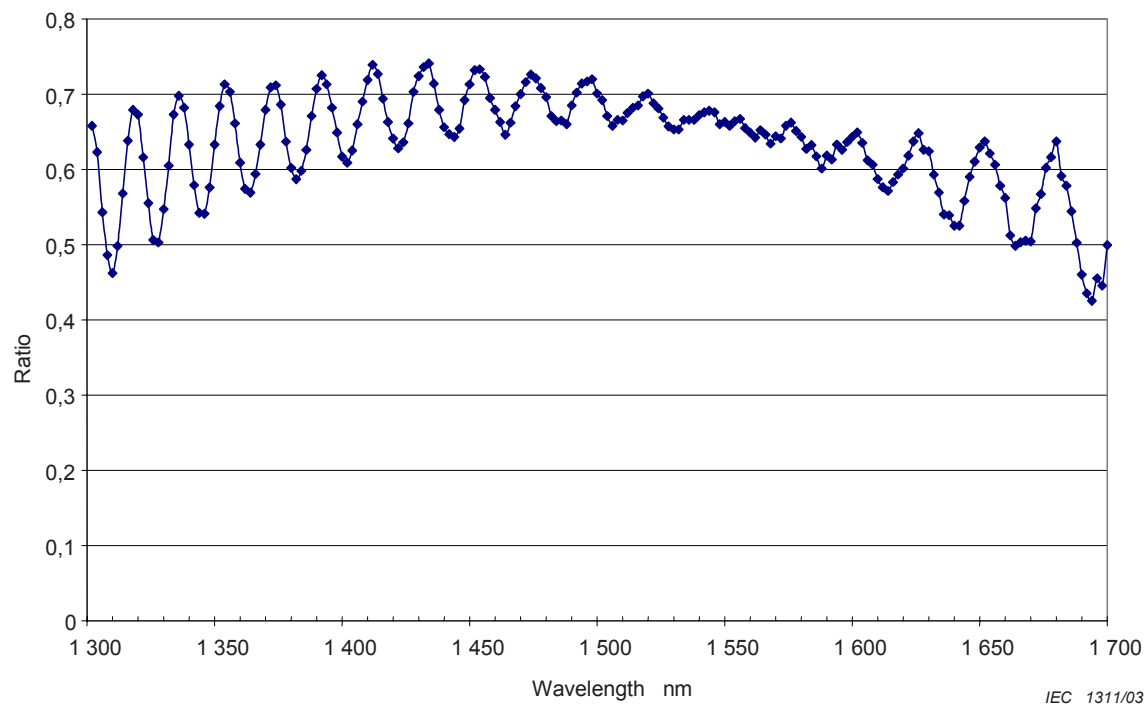


Figure A.2a – Fixed analyzer results for a negligible mode-coupled sample

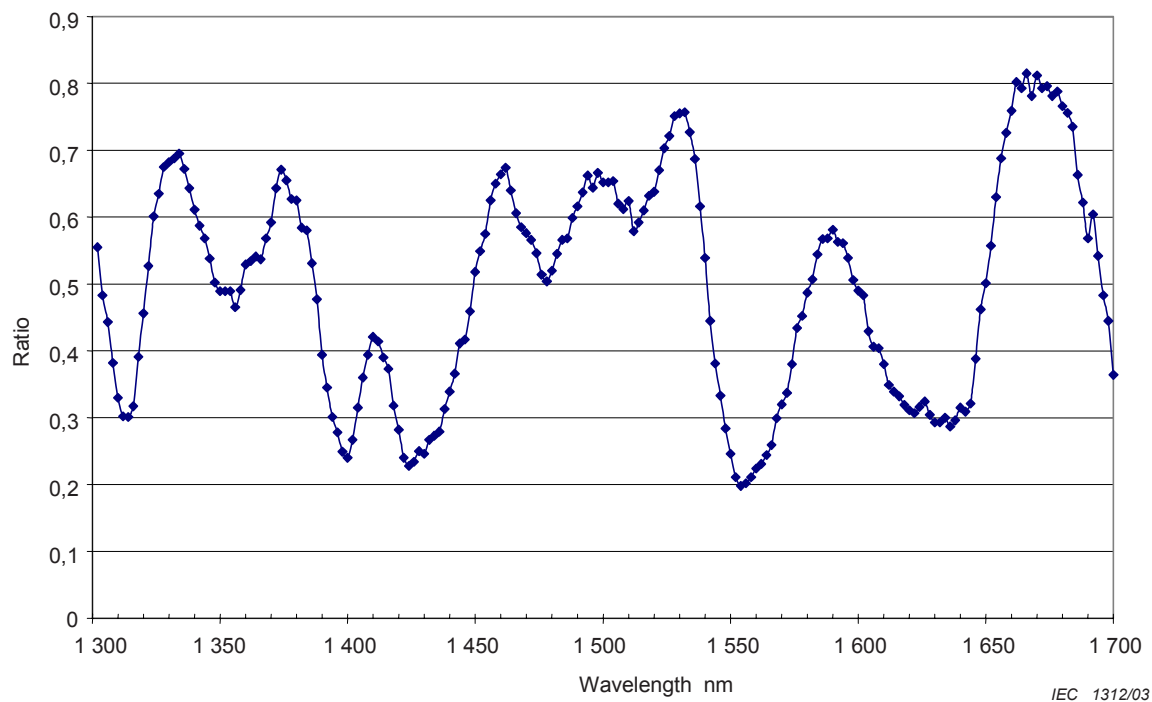


Figure A.2b – Fixed analyzer results for a randomly mode-coupled sample

Figure A.2 – Examples of the R-function for the fixed analyser method