

# TECHNICAL REPORT



Application guidelines for nonlinear coefficient measuring methods

IECNORM.COM : Click to view the full PDF of IEC TR 62285:2023



## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2023 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, 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 either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

### About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

### About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

#### IEC publications search - [webstore.iec.ch/advsearchform](http://webstore.iec.ch/advsearchform)

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, ...). It also gives information on projects, replaced and withdrawn publications.

#### IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

#### IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [sales@iec.ch](mailto:sales@iec.ch).

#### IEC Products & Services Portal - [products.iec.ch](http://products.iec.ch)

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

#### Electropedia - [www.electropedia.org](http://www.electropedia.org)

The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IECNORM.COM : Click to view the full PDF IEC 62255-2023

# TECHNICAL REPORT



---

**Application guidelines for nonlinear coefficient measuring methods**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

ICS 33.180.10

ISBN 978-2-8322-7739-3

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

## CONTENTS

|                                                                 |    |
|-----------------------------------------------------------------|----|
| FOREWORD.....                                                   | 4  |
| 1 Scope.....                                                    | 6  |
| 2 Normative references .....                                    | 6  |
| 3 Terms and definitions .....                                   | 6  |
| 4 Abbreviated terms and symbols .....                           | 6  |
| 4.1 Abbreviated terms.....                                      | 6  |
| 4.2 Symbols.....                                                | 7  |
| 5 Background and overview of methods.....                       | 7  |
| 6 Apparatus.....                                                | 8  |
| 6.1 General.....                                                | 8  |
| 6.2 Light source .....                                          | 8  |
| 6.3 Input optics .....                                          | 8  |
| 6.4 Input positioner .....                                      | 8  |
| 6.5 Cladding mode stripper .....                                | 8  |
| 6.6 Output positioner .....                                     | 8  |
| 6.7 Output optics .....                                         | 8  |
| 6.8 Computer.....                                               | 9  |
| 7 Samples and specimens .....                                   | 9  |
| 8 Procedure.....                                                | 9  |
| 9 Calculations of interpretation of results.....                | 9  |
| 10 Results .....                                                | 10 |
| 10.1 Information available with each measurement.....           | 10 |
| 10.2 Information available upon request .....                   | 10 |
| Annex A (normative) Continuous wave dual-frequency method ..... | 12 |
| A.1 General.....                                                | 12 |
| A.2 Apparatus .....                                             | 12 |
| A.2.1 Layout of apparatus .....                                 | 12 |
| A.2.2 Sources.....                                              | 13 |
| A.2.3 Optical signal conditioning.....                          | 13 |
| A.2.4 Power meters .....                                        | 14 |
| A.2.5 Optical spectrum analyser .....                           | 14 |
| A.3 Samples and specimens .....                                 | 14 |
| A.4 Procedure .....                                             | 15 |
| A.4.1 General .....                                             | 15 |
| A.4.2 Calibration .....                                         | 15 |
| A.4.3 Operation .....                                           | 15 |
| A.5 Calculations .....                                          | 16 |
| A.5.1 Calculate phase values.....                               | 16 |
| A.5.2 Confirm assumptions .....                                 | 16 |
| A.5.3 Complete the calculation .....                            | 16 |
| Annex B (normative) Pulsed single-frequency method (PM) .....   | 18 |
| B.1 General.....                                                | 18 |
| B.2 Apparatus .....                                             | 18 |
| B.2.1 Layout of apparatus .....                                 | 18 |
| B.2.2 Source.....                                               | 18 |
| B.2.3 Optical signal conditioning.....                          | 18 |

|                                                                                                                                           |                                      |    |
|-------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|----|
| B.2.4                                                                                                                                     | Power meters .....                   | 19 |
| B.2.5                                                                                                                                     | Optical pulsewidth measurement ..... | 19 |
| B.2.6                                                                                                                                     | Optical spectrum analyser .....      | 19 |
| B.3                                                                                                                                       | Samples and specimens .....          | 19 |
| B.4                                                                                                                                       | Procedure .....                      | 20 |
| B.5                                                                                                                                       | Calculations .....                   | 20 |
| B.5.1                                                                                                                                     | Peak power .....                     | 20 |
| B.5.2                                                                                                                                     | Phase shift .....                    | 20 |
| B.5.3                                                                                                                                     | Complete the calculations.....       | 20 |
| Annex C (informative) Guidance on the selection of fibre test length, power and difference in optical wavelength when using method A..... |                                      | 22 |
| Bibliography.....                                                                                                                         |                                      | 23 |
| Figure A.1 – Output spectral characteristics.....                                                                                         |                                      | 12 |
| Figure A.2 – Apparatus for method A .....                                                                                                 |                                      | 13 |
| Figure A.3 – Relationship of phase to intensity ratio.....                                                                                |                                      | 16 |
| Figure A.4 – Relationship of phase to power .....                                                                                         |                                      | 17 |
| Figure B.1 – Test set-up for method B .....                                                                                               |                                      | 18 |
| Figure B.2 – Output spectra .....                                                                                                         |                                      | 19 |
| Figure B.3 – Phase vs. peak input power for method B.....                                                                                 |                                      | 21 |
| Table C.1 – Fibre characteristics for method A (representative values).....                                                               |                                      | 22 |

IECNORM.COM : Click to view the full PDF of IEC TR 62285:2023

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**APPLICATION GUIDELINES FOR NONLINEAR  
COEFFICIENT MEASURING METHODS****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.

IEC TR 62285 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics. It is a Technical Report.

This third edition cancels and replaces the second edition published in 2005. It constitutes a technical revision.

This edition includes the following signification technical changes with respect to the previous revision:

- a) change fibre type of pigtail to B-652.D fibre or fibre of same type with the fibre under test;
- b) modifications on Figure A.1 and Formulas (A.3), (A.4);
- c) add example values and recommended method A test conditions for B-G.654.E fibre, update Table C.1.

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

| Draft        | Report on voting |
|--------------|------------------|
| 86A/2190/DTR | 86A/2325/RVDTR   |

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/publications](http://www.iec.ch/publications).

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under [webstore.iec.ch](http://webstore.iec.ch) in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

**IMPORTANT – The "colour inside" logo on the cover page of this document 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.**

## APPLICATION GUIDELINES FOR NONLINEAR COEFFICIENT MEASURING METHODS

### 1 Scope

This document provides guidelines for uniform measurements of the nonlinear coefficient of class B single-mode fibres (see IEC 60793-2-50) in the 1 550 nm region.

Measurements of the nonlinear coefficient are used to characterise specific single-mode fibre designs for the purpose of system design relative to power levels and distortion or noise effects derived from the nonlinear optical behaviour.

### 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 (all parts), *Optical fibres – Part 1: Measurement methods and test procedures*

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-2 and IEC 60793-1 (all parts) apply.

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>

### 4 Abbreviated terms and symbols

#### 4.1 Abbreviated terms

|      |                                 |
|------|---------------------------------|
| ASE  | amplified spontaneous emission  |
| BPF  | bandpass filter                 |
| CW   | continuous wave                 |
| EDFA | erbium doped fibre amplifier    |
| FWM  | four-wave mixing                |
| OSA  | optical spectrum analyser       |
| SPM  | self-phase modulation           |
| SBS  | stimulated Brillouin scattering |
| VA   | variable attenuator             |
| XPM  | cross-phase modulation          |

## 4.2 Symbols

|                      |                                                        |
|----------------------|--------------------------------------------------------|
| $A_{\text{eff}}$     | effective area                                         |
| $D$                  | chromatic dispersion coefficient                       |
| $I$                  | intensity                                              |
| $k$                  | slope                                                  |
| $L$                  | specimen length                                        |
| $J_n()$              | Bessel function of the first kind of integer order $n$ |
| $L_{\text{eff}}$     | effective length                                       |
| $nLc$                | non-linear coefficient                                 |
| $n_2$                | Kerr nonlinear refractive index                        |
| $n_2/A_{\text{eff}}$ | non-linear coefficient                                 |
| $P$                  | input power                                            |
| $P_{\text{peak}}$    | peak input power                                       |
| $R$                  | ratio                                                  |
| $\nu$                | optical frequency                                      |
| $\alpha$             | attenuation coefficient (Np/m)                         |
| $\alpha_{\text{dB}}$ | attenuation coefficient (dB/km)                        |
| $\varphi$            | non-linear phase shift                                 |
| $\lambda$            | wavelength                                             |
| $\omega$             | angular optical frequency                              |

## 5 Background and overview of methods

The nonlinear coefficient ( $nLc$ ) is the ratio of the Kerr nonlinear refractive index  $n_2$  to the effective area  $A_{\text{eff}}$  [1]<sup>1</sup>, expressed as:

$$nLc = \frac{n_2}{A_{\text{eff}}} \quad (1)$$

The nonlinear coefficient is related to the following nonlinear optical distortion effects as a combined parameter:

- self-phase modulation (SPM);
- cross-phase modulation (XPM);
- four-wave mixing (FWM).

Other fibre attributes, such as chromatic dispersion and polarisation mode dispersion, also influence the transmission.

Two methods are given, with details specific to each in normative annexes. They are:

- Method A Continuous wave dual-frequency;
- Method B Pulsed single-frequency.

<sup>1</sup> The numbers in square brackets refer to the Bibliography.

Both methods require injecting very high power (5 dBm or more) into the fibre, measurement of this power (absolute) and measurement of the output spectrum (which is modified by nonlinear effects). Both methods use calculations that combine these measured results with those derived from other measurements such as attenuation (see IEC 60793-1-40) and chromatic dispersion (see IEC 60793-1-42). Both methods have limitations on the length of fibre that can be measured – in relationship with the chromatic dispersion at the wavelength being measured.

Method A [1] requires injecting the light of two wavelengths into the fibre. The light of both wavelengths is constant at various power levels. At higher power, the lights beat due to the nonlinear effect and produce an output spectrum that is spread. The relationship of the power level to a particular metric of spectrum spreading is used to calculate the nonlinear coefficient.

Method B [3], [4] requires injecting pulsed light at a single wavelength. The pulses would be of duration substantially less than 1 ns and the input peak power of these pulses would be measured and related to the nonlinear spreading of the output spectrum.

## **6 Apparatus**

### **6.1 General**

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

### **6.2 Light source**

See Annex A and Annex B for detailed characteristics of the light sources.

### **6.3 Input optics**

The input optics can include one or more lasers, polarisation controllers, couplers, polarisers, amplifiers, bandpass filters, variable attenuators and power meters. Oscilloscopes may be needed for method B. See Annex A and Annex B for specific details.

### **6.4 Input positioner**

Provide means of positioning the input end of the specimen to the input optics. Typically, this connection is with a fusion splice to a short (1 m) pigtail of type B-652.D fibre or fibre of same type with the fibre under test.

### **6.5 Cladding mode stripper**

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

### **6.6 Output positioner**

Provide a suitable means for aligning the fibre to the output optics. Typically, this connection is with a fusion splice to a pigtail of type B-652.D fibre or fibre of same type with the fibre under test.

### **6.7 Output optics**

The output optics include a power meter and optical spectrum analyser (OSA). An oscilloscope may be required for method B. See Annex A and Annex B for details.

## 6.8 Computer

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

## 7 Samples and specimens

A specimen is a known length of single-mode optical fibre (see IEC 60793-2-50). The sample and pigtails would be fixed in position at a nominally constant temperature throughout the measurement. Standard atmospheric conditions (see IEC 60793-1-1) would be employed, unless otherwise specified.

End faces for the input and output ends of the test sample would be prepared as appropriate to obtain low loss fusion splices.

The measurement method is limited with regard to the measurable length because of chromatic dispersion. For this reason, the specimen is normally cut from a longer piece of fibre that has been characterised for attenuation coefficient  $\alpha_{dB}$  and chromatic dispersion  $D$  at the wavelength of interest (1 550 nm). The length of the fibre after being cut-back is referred to as  $L$ .

Annex C provides guidance on the optimum selection of length for different chromatic dispersion coefficient values.

The fibre may be deployed on a common shipping spool.

## 8 Procedure

The test procedure is as follows:

- deploy the fibre or cable and prepare the ends;
- attach the ends to the input and output optics;
- engage the computer to complete the scans and measurements found in Annex A and Annex B for the measurement method;
- complete documentation.

## 9 Calculations of interpretation of results

The fundamental relationships for the two methods are nearly the same, so they are presented here for comparison.

Method A 
$$\varphi = \frac{2\pi}{\lambda} \frac{n_2}{A_{\text{eff}}} L_{\text{eff}} 2P \quad (2)$$

Method B 
$$\varphi = \frac{2\pi}{\lambda} \frac{n_2}{A_{\text{eff}}} L_{\text{eff}} P_{\text{peak}} \quad (3)$$

where

- $\varphi$  is the nonlinear phase shift (rad);
- $\lambda$  is the wavelength (m) (centre of two wavelengths for method A);
- $L_{\text{eff}}$  is the effective length (m);
- $P$  is the input power (W) (either wavelength for method A);

$P_{\text{peak}}$  is the peak input power (W) (method B).

If peak input power of method B were equal to twice the input power of method A, the two equations would be identical.

The effective length is defined as the following:

$$L_{\text{eff}} = \frac{1 - \exp(-\alpha L)}{\alpha} \quad (4)$$

where

$L$  is the length (m);

$\alpha$  is the attenuation coefficient (Np/m).

$$\alpha = \frac{\alpha_{\text{dB}}}{4,343} \times 10^{-3} \quad (5)$$

where

$\alpha_{\text{dB}}$  is the attenuation coefficient (dB/km).

The two methods differ in how the phase shift is determined as a function of input power. Once the relationship between phase shift and power has been determined, the inverse of Formula (2) or (3), to obtain the nonlinear coefficient, is easily computed with the other known quantities.

Provided as examples of the result, the nonlinear coefficient has been measured to be

- approximately  $2,9 \times 10^{-10} \text{ W}^{-1}$  for type B-652 fibre;
- approximately  $2,0 \times 10^{-10} \text{ W}^{-1}$  for type B-654.E fibres with  $A_{\text{eff}}$  around  $110 \mu\text{m}^2$ ;
- and approximately  $1,7 \times 10^{-10} \text{ W}^{-1}$  to  $1,8 \times 10^{-10} \text{ W}^{-1}$  for type B-654.E fibres with  $A_{\text{eff}}$  around  $130 \mu\text{m}^2$ [5].

## 10 Results

### 10.1 Information available with each measurement

The following information are reported with each measurement:

- date and title of measurement;
- specimen identification;
- nonlinear coefficient:  $n_2/A_{\text{eff}}$  ( $\text{W}^{-1}$ );
- fibre dispersion coefficient ( $\text{ps}/(\text{nm} \cdot \text{km})$ );
- fibre attenuation coefficient ( $\text{dB}/\text{km}$ );
- fibre length (m).

### 10.2 Information available upon request

The following information are available upon request:

- measurement method used;
- description of the equipment set-up;
- wavelength(s) of the source;
- pulse duration (method B only);
- typical input power levels;

- fibre effective area:  $A_{\text{eff}}$  ( $\mu\text{m}^2$ ).

IECNORM.COM : Click to view the full PDF of IEC TR 62285:2023

## Annex A (normative)

### Continuous wave dual-frequency method

#### A.1 General

Annex A contains requirements specific to method A. The principle of the method is to inject two continuous wave (CW) optical frequencies,  $\omega_a$  and  $\omega_b$ , into the specimen at various power levels. The two frequencies beat due to nonlinear effects and create sidebands at frequencies  $(2\omega_a - \omega_b)$  and  $(2\omega_b - \omega_a)$  (see Figure A.1). The relative intensity of the sidebands  $I_1$  to the intensity of the main bands  $I_0$  is related to both the phase shift and power injected.

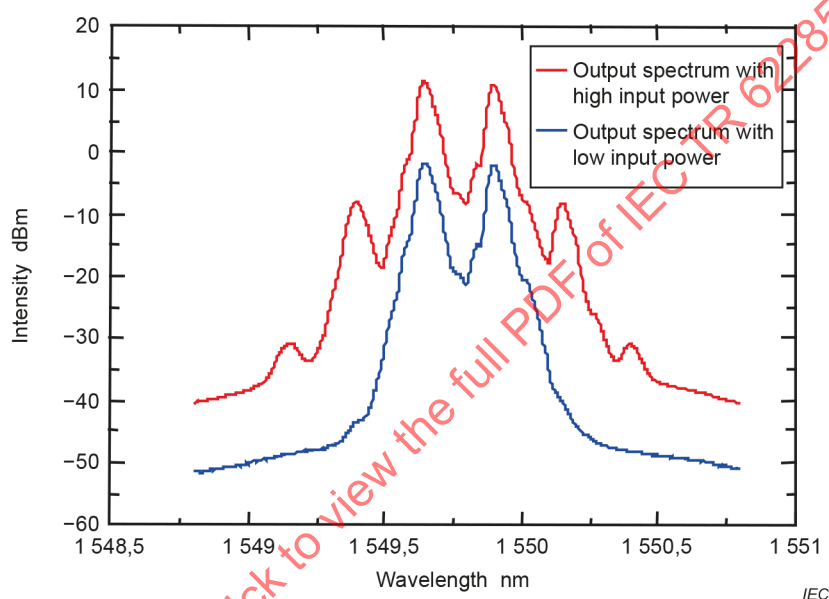


Figure A.1 – Output spectral characteristics

#### A.2 Apparatus

##### A.2.1 Layout of apparatus

Figure A.2 shows a typical arrangement of the test apparatus.

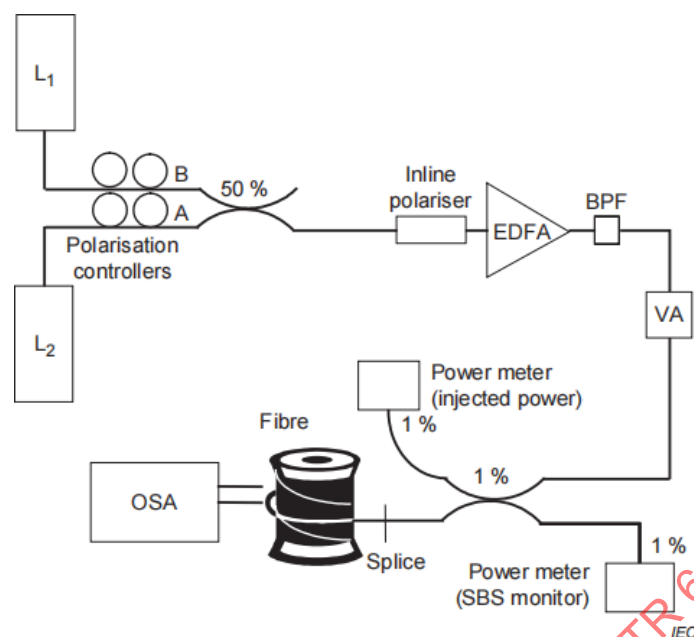


Figure A.2 – Apparatus for method A

### A.2.2 Sources

Two laser sources,  $L_1$  and  $L_2$  in Figure A.2, are operated in the CW mode at optical frequencies,  $\omega_a$  and  $\omega_b$ , both within the frequency window corresponding to optical wavelength  $(1\,550 \pm 10)$  nm. The frequency difference,  $\Delta\omega_0 = \omega_a - \omega_b$ , corresponds to a wavelength difference  $\Delta\lambda_0$ , which places an upper limit on the spectral width of each of the sources: the source spectral widths would not exceed  $0,1 \times \Delta\lambda_0$ . The lower limit on the spectral width is set by the need to avoid stimulated Brillouin scattering (SBS) (see A.2.4).

The wavelength difference lower limit is set by the ability of the OSA to resolve the sidebands, and the upper limit is set by the chromatic dispersion of the specimen (see Clause A.3). A typical separation could be 0,035 THz (0,28 nm), but others are feasible depending on the other details of the set-up.

The source powers would be within  $\pm 0,2$  dB of one another. The source power is further conditioned by polarisers, optically amplified, and variably attenuated. The minimum injected power is set by the limit at which the sidebands are induced. The maximum is set by the need to avoid SBS.

### A.2.3 Optical signal conditioning

Polarisation controllers, couplers, amplifiers, variable optical attenuators and polarisers would be used in combination so that the lights injected into the specimen are in the same polarisation state and within  $\pm 0,2$  dB of one another.

In the example of Figure A.2, the erbium doped fibre amplifier (EDFA) is used to boost the power to levels sufficient to induce nonlinear effects. This generates amplified spontaneous emission (ASE) which would be removed by either:

- a bandpass filter (BPF) as shown in Figure A.2, or
- a subtraction of the baseline as determined in the region of the sidebands of the OSA.

NOTE An accurate baseline subtraction can be obtained by measuring the phase response of the measurement system without a test fibre in place.

#### A.2.4 Power meters

Figure A.2 shows two power meters: one to monitor forward propagation of light injected into the specimen and the other to monitor back-reflected light that could be induced by SBS – to ensure that it remains in the spontaneous, and not the stimulated regime.

Power meters would be linear and accurate to within  $\pm 3\%$  for the levels used in the test (see IEC 61315 for calibration details).

The power detected by the forward power meter can be calibrated with regard to the power injected into the specimen by cutting the specimen immediately after the splice and measuring the output power at this point.

NOTE 1 The output power emitted from the cut-back specimen will be reduced by Fresnel reflection of approximately 3 % – which will be taken into account. The required power values are those that are launched into the specimen without the cut.

NOTE 2 Some set-ups feature a third power meter to confirm the splice loss at least one power level following the primary test measurements. Alternatively, measurement of the output of the full specimen, in conjunction with fibre attenuation coefficient and length, can be used to confirm the splice loss.

For a source whose spectral width is much less than the 0,038 THz spontaneous Brillouin linewidth, the threshold for SBS is approximately 20 mW. Increasing the source spectral width to 100 MHz raises this threshold to approximately 100 mW. Other strategies for reducing SBS include:

- modulating the sources at 100 MHz to 1 GHz to increase the effective width;
- reducing the maximum power level;
- reducing the fibre length.

#### A.2.5 Optical spectrum analyser

The optical spectrum emerging from the specimen is measured with an OSA. The resolution would be sufficient to clearly resolve the sidebands.

### A.3 Samples and specimens

The fibre chromatic dispersion coefficient  $D$  (ps/(nm·km)) should be known at the test wavelength before the test is conducted. The length of the specimen may be reduced so the following restriction is satisfied:

$$2\pi \times c \left( \frac{\Delta\omega_0}{\omega_0} \right)^2 \varphi_{\max} |D| L \ll 1 \quad (\text{A.1})$$

where

- $c$  is the speed of light in vacuum ( $2,997\,924\,58 \times 10^8$  m/s);
- $\varphi_{\max}$  is the maximum anticipated phase shift (rad);
- $\Delta\omega_0$  is the difference in optical angular frequencies (rad/s);
- $\omega_0$  is the average of the two optical angular frequencies (rad/s);
- $|D|$  is the absolute value of dispersion coefficient (s/(m·km));
- $L$  is the specimen length (km).

Example:

$$\begin{aligned}\lambda_a &= 1\,550,00 \text{ nm} \\ \lambda_b &= 1\,550,28 \text{ nm} \\ D &= 17,0 \text{ ps}/(\text{nm}\cdot\text{km}) = 0,017 \text{ s}/(\text{m}\cdot\text{km}) \\ L &= 0,5 \text{ km} \\ \varphi_{\max} &= 0,3 \text{ rad}\end{aligned}$$

Formula (A.1) reduces to:

$$2\pi c \left[ 1\,550,14 \left( \frac{1}{1\,550,00} - \frac{1}{1\,550,28} \right) \right]^2 \times 0,3 \times 0,017 \times 0,5 = 0,157 \quad (\text{A.2})$$

Annex C gives guidance on the selection of values to use for specimen test length, power, and wavelength difference (see Table C.1).

## A.4 Procedure

### A.4.1 General

The procedure requires stepping through a series of power levels. For each power level, the power injected into the specimen is measured or calculated and the ratio of the intensity of the sideband to the main band is measured on the OSA.

### A.4.2 Calibration

Attach a calibrated power meter to the output of the source end of the system. Cycle through the desired power levels and at each measure the power with the forward power meter and with the calibration power meter. Remove the effect of Fresnel reflection on the light emitted from the system on the detected output power. The relationship between the measured powers would be used to determine the power launched into the specimen based on the light measured by the forward power meter on normal measurements.

### A.4.3 Operation

Attach the specimen to both the source and receive ends of the system with fusion splices.

Cycle through the power levels – indexed with  $i$ . For each:

- record the measured power levels and calculate the power injected into the specimen,  $P_i$ ;
- complete the OSA scan of the output spectrum;
- if necessary, subtract the amplifier induced ASE noise from the OSA data;
- determine the intensity of the main bands,  $I_0$ , and sidebands,  $I_1$ . See Figure A.1;
- determine the ratio of the sidebands to main bands as  $R_i = I_1/I_0$ ;
- confirm the absence of SBS.

Disconnect the specimen and take any power measurements that may be needed to confirm the splice loss.

Complete any adjustments to the input power values that may be done with output power measurements or post disconnection measurements.

## A.5 Calculations

### A.5.1 Calculate phase values

For each power level, calculate the phase shift  $\varphi_i$  by inverting the following ratio of Bessel functions:

$$R_i = \frac{J_1^2(\varphi_i / 2) + J_2^2(\varphi_i / 2)}{J_0^2(\varphi_i / 2) + J_1^2(\varphi_i / 2)} \quad (\text{A.3})$$

This inversion can be done in various ways, one of which is to:

- calculate the  $R$  intensity ratio for each of a range of phase values using Equation A.3;
- plot phase versus  $R$  (see Figure A.3);
- characterise the relationship across the range of phase values that are anticipated.

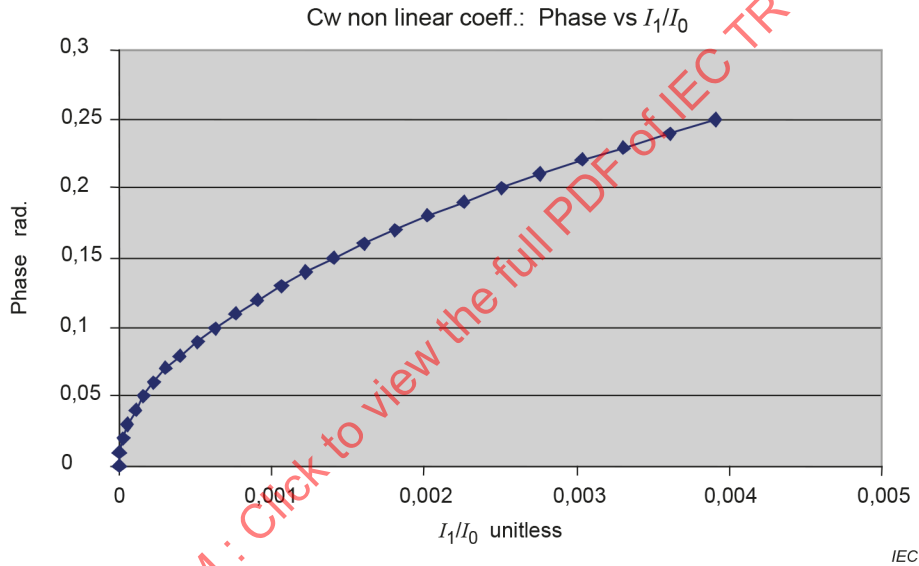


Figure A.3 – Relationship of phase to intensity ratio

### A.5.2 Confirm assumptions

Confirm that the range of phase conforms with Formula (A.1). If this is not confirmed, either eliminate the data outside the limit or repeat the measurement with a different length of fibre.

### A.5.3 Complete the calculation

Form a plot of phase (rad) vs. power (W) similar to that shown in Figure A.4 and perform a linear regression to obtain the intercept and slope  $k$  of the fitted data.

The nonlinear coefficient ( $\text{W}^{-1}$ ) is computed with slope  $k$  of the linear regression as:

$$\frac{n_2}{A_{\text{eff}}} = \frac{k \cdot \lambda_0}{4\pi L_{\text{eff}}} \quad (\text{A.4})$$

where

$k$  is the fitted regression slope (rad/W);

$\lambda_0$  is the average of input wavelengths (m);

$L_{\text{eff}}$  is the effective length (m) [see Clause 9].

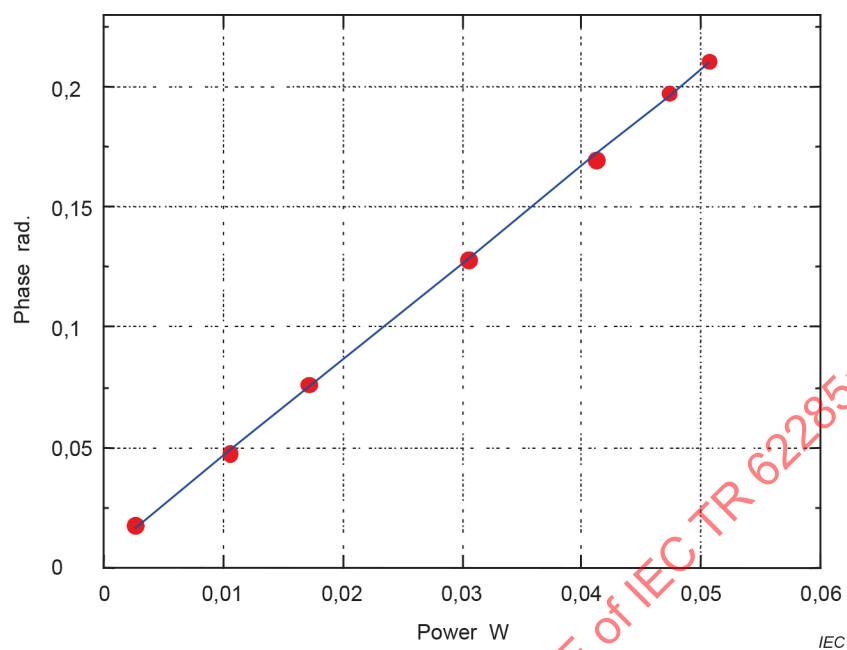


Figure A.4 – Relationship of phase to power

## Annex B (normative)

### Pulsed single-frequency method (PM)

#### B.1 General

Annex B contains requirements specific to method B, pulsed single-frequency method. The principle of the method is to launch a pulsed, narrow spectral width light that is at a power sufficient to induce self-phase modulation at a given level. The peak-input power at this level is used to calculate the nonlinear coefficient.

#### B.2 Apparatus

##### B.2.1 Layout of apparatus

Figure B.1 shows a sample layout of the apparatus, along with some of the options.

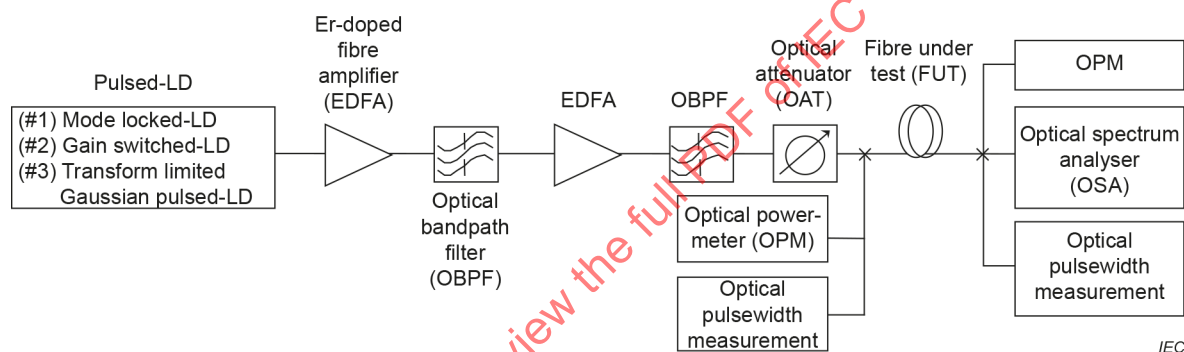


Figure B.1 – Test set-up for method B

##### B.2.2 Source

Use a transform limited Gaussian optical source with a stable wavelength (no mode hopping) such as:

- mode locked laser diode;
- gain switched laser diode;
- transform limited Gaussian pulsed laser diode.

To avoid electrostriction effects, the pulse width  $\Delta\tau$  (ps) would be less than 1 ns. Pulse widths in the range of 20 ps to 100 ps are recommended. For such pulses, a repetition rate of around 2 GHz is used.

The source would be within  $(1\,550 \pm 10)$  nm. The spectral width  $\Delta\nu$  (THz) requirement of the light injected into the specimen, which can also be modified with a BPF, is interactive with the pulse width. For the transform limited Gaussian case, the product,  $\Delta\tau \times \Delta\nu$ , would be approximately 0,5.

##### B.2.3 Optical signal conditioning

The light is amplified to levels needed to induce significant nonlinear effects with one or more amplifiers and band pass filters to remove ASE.

A variable optical attenuator is used to fine tune the input power to obtain the optimum spreading of the output spectrum as viewed on the OSA.

### B.2.4 Power meters

Power meters would be linear and accurate to within  $\pm 3\%$  for the levels used in the test (see IEC 61315 for calibration details).

The power meter at the source end of the system is used to determine the input power after the optimum power has been identified. This is done by cutting the specimen off the system and completing the measurement. This value, in conjunction with the pulse data, is used to calculate the peak-input power.

The power meter at the receive end of the system is used to evaluate the transmitted power to confirm proper set-up and to confirm that no SBS is occurring.

### B.2.5 Optical pulsewidth measurement

This involves a combination of detector and oscilloscope.

Both units are used in conjunction with the power meter measurements to determine the peak-input power of the pulses.

### B.2.6 Optical spectrum analyser

The optical spectrum emerging from the specimen is measured with an OSA. The resolution would be sufficient to clearly resolve the sidebands which are induced by nonlinear effects. See Figure B.2.

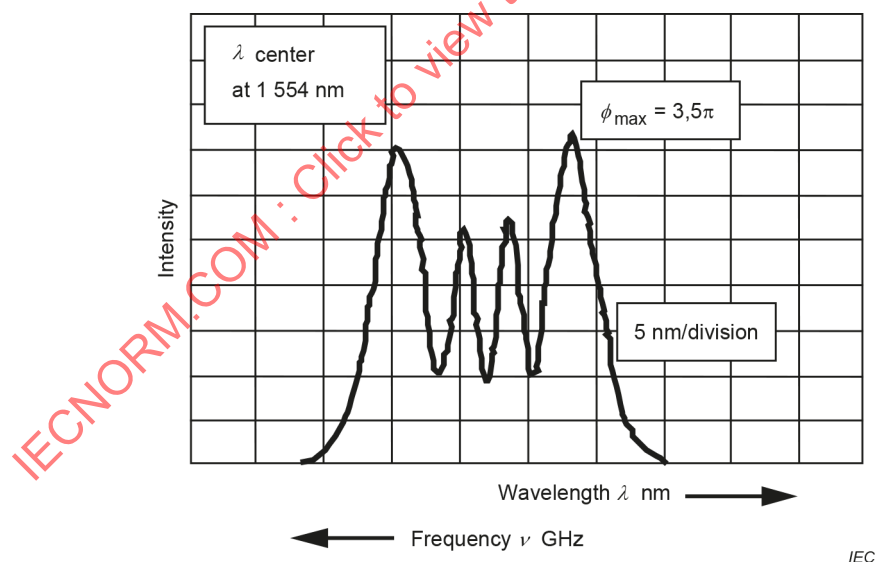


Figure B.2 – Output spectra

## B.3 Samples and specimens

The combination of chromatic dispersion coefficient  $D$  (ps/(nm·km)), value and sign, at the test wavelength and effective area, are interactive with regard to the length  $L$  (km) of the specimen that can be tested.

The limiting condition is expressed with the product of dispersion coefficient and length,  $D \times L$  (ps/nm). If this product is not suitable, the fibre would be cut to a length that is suitable.

For specimens with higher effective area and positive dispersion coefficient, (types B-652, B-654, and some category B-655 fibres),  $D \times L$  would be less than 8,0 ps/nm.

For specimens with lower effective area and positive dispersion coefficient (category B-653 and some category B-655 fibres),  $D \times L$  would be less than 2,0 ps/nm.

For fibres with significant negative dispersion, such as those used for dispersion accommodation, pulse compression can alter the results. For these fibres, the pulse compression (ps) from the transform limit is calculated using  $D \times L$ , the pulse width, and the spectral width.

If the pulse compression is less than 15 ps, the length is suitable. If the pulse compression is larger, either the length would be decreased or the pulse width would be increased (but not over approximately 100 ps).

## B.4 Procedure

The specimen is connected to the source and receive ends of the system with fusion splices.

The input power is varied with the variable attenuator until a symmetric spectrum with an integer number of peaks,  $M$ , such as shown in Figure B.2, is obtained. The output power and output pulse shapes are measured at this optimal setting.

The specimen is cut at the source end on the far side of the splice and the power and pulse shape at the optimum setting is measured.

NOTE To enhance the precision of the result, the test can be applied at multiple optimal power settings to produce output spectra with different numbers of peaks as long as the variable attenuator can be restored to these settings after the specimen is cut.

## B.5 Calculations

### B.5.1 Peak power

Use the power meter values, the measured pulse shape and the repetition rate to calculate the peak input power,  $P_{\text{peak}}$  (W), at the input and output ends of the specimen.

The peak output power in combination with the fibre attenuation coefficient can be used to confirm the input power value.

### B.5.2 Phase shift

The phase shift  $\varphi$  (rad) is calculated from the number of peaks in the output spectrum,  $M$  (integer), as:

$$\varphi = \pi(M - 0,5) \quad (\text{B.1})$$

### B.5.3 Complete the calculations

If a single power setting was completed, the nonlinear coefficient ( $\text{W}^{-1}$ ) can be calculated as:

$$\frac{n_2}{A_{\text{eff}}} = \frac{\varphi \lambda}{2\pi L_{\text{eff}} P_{\text{peak}}} \quad (\text{B.2})$$

where