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TECHNICAL REPORT

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Application guidelines for nonlinear coefficient measuring methods

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Application guidelines for nonlinear coefficient measuring methods

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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APPLICATION GUIDELINES FOR NONLINEAR COEFFICIENT MEASURING METHODS

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TR 62285:2005. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

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. The main document types developed by IEC are described in greater detail at 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 in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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APPLICATION GUIDELINES FOR NONLINEAR COEFFICIENT MEASURING METHODS

1 Scope

This document provides ~~guidance~~ 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 60793-1-1, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*~~

~~IEC 60793-1-40, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*~~

~~IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*~~

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

~~IEC 61315, *Calibration of fibre optic power meters*~~

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_{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_{eff}	effective length
$n\mathrm{Lc}$	non-linear coefficient
n_2	Kerr nonlinear refractive index
n_2/A_{eff}	non-linear coefficient
P	input power
P_{peak}	peak input power
R	ratio
ν	optical frequency
α	attenuation coefficient (Np/m)
α_{dB}	attenuation coefficient (dB/km)
φ	non-linear phase shift
λ	wavelength
ω	angular optical frequency

5 Background and overview of methods

The nonlinear coefficient ($n\mathrm{Lc}$) is the ratio of the Kerr nonlinear refractive index n_2 to the effective area A_{eff} [1] [1], expressed as:

[1] The numbers in square brackets refer to the Bibliography.

$$nLc = \frac{n_2}{A_{\text{eff}}} \tag{1}$$

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.

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 ~~should~~ would be of duration substantially less than 1 ns and the input peak power of these pulses ~~should~~ 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~~, couplers~~ and power meters. ~~Bandpass filters and~~ 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 ~~light source~~ input optics. Typically, this connection is with a fusion splice to a short (1 m) pigtail of type ~~B1.1 fibre~~ 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 ~~B1.1 fibre~~ 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 ~~should~~ would be fixed in position at a nominally constant temperature throughout the measurement. Standard ~~ambient~~ atmospheric conditions (see IEC 60793-1-1) ~~should~~ would be employed, unless otherwise specified.

End faces for the input and output ends of the test sample ~~should~~ 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 α_{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:

a) deploy the fibre or cable and prepare the ends;

b) attach the ends to the input and output optics;

c) engage the computer to complete the scans and measurements found in Annex A and Annex B for the measurement method;

d) complete documentation.

9 Calculations of interpretation of results

~~Unless otherwise specified, the units are in meters, seconds, watts, and radians.~~

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

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

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

where

φ is the nonlinear phase shift (rad);

λ is the wavelength (m) (centre of two wavelengths for method A);

L_{eff} is the effective length (m);

P is the input power (W) (~~both~~ either wavelength~~s~~ for method A);

P_{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:

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

where

L is the length (m);

α is the ~~"natural"~~ attenuation coefficient (Np/m).

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

where

α_{dB} is the ~~normal~~ 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.

~~For type B1.1 fibre, the non-linear coefficient has been measured to be approximately 2,9 × 10^−10 W^−1, provided as an example of the result.~~

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

– approximately $2{,}9 \times 10^{-10}$ W^{-1} for type B-652 fibre;

– approximately $2{,}0 \times 10^{-10}$ W^{-1} for type B-654.E fibres with A_{eff} around 110 μm^2;

– and approximately $1{,}7 \times 10^{-10}$ W^{-1} to $1{,}8 \times 10^{-10}$ W^{-1} for type B-654.E fibres with A_{eff} around 130 μm^2[5].

10 Documentation Results

10.1 Information to be provided available with each measurement

The following information are reported with each measurement:

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

10.2 Information available upon request

The following information are available upon request:

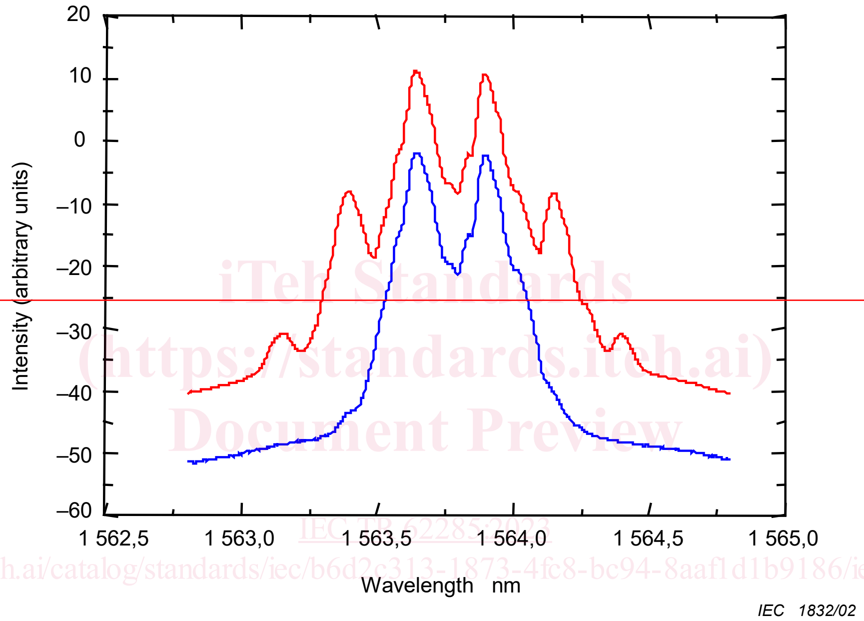
- measurement method used;
- description of the equipment set-up;
- wavelength(s) of the source;
- pulse duration (method B only);
- typical input power levels;
- fibre effective area: A_{eff} (μm^2).

Annex A
(normative)

Continuous wave dual-frequency method

A.1 ~~Introduction~~ General

Annex A contains requirements specific to method A. The principle of the method is to inject two continuous wave (CW) optical frequencies, ω_a and ω_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.



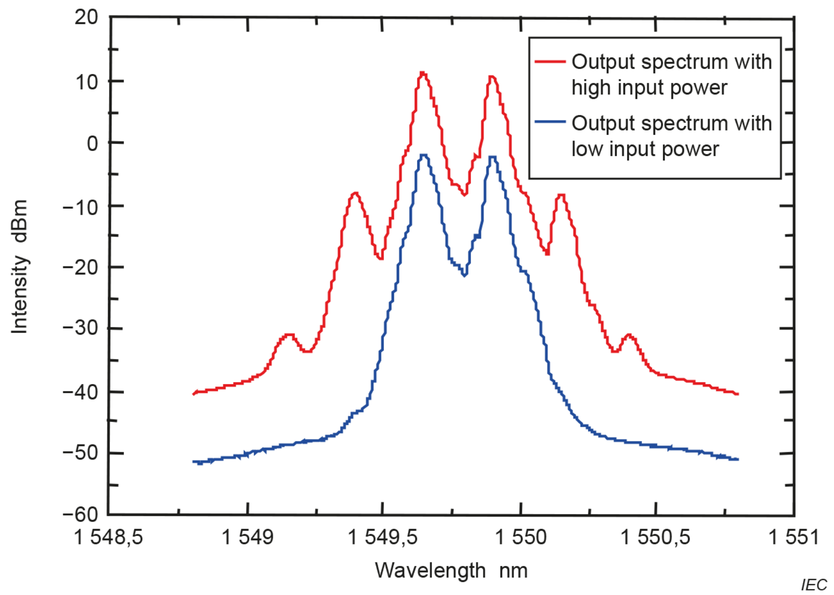


Figure A.1 – Output spectral characteristics