TECHNICAL REPORT

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Second edition
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**Single-mode optical fibres –
Raman gain efficiency measurement using continuous wave method –
Guidance**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SINGLE-MODE OPTICAL FIBRES – RAMAN GAIN EFFICIENCY MEASUREMENT USING CONTINUOUS WAVE METHOD – GUIDANCE

FOREWORD

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IEC/TR 62324, which is a technical report, has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition published in 2003. It constitutes a technical revision.

This second edition differs from the first in that in the previous edition, in the paragraph before Figure 2, there was an approximation of the relationship between wavelength and optical frequency that led to some inconsistencies in interlaboratory agreement. This approximation has been removed.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86A/1058/DTR	86A/1072/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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- withdrawn,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.

A bilingual version of this publication may be issued at a later date.

SINGLE-MODE OPTICAL FIBRES – RAMAN GAIN EFFICIENCY MEASUREMENT USING CONTINUOUS WAVE METHOD – GUIDANCE

1 Scope and object

This technical report is applicable to the Raman gain efficiency measurement of a single-mode transmission optical fibre. It is useful in assessing the fibre's performance in Raman amplified transmission systems.

This technical report describes a method that uses two unmodulated continuous waves to measure the Raman gain efficiency of a single-mode transmission optical fibre. This parameter assesses the fibre's efficiency at converting input pump power to information signal power.

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 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

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

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide*

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
effective length
L_{eff}
the fibre's effective length accounts for decreasing nonlinear effects as light attenuates along a fibre's length, and is defined as:

$$L_{\text{eff}} = \frac{1 - e^{-0{,}23\alpha L}}{0{,}23\alpha} \quad (1)$$

where α is the fibre attenuation coefficient in decibels per kilometre (dB/km), and L is the fibre length in kilometres (km).

NOTE 1 When the α in equation (1) is expressed in nepers per kilometre (Np/km), the two occurrences of 0,23 disappear, and the resultant equation is the form that typically appears in the technical literature.

NOTE 2 When 0,23αL >>1, equation (1) simplifies to give $L_{eff} \approx 1/(0,23\alpha)$, which is the length at which the power in the fibre has decreased by a factor of 1/e. As an example, L_{eff} = 17,4 km when α = 0,25 dB/km.

3.2
depolarized light
light whose electric field vector, described in a plane perpendicular to the direction of propagation, is uniformly distributed in all radial directions

NOTE 1 Rotation of a polarizer in a beam of depolarized light reduces its intensity by 50% regardless of the polarizer's angular orientation. This test, however, is not sufficient to assess whether the light is depolarized because circularly polarized light produces the same result. To guard against this possibility, a rotatable quarter wave retarder should be inserted before the polarizer. If the output intensity is constant over all independent rotations of the retarder and the polarizer, the input light can be considered depolarized.

NOTE 2 Depolarized light is also termed unpolarized or randomly polarized.

4 Overview

When a fibre carries high optical intensities, the optical power can be scattered because of interactions with mechanical vibrations in the fibre. For low power levels, the scattered power is a small fraction of the incident power. However, as the incident power increases, the scattered power increases at a faster pace, and is said to be "stimulated". There are two forms of nonlinear stimulated scattering—Brillouin and Raman.

Stimulated Brillouin Scattering (SBS) arises because of an interaction between light and mechanical vibrations that occur in the form of a sound wave travelling along the length of the fibre (an "acoustic phonon"). SBS scatters light in the reverse direction.

Stimulated Raman Scattering (SRS) is an interaction between light and the fibre's molecular vibrations as adjacent atoms vibrate in opposite directions (an "optical phonon"). Some of the energy in an optical pump wave λ_p is transferred to the molecules, thereby further increasing the amplitude of their vibrations. If the vibrational amplitudes become large, a threshold is reached at which the local index of refraction changes. These local changes then scatter light in all directions—similar to Rayleigh scattering. However, unlike Rayleigh scattering, the wavelength of the Raman scattered light λ_R is shifted to longer wavelengths by an amount that corresponds to the vibrational frequencies of the molecules. The Raman scattered light amplifies information signals λ_s. The magnitude or gain efficiency of this amplification depends on:

- pump wavelength λ_p;
- signal wavelength λ_s;
- fibre effective area A_{eff} (the larger the area, the lower the power density);
- fibre material composition (vibration frequency and amplitude depend on material);
- fibre attenuation coefficient, and
- fibre length.

The Raman gain efficiency of a fibre varies with signal wavelength when measured with a specific pump source. Consequently, Raman gain efficiency $E_R(\lambda_s)$ is measured over a range of signal wavelengths. The peak Raman gain efficiency corresponds to a Stokes downshifted frequency of about 13 THz, which equates to an upshifted wavelength of ~110 nm for a 1 450 nm pump, and ~70 nm for a 1 240 nm pump. The Full Width Half Maximum (FWHM) of the gain profile is about 7 THz (55 nm) at 1 550 nm.

NOTE The notation "C_R" is often used in the technical literature, and is variously referred to as the "Raman gain coefficient"[1], the "Raman efficiency"[2], and the "Raman gain."[3] [1)]

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1) Figures in square brackets refer to the Bibliography.

5 Method

5.1 Description

The method described in this technical report for measuring Raman gain efficiency uses unmodulated continuous waves generated by a signal source and a pump source. The signal source can be broadband (such as an LED or amplified spontaneous emission (ASE)) or narrowband (such as one or more tunable lasers). If using a broadband signal source, a tunable filter might be needed at the source's output so that short signal wavelengths do not pump longer signal wavelengths. To minimize the influence of a noisy pump or one whose output power is not completely depolarized, the measurement is made by injecting light from the signal and pump sources so that they propagate in opposite directions (counter propagation) in the fibre under test. The fibre has an effective length L_{eff}.

A pump source having wavelength λ_p injects optical power P_p into the fibre under test so as to induce stimulated Raman scattering. The pump power should be chosen to minimize ASE noise and amplified double Rayleigh backscattered signal power. Subclause 6.2 gives guidance on how to choose the pump power level and spectral width.

The pump-induced SRS in the fibre under test amplifies an input signal having wavelength λ_s, which is launched into the fibre under test in a direction opposite to that of the pump. Subclause 6.2 gives guidance on how to choose the signal power level and spectral width.

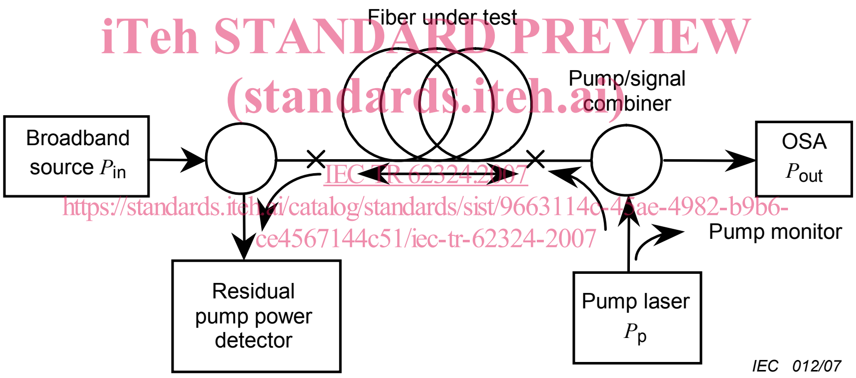

Figure 1 – Typical test set-up for measuring the Raman gain efficiency of a fibre

Figure 1 shows a typical test set-up. The output power P_{out} is measured in three configurations:

- P_1 – signal "on" and pump "off." This indicates the relative magnitude of the launched signal power diminished by the attenuation of the components. P_1 includes double Rayleigh backscattered power from the unamplified signal.
- P_2 – signal "off" and pump "on." This measures the ASE.
- P_3 – signal "on" and pump "on." This measures the Raman amplified signal, ASE, and double Rayleigh backscattered power from the amplified signal.

These three powers are measured over a range of signal wavelengths $\lambda_s > \lambda_p$. The "on/off" gain $G_{on/off}(\lambda_s)$ is then computed at each signal wavelength using:

$$G_{on/off}(\lambda_s) = \frac{P_3 - P_2}{P_1} \qquad (2)$$

where the Ps are in linear units, such as watts (W) or milliwatts (mW). The dimensionless quantity $G_{on/off}(\lambda_s)$ is used to compute the fibre's Raman gain efficiency for depolarized light: