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TECHNICAL REPORT

Optical amplifiers –
Part 1: Parameters of optical fibre amplifier components

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FOREWORD

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IEC TR 61292-1 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics. It is a Technical Report.

This third edition cancels and replaces the second edition published in 2009. This edition constitutes a technical revision.

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

a) Change of document title from "Parameters of amplifier components" to "Parameters of optical fibre amplifier components";
b) Addition of parameters for optical components used in fibre Raman amplifiers;
c) Addition of Table 1, listing various documents that specify terms and definitions for optical components used in optical fibre amplifiers;
d) Addition of Figure 2 and Figure 3, showing typical component layouts for distributed and lumped fibre Raman amplifiers;

e) Harmonization of the descriptions of optical component parameters with the definitions in other standards on optical components.

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

Draft	Report on voting
86C/1775/DTR	86C/1784/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.

A list of all parts of the IEC 61292 series, published under the general title *Optical amplifiers,* can be found on the IEC website.

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- withdrawn,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.

OPTICAL AMPLIFIERS –

Part 1: Parameters of optical fibre amplifier components

1 Scope

This part of IEC 61292, which is a Technical Report, applies to optical components of optical fibre amplifiers (OFAs). This document provides information about the most relevant parameters of these optical components, especially for erbium doped fibre amplifiers (EDFAs) and fibre Raman amplifiers (FRAs). It provides introductory information for a better understanding operation and applications of EDFAs and FRAs.

NOTE IEC TR 61292-6 provides more technical information on FRAs.

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 61291-1:2018, *Fibre amplifiers – Generic specification*

IEC TR 61931, *Fibre optic – Terminology*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61291-1, IEC TR 61931, and the following apply.

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

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

3.1.1 Parameters for active fibres

3.1.1.1
maximum input signal power
<active fibres> maximum power of the input signal above which the active fibre gets damaged, causing impossibility of normal operation for a given active fibre

3.1.1.2
insertion loss at out-of-band wavelength
<active fibres> insertion loss for a signal at the specified out-of-band wavelength(s) for a given active fibre

Note 1 to entry: IEC 61290-7-1 defines the measurement procedure of out-of-band insertion loss.

[SOURCE: IEC 61291-1:2018, 3.2.1.59, modified – Term changed from "out-of-band insertion loss", the specific use "active fibres" has been added, and Note 1 to entry has been added.]

3.1.1.3
polarization-dependent gain
<active fibres> maximum variation of the active fibre gain due to a variation of the state of polarization of the input signal

[SOURCE: IEC 61291-1:2018, 3.2.1.12, modified – The notes to entry have been deleted and the specific use has been added.]

3.1.1.4
polarization mode dispersion
PMD
<active fibres> maximum PMD at the signal wavelength which is launched into the input port of the active fibre and exits from signal output port of the active fibre

Note 1 to entry: PMD is expressed in ps.

Note 2 to entry: When an optical signal travels through an optical fibre, optical component or subsystem (e.g. an OFA), the change in the shape and width of the pulse due to the differential group delay (DGD) [the propagation delay difference between the two principal states of polarization (PSPs)] and to the waveform distortion for each PSP, is due to PMD. PMD, together with polarization dependent loss (PDL) and polarization dependent gain (PDG), can introduce large waveform distortions leading to an unacceptable bit error ratio increase.

Note 3 to entry: The level of PMD can depend on temperature and operating conditions.

3.1.1.5
mode field diameter
MFD
2*w*
<active fibres> for a given active fibre, a measure of the transverse width of the guided mode of a single-mode fibre, given from the far-field intensity distribution $F(q)$ by:

$$2w = \frac{2}{\pi}\left[\frac{2\int_0^{\infty} q^3 F(q)^2 \, dq}{\int_0^{\infty} q F(q)^2 \, dq}\right]^{-\frac{1}{2}}$$

where

$$q = \sin(\theta) / \lambda$$

Note 1 to entry: For Gaussian distributions in single-mode fibres the mode field diameter is the diameter at the 1/e points of the optical field amplitude distribution, which is also equivalent to the 1/e^2 points of the optical power distribution.

Note 2 to entry: Sometimes the MFD of active fibres is smaller than that of conventional single-mode fibres in order to concentrate the pump power with the signal optical power.

[SOURCE: IEC TR 61931:1998, 2.4.31, modified – Specific use added and Note 2 to entry has been added.]

3.1.1.6
cut-off wavelength
<active fibres> for a given active fibre, the free space wavelength corresponding to the cut-off normalized frequency of a mode

[SOURCE: IEC TR 61931:1998, 2.4.38, modified – Specific use has been added.]

3.1.1.7
cladding diameter
<active fibres> for a given active fibre, the diameter of the circle defining the cladding centre

[SOURCE: IEC TR 61931, 2.3.39]

3.1.1.8
cladding non-circularity
<active fibres> for a given active fibre, the difference between the diameters of the two circles defined by the cladding tolerance field divided by the cladding diameter

[SOURCE: IEC TR 61931:1998, 2.3.51, modified – Specific use has been added.]

3.1.1.9
mode field concentricity error
<active fibres> for a given active fibre, the distance between the mode field centre and the cladding centre

[SOURCE: IEC TR 61931:1998, 2.4.34, modified – Specific use has been added.]

3.1.1.10
composition
<active fibres> composition of the active fibre, intended as the host glass composition as well as the dopant element and its concentration

3.1.1.11
length
<active fibres> length of the active fibre

Note 1 to entry: Changing fibre length can optimize gain characteristics of EDFA.

3.1.1.12
dopant distribution
<active fibres> concentration of dopant rare-earth ions in the active fibre as a function of the fibre radial coordinate

3.1.1.13
slope efficiency
<active fibres> for a given active fibre, the slope of the laser output versus pump power curve under specified operating conditions

Note 1 to entry: IEC TR 63309 defines the measurement procedure of slope efficiency.

3.1.1.14
saturation pump power
<active fibres> for a given active fibre, the minimum pump power above which the small-signal gain shows no further increase

3.1.1.15
threshold pump power
<active fibres> minimum pump power necessary to reach a small-signal gain equal to 1 in a given active fibre when the fibre length is short enough so that the pump optical power remains constant along the fibre

Note 1 to entry: IEC TR 63309 defines the measurement procedure of threshold pump power.

3.1.2 Parameters for pump lasers

3.1.2.1
pumping wavelength
<pump lasers> centroidal or peak wavelength of the emission spectrum of the pump laser

Note 1 to entry: In erbium-doped fibre amplifiers (EDFAs), pumping wavelengths of 980 nm and 1 480 nm are commonly used. In fibre Raman amplifier (FRAs), the pumping wavelength depends on the wavelength of the signal light. In this case, the frequency of the pump laser should be about 13 THz higher than that of the signal light.

Note 2 to entry: Centroidal wavelength is defined in IEC 61280-1-3.

Note 3 to entry: For multi-longitudinal-mode laser diodes (LD), centroidal wavelength is often used. For single-longitudinal-mode LD, peak wavelength is often used.

Note 4 to entry: For 980 nm LD, a wavelength stabilizer by FBG is sometimes used to the output pigtail of the LD.

3.1.2.2
pumping scheme
<pump lasers> set-up of the OFA characterized by the direction of pump optical power propagation with respect to signal direction

Note 1 to entry: Usually, three schemes are used: co-propagating, where the pump and the signal propagate through the active fibre in the same direction; counter-propagating, where the signal and the pump propagate through the active fibre in opposite directions; bi-directional, where two pumps propagate simultaneously through the active fibre in both directions. Regarding pumping schemes other than pump direction, a polarization combining scheme and a wavelength combining scheme are considered in the detailed design to increase pump power. However, a single laser diode pump scheme is described as a classic example in this technical report.

Note 2 to entry: IEC TR 61292-3 describes the pumping method.

3.1.2.3
pumping power
<pump lasers> at the active fibre or at the output of the pump, optical power associated with the pump, injected into the active fibre

3.1.2.4
centroidal wavelength
<pump lasers> mean or average wavelength of an optical spectrum of pump LD

Note 1 to entry: Regarding many pump LDs of 980 nm and 1 480 nm, centroidal wavelength λ_{avg} is applied for centre wavelength λ_c. The definition of centroidal wavelength is described as follows:

$$\lambda_{avg} = \left(\frac{1}{P_0}\right)\sum_{i=1}^{N} P_i\ \lambda_i$$

where

λ_i is the wavelength of the i^{th} peak point (nm);

i corresponds to mode number for output spectra of pump LD;

P_i is the power of the i^{th} peak point (nW); and

P_0 is the total power summed for all peak points (nW):

$$P_0 = \sum_{i=1}^{N} P_i$$

N is the number of peak points.

Note 2 to entry: The pump efficiency of an EDF depends on the overlap integral of the EDF absorption spectrum and the pump LD spectrum, so the centroidal wavelength of the pump laser is crucial for EDF pumping.

3.1.2.5
peak wavelength
<pump lasers> wavelength which corresponds to the maximum power value of the optical spectrum of pump LD

Note 1 to entry: For some pump LDs operating at 980 nm and 1 480 nm with FBG stabilizer, the peak wavelength λ_{peak} is used as the centre wavelength λ_c. The definition of peak wavelength is described as follows:

$$\lambda_c = \lambda_{peak}$$

Note 2 to entry: Refer to IEC 61280-1-3 for details.

3.1.2.6
root mean square (RMS) spectral width
spectral width defined by RMS

Note 1 to entry: Regarding many pump LDs of 980 nm and 1 480 nm, the RMS spectral width $\Delta\lambda_{rms}$ is used to characterize spectral width. The definition of RMS spectral width is described as follows:

$$\Delta\lambda_{rms} = \left[\frac{1}{P_0} \sum_{i=1}^{N} P_i \, (\lambda_i - \lambda_c)^2 \right]^{\frac{1}{2}}$$

Note 2 to entry: The pump efficiency of an EDF depends on the overlap integral of the EDF absorption spectrum and the pump LD spectrum, so the pumping spectral width of pump laser is a crucial factor for EDF pumping in order to quantify the power band width of the pump LD.

3.1.2.7
full-width at half maximum (FWHM) spectral width
spectral width defined by FWHM

Note 1 to entry: Regarding some pump LDs of 980 nm and 1 480 nm with FBG stabilizer, full-width at half maximum (FWHM) $\Delta\lambda_{fwhm}$ is used to characterize spectral width. The definition of the FWHM spectral width is described as follows:

1) The positive difference of the closest spaced wavelengths, one above and one below the peak wavelength λ_{peak}, at which the spectral power density is 3 dB down from its peak value;
2) If the pump laser does not emit light at these half-power wavelengths, the FWHM spectral width can be determined by interpolation as follows;
3) Connect the tip of each mode to the tips of adjacent modes; draw a horizontal line 3 dB down from the peak power point;
4) The two or more intersection points define the half-power wavelengths. The maximum difference in half-power wavelengths is $\Delta\lambda_{fwhm}$.

Note 2 to entry: See IEC 61280-1-3 for more details.

3.1.2.8
wavelength stability
<pump lasers> rate of variation of pumping wavelength with respect to operating and environmental conditions

3.1.2.9
pumping spectral width
<pump lasers> effective width of emission spectrum of the pump laser

Note 1 to entry: Commonly, RMS spectral width is used.

3.1.2.10
threshold current
<pump lasers> driving current at which the pump laser starts to lase

Note 1 to entry: Practically, this value is specified as the crossing condition between the spontaneous emission and lasing regions.