IEC TR 61292-1

Edition 3.0   2022-05

TECHNICAL
REPORT

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

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
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 It also gives information on projects, replaced and withdrawn publications.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
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
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - 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
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.

IEC TR 61292-1

Edition 3.0   2022-05

TECHNICAL
REPORT

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

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

OPTICAL AMPLIFIERS –

Part 1: Parameters of optical fibre amplifier components

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 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
$2w$
<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 ith peak point (nm);

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

P_i is the power of the ith 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:

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

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 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.

3.1.2.11
maximum allowed current
<pump lasers> maximum driving current which can cause irreversible damage to the pump laser

Note 1 to entry: The absolute maximum rated current is generally applied.

3.1.2.12
pump LD chip temperature
<pump lasers> temperature of LD chip to be controlled for normal operation, where performance of pump LD is ensured

Note 1 to entry: The output power and operating wavelength are affected by laser chip temperature. Therefore, ordinary pump LD modules include a thermoelectric cooler (TEC) so as to maintain a constant LD chip temperature. A temperature range of 25 ˚C to 45 ˚C is commonly specified by LD suppliers. Previous generation chips are specified at 25 ˚C, and some more recent chips are specified to operate at 35 ˚C or 45 ˚C.

3.1.2.13
pump LD case temperature
<pump lasers> operative temperature range of LD case within which the pump laser module can be operated while still meeting all its specified parameter values, given in the relevant detail specification

Note 1 to entry: The power consumption of temperature-controlled pump LD modules with TEC varies with case temperatures, since the TEC controls the LD chip temperature relative to the case temperatures. The case temperature also affects centre wavelength and wavelength stability of pump lasers with FBG wavelength stabilizer, since the reflection wavelength of the FBG can vary with case temperature. Therefore, the pump LD case temperature is specified by the LD vendor to ensure normal operation of all the related performance. Most LD modules are specified for case temperatures ranging from 0 ˚C to 75 ˚C.

3.1.2.14
temperature dependence of threshold current
<pump laser> temperature dependence of threshold current of pump laser

3.1.2.15
temperature dependence of wavelength
<pump lasers> temperature dependence of the centroidal or peak wavelength among emission wavelengths of the pump laser

3.1.2.16
device reliability
probability of performing required functions and performances at specified duration, specified operating and environmental conditions

Note 1 to entry: The reliability of a pump laser is expressed by either of the following two parameters: mean time between failure (MTBF) or failure in time (FIT):

1) MTBF is the mean period of continuous operation without any failure at specified operating and environmental conditions.

2) FIT is the number of failures in an accumulated device operating time of 10^9 hours at specified operating and environmental conditions.

3.1.3   Parameters for WDM couplers

3.1.3.1
signal insertion loss
<WDM couplers> ratio of the signal power incident on the signal input port of the WDM coupler to the output power from the signal output port

Note 1 to entry: Signal insertion loss is expressed in decibels (dB).

3.1.3.2
pump insertion loss
<WDM couplers> ratio of the pump power incident on the pump input port of the WDM coupler to the output power from the signal output port

Note 1 to entry: Pump insertion loss is expressed in decibels (dB).

3.1.3.3
polarization dependent loss
PDL

<WDM couplers> maximum insertion loss variation due to the change of the input light state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

Note 2 to entry: This term is defined for both signal input port and pump input port.

3.1.3.4
signal reflectance

<WDM couplers> ratio of the signal power incident on the signal input port of the WDM coupler to the output power reflected back from the signal input port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.3.5
pump leakage at the signal input port

<WDM couplers> ratio of the pump power incident on the pump input port of the WDM coupler to the output power from the signal input port

Note 1 to entry: Pump leakage is expressed in decibels (dB).

3.1.4   Parameters for pump WDM couplers

3.1.4.1
insertion loss

<pump WDM couplers> ratio of the pump power at the nth wavelength incident on the nth wavelength pump input port of the pump WDM coupler to the output power from the common pump output port

Note 1 to entry: Insertion loss is expressed in decibels (dB).

Note 2 to entry: This term applies to all pump input ports.

3.1.4.2
polarization dependent loss
PDL

<pump WDM couplers> maximum insertion loss variation due to the change of the input light state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

Note 2 to entry: This term is defined for all pump input ports.

3.1.4.3
pump reflectance

<pump WDM couplers> ratio of the pump power incident on the pump input port of the pump WDM coupler to the output power reflected back from the pump input port

Note 1 to entry: Pump reflectance is expressed in decibels (dB).

Note 2 to entry: This term applies to all pump input ports.

3.1.5   Parameters for optical isolators

3.1.5.1
insertion loss

<optical isolators> maximum value of logarithmic transmission coefficient, a_{ij} (where $i \neq j$) within the passband for conducting port pair

Note 1 to entry: It is the optical attenuation from a given port to a port which is another port of conducting port pair of the given port of a passive device. Insertion loss, a_{IL} is a positive value in decibels (dB). It is calculated as:

$$a_{IL} = -10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

where

P_{in} is the optical power launched into the port;

P_{out} is the optical power received from the other port of the conducting port pair.

Note 2 to entry: In the case of an optical isolator as a non-reciprocal device, a_{IL} is defined as the maximum value of attenuation from the input port to the output port.

Note 3 to entry: In the case of an optical isolator as nominally a wavelength independent and wavelength non-selective device, passband is nominally same as operating wavelength range.

Note 4 to entry: In the case of a polarization-independent isolator, a_{IL} is defined as the maximum value for any state of polarization of P_{in}.

Note 5 to entry: In the case of a polarization-dependent isolator, a_{IL} is defined as the linearly polarized light which coincides with the polarizing direction of the polarizer in the isolator of P_{in}.

[SOURCE: IEC 61202-1:2016, 3.3.3, modified – Specific use has been added.]

3.1.5.2
isolation
minimum value of the logarithmic transmission coefficient a_{ij} (where $i \neq j$) for isolated port pair

Note 1 to entry: Isolation is the minimum attenuation value in the backward direction.

Note 2 to entry: Isolation is a positive value expressed in decibels (dB).

[SOURCE: IEC 61202-1:2016, 3.3.4]

3.1.5.3
polarization mode dispersion
PMD
<optical isolators> maximum PMD at the signal wavelength which is launched into the input port of the isolator and exits from signal output port of the isolator

Note 1 to entry: PMD is expressed in picoseconds (ps).

Note 2 to entry: Refer to IEC 61753-061-2.

3.1.5.4
operating wavelength range
<optical isolators> wavelength range within which the optical isolator operates the required performances in the operating temperature range

Note 1 to entry: A Faraday rotator typically exhibits wavelength dependency of the rotation angle, e.g. typically 0,08 degree (angle)/nm.

3.1.5.5
polarization dependent loss
PDL
<optical isolators> maximum variation of insertion loss due to a variation of the state of polarization of the input signal

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.6   Parameters for ASE rejection filters

3.1.6.1
insertion loss
<ASE rejection filters> ratio of the signal power incident on the signal input port of the ASE rejection filter to the output power from the output port

Note 1 to entry: Insertion loss is expressed in decibels (dB).

3.1.6.2
signal reflectance on the input port
<ASE rejection filters> ratio of the signal power incident on the signal input port of the ASE rejection filter to the output power reflected back from the signal input port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.6.3
signal reflectance on the output port
<ASE rejection filters> ratio of the signal power incident on the signal output port of the ASE rejection filter to the output power reflected back from the signal output port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.6.4
polarization dependent loss
PDL
<ASE rejection filters> maximum variation of insertion loss due to a variation of the state of polarization of the input signal

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.6.5
peak wavelength
<ASE rejection filters> wavelength at which the insertion loss of the ASE rejection filter is minimum

3.1.7   Parameters for pump rejection filters

3.1.7.1
insertion loss
<pump rejection filters> ratio of the signal power incident on the signal input port of the pump rejection filter to the output power reflected back from the signal input port

Note 1 to entry: Insertion loss is expressed in decibels (dB).

3.1.7.2
signal reflectance on the output port
<pump rejection filters> ratio of the incident on the output port of the pump rejection filter to the output power reflected from the output port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.7.3
polarization dependent loss
PDL
<pump rejection filters> maximum variation of insertion loss due to a variation of the state of polarization of the input signal

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.7.4
extinction ratio
<pump rejection filters> ratio of the pump power incident on the input port of the pump rejection filter to the output pump power from the output port

Note 1 to entry: Extinction ratio is expressed in decibels (dB).

3.1.8   Parameters for gain flattening filters

3.1.8.1
operating wavelength range
<gain flattening filters> operating wavelength interval within which the signal gain of the OFA is adjusted to be flattened by the GFF

3.1.8.2
insertion loss
<gain flattening filters> ratio of the signal power incident on the input port of the GFF to the output power from the output port

Note 1 to entry: Insertion loss is expressed in decibels (dB).

Note 2 to entry: This value is generally defined as the minimum value within the GFF operating wavelength range.

3.1.8.3
error function
<gain flattening filters> difference between design target loss profile and actual loss profile of the filter within the GFF wavelength range

Note 1 to entry: Error function is expressed in decibels (dB).

Note 2 to entry: The error function is defined as:

$$F_{\text{error}}(\lambda) = L_{\text{actual}}(\lambda) - L_{\text{design}}(\lambda)$$

where,

$F_{\text{error}}(\lambda)$ is the error function as a function of wavelength;

$L_{\text{actual}}(\lambda)$ is the actual loss as a function of wavelength;

$L_{\text{design}}(\lambda)$ is the design target loss as a function of wavelength.

Note 3 to entry: The error function is a function of wavelength.

3.1.8.4
polarization dependent loss
PDL
<gain flattening filters> maximum variation of insertion loss due to a variation of the state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.8.5
signal reflectance on the input port
<gain flattening filters> ratio of the signal power incident on the input port of the GFF to the output power reflected back from the input port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.8.6
signal reflectance of on the output port
<gain flattening filters> ratio of the signal power incident on the output port of the GFF to the output power reflected back from the output port

Note 1 to entry: Signal reflectance is expressed in decibels (dB).

3.1.9   Parameters for tap couplers

3.1.9.1
coupling ratio
CR
<tap couplers> for a given input port i, the ratio of light at a given output port k to the total light from all output ports

Note 1 to entry: CR is calculated as

$$R_{\text{c}.ik} = t_{ik} \, / \sum_{j} t_{ij}$$

where t_{ij} (transfer matrix element) is the ratio of the optical power P_{ij} transferred out of port j with respect to input power P_i into port i, that is:

$$t_{ij} = P_{ij} \, / \, P_i$$

3.1.9.2
insertion loss
<tap couplers> reduction of optical power, when the signal transmitted between the input and output ports of the tap coupler

Note 1 to entry: Insertion loss is expressed in decibels (dB).

3.1.9.3
PDL in the signal path
<tap couplers> maximum variation of the insertion loss due to a variation of the state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.9.4
PDL in the tap path
<tap couplers> maximum variation of the output power at the tap port due to a variation of the state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

3.1.9.5
wavelength and temperature dependent loss variation in the signal path
<tap couplers> maximum variation of the insertion loss due to a variation of signal wavelength and temperature

Note 1 to entry: Loss variation is expressed in decibels (dB).

3.1.9.6
wavelength and temperature dependent loss variation in the tap path
<tap couplers> maximum variation of the coupling ratio of the tap coupler due to a variation of signal wavelength and temperature

Note 1 to entry: Loss variation is expressed in decibels (dB).

3.1.9.7
signal reflectance on the input port
<tap couplers> ratio of the signal power incident on the input port of the tap coupler to the output power reflected back from the input port

Note 1 to entry: Reflectance is expressed in decibels (dB).

3.1.9.8
signal reflectance on the output port
<tap couplers> ratio of the signal power incident on the output port of the tap coupler to the output power reflected from the output port

Note 1 to entry: Reflectance is expressed in decibels (dB).

3.1.9.9
signal reflectance on the tap port
<tap couplers> ratio of the signal power incident on the tap port of the tap coupler to the output power reflected from the tap port

Note 1 to entry: Reflectance is expressed in decibels (dB).

3.1.10   Parameters for PIN-photodiodes

3.1.10.1
operating wavelength range
<PIN-photodiodes> wavelength interval within which the PIN-PD normally operates in its nominal specification

3.1.10.2
reverse voltage
<PIN-photodiodes> operative reverse bias voltage applied to the PIN-PD

3.1.10.3
responsivity
<PIN-photodiodes> ratio of an optical detector's electrical output to its optical input

Note 1 to entry: Responsivity is generally expressed in A/W or V/W of incident radiant optical power.

Note 2 to entry: "Sensitivity" is sometimes used as an imprecise synonym for responsivity.

[SOURCE: IEC 60050-731:1991, 731-06-36, modified – Specific use added.]

3.1.10.4
back reflectance
<PIN-photodiodes> fraction of the optical power associated with the input signal which is reflected by the facet of PIN-PD

Note 1 to entry: Back reflectance is expressed in decibels (dB).

3.1.10.5
dark current
<PIN-photodiodes> output current of an optical detector in the absence of incident radiation

Note 1 to entry: The dark current typically increases when the temperature of the PIN-PD rises.

[SOURCE: IEC 60050-731:1991, 731-06-33, modified – Note to entry added and specific use added.]

3.1.10.6
capacitance
<PIN-photodiodes> junction capacitance when specified reverse bias voltage is applied

Note 1 to entry: Capacitance is expressed in pico farad (pF).

3.1.11   Parameters for variable optical attenuators (VOAs)

3.1.11.1
operating wavelength range
<VOAs> wavelength interval within which the VOA normally operates in its nominal specification

3.1.11.2
minimum insertion loss
<VOAs> lowest insertion loss to which a VOA is adjusted

[SOURCE: IEC 60869-1:2018, 3.2.7, modified – Specific use added.]

3.1.11.3
variable attenuation range
<VOAs> range of attenuation to which a VOA can be adjusted

[SOURCE: IEC 60869-1:2018, 3.2.8, modified – Specific use added and note to entry deleted.]

3.1.11.4
maximum attenuation
<VOAs> attenuation of the maximum value which is adjusted

[SOURCE: IEC 60869-1:2018, 3.2.10, modified – "set" replaced with "adjusted".]

3.1.11.5
polarization dependent loss
PDL
<VOAs> maximum insertion loss variation due to the change of the input signal state of polarization

Note 1 to entry: PDL is expressed in decibels (dB).

Note 2 to entry: PDL generally depends on the attenuation value.

3.1.11.6
attenuation range
<VOAs> attenuation range or total loss range that can be adjusted at the VOA in its nominal specification

3.1.11.7
response time
<VOAs> maximum time needed to change the attenuation from the beginning attenuation status until the end of the change

Note 1 to entry: The response time is practically defined under the condition that attenuation is changed from the minimum value to the maximum value of its nominal specification.

3.1.11.8
repeatability
<VOAs> maximum deviation of the insertion loss of the device at a given setting in multiple times of repeated settings

Note 1 to entry: A method to measure the repeatability of the attenuation settings of a VOA is defined in IEC 61300-3-14.

[SOURCE: IEC 60869-1:2018, 3.2.14, modified – "of setting attenuation value" deleted from the term and note to entry has been replaced.]

3.1.11.9
input signal reflectance
<VOAs> fraction of the optical power associated with the input signal which is reflected by the signal from input port of the VOA

Note 1 to entry: Reflectance is expressed in decibels (dB).

3.1.11.10
output signal reflectance
<VOAs> fraction of the optical power associated with the reverse propagating light which is reflected by the signal from output port of the VOA

Note 1 to entry: Reflectance is expressed in decibels (dB).

3.1.12   Parameters for optical connectors

3.1.12.1
category of optical fibre
<optical connectors> category of optical fibre used in optical connectors for OFA input and output interfaces

Note 1 to entry: The categories of single-mode fibres are defined in IEC 60793-2-50.

3.1.12.2
connector type
<optical connectors> type of a connector used at the OFA input and output ports

Note 1 to entry: The various types of optical connector interfaces are defined in the IEC 61754 series, where IEC 61754-4 defines the mechanical interface dimensions for the SC connector family for example, and IEC 61754-20 defines those for the LC connector family.

3.1.12.3
attenuation
<optical connectors> reduction of the optical power at the connection of two optical connectors

Note 1 to entry: Attenuation is expressed in decibels (dB).

Note 2 to entry: IEC 61753-1 defines the requirement of the attenuation grades for optical connectors.

Note 3 to entry: IEC 61300-3-4 defines the measurement procedures for attenuation.

Note 4 to entry: IEC 60050-731, 01-48 defines attenuation.

Note 5 to entry: Sometimes, the term of insertion loss is used instead of attenuation.

3.1.12.4
return loss
<optical connectors> ratio of the power incident on, or entering, the optical connector to the total power reflected by the optical connector

Note 1 to entry: Return loss is expressed in decibels (dB).

Note 2 to entry: IEC 61753-1 defines the return loss grades for optical connectors.

Note 3 to entry: IEC 61300-3-6 defines the measurement procedures for return loss.

3.2   Abbreviated terms

ASE   amplified spontaneous emission

EDF   erbium-doped fibre

EDFA   erbium-doped fibre amplifier

DCF   dispersion compensating fibre

DRA   distributed Raman amplifier

DSF	dispersion shifted fibre
FBG	fibre Bragg grating
FIT	failure in time
FRA	fibre Raman amplifier
FWHM	full-width at half maximum
GFF	gain flattening filter
LD	laser diode
MTBF	mean time between failure
OA	optical amplifier
OFA	optical fibre amplifier
PBC	polarization beam combiner
PDL	polarization dependent loss (variation)
PIN-PD	PIN (positive-intrinsic-negative)-photodiode
PMD	polarization mode dispersion
RMS (r.m.s)	root mean square
TEC	thermo-electric cooler
VOA	variable optical attenuator
WDM	wavelength division multiplexing

3.3   Symbols

$2w$	mode field diameter
a_{IL}	insertion loss
$F_{error}(\lambda)$	error function as a function of wavelength
$F(q)$	far-field intensity distribution
$L_{actual}(\lambda)$	actual loss as a function of wavelength
$L_{design}(\lambda)$	design target loss as a function of wavelength
P_i	optical power of ith peak point for LDs
	and optical input power to i^{th} port for tap couplers
P_o	total optical power for LDs
P_{ij}	optical power of jth output port from i^{th} input port for tap couplers
$R_{c.ik}$	coupling ratio for i^{th} input port to k^{th} output port
t_{ij}	transfer matrix element of port i to port j for tap couplers
λ_{avg}	centroidal wavelength
λ_c	centre wavelength
λ_i	wavelength of ith peak point
λ_{peak}	wavelength of peak point
$\Delta\lambda_{fwhm}$	full-width at half maximum spectral width
$\Delta\lambda_{rms}$	root mean square spectral width

4   OFA components

The parameters relevant for a satisfactory understanding of OFA operation are covered by the following optical components:

a) active fibre;

b) transmission fibre;

c) gain fibre for FRA;

d) pump laser;

e) wavelength division multiplexing (WDM) coupler;

f) pump WDM coupler;

g) polarization beam combiner;

h) optical isolator;

i) amplified spontaneous emission (ASE) rejection filter;

j) pump rejection filter;

k) gain flattening filter (GFF);

l) tap coupler;

m) PIN-photodiode (PIN-PD);

n) variable optical attenuator (VOA);

o) optical connector.

Table 1 displays a list of documents defining terms and definitions for each component of optical fibre amplifiers.

Table 1 – Documents defining terms and definitions of each component

| Optical component	Document number	Document title
Active fibre	IEC TR 63309[a]	Active fibres – Characteristics and Measurement Methods – Guidance
Transmission fibre	IEC 60793-2-50	Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single-mode fibres
Gain fibre for FRA	(None)	(None)
Pump laser	IEC 62007-1:2015, Clause 10	Semiconductor optoelectronic devices for fibre optic system applications – Part 1: Specification template for essential ratings and characteristics
WDM coupler Pump WDM coupler	IEC 62074-1	Fibre optic interconnecting devices and passive components – Fibre optic WDM devices – Part 1: Generic specification
Polarization beam combiner	(None)	(None)
Optical isolator	IEC 61202-1	Fibre optic interconnecting devices and passive components – Fibre optic isolators – Part 1: Generic specification
ASE rejection filter Pump rejection filter GFF	IEC 61977	Fibre optic interconnecting devices and passive components – Fibre optic fixed filters – Generic specification
Tap coupler	IEC 60875-1:2015	Fibre optic interconnecting devices and passive components – Non-wavelength-selective fibre optic branching devices – Part 1: Generic specification
PIN PD	IEC 62007-1:2015, Clause 6	Semiconductor optoelectronic devices for fibre optic system applications – Part 1: Specification template for essential ratings and characteristics
VOA	IEC 60869-1	Fibre optic interconnecting devices and passive components – Fibre optic passive power control devices – Part 1: Generic specification
Optical connector	IEC 61753-1	Fibre optic interconnecting devices and passive components – Performance standard – Part 1: General and guidance
	IEC 61754-1	Fibre optic interconnecting devices and passive components – Fibre optic connector interfaces – Part 1: General and guidance
	IEC 61755-1	Fibre optic connector optical interfaces – Part 1: Optical interfaces for single mode non-dispersion shifted fibres – General and guidance
[a] Under consideration		

Figure 1 provides an example of the component layout for an EDFA.

^aOptional components (can be placed elsewhere)
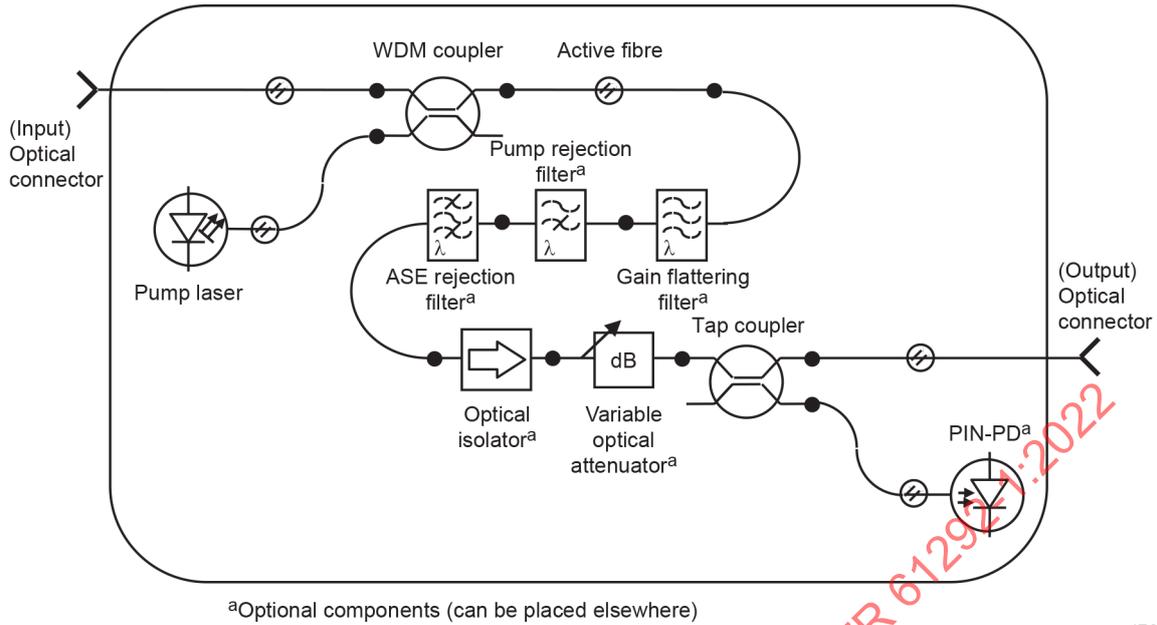
IEC

**Figure 1 – Example of the components inside an EDFA operating
in a co-propagating pumping scheme**

Figure 2 provides an example of the component layout of a DRA.

^aOptional components (can be placed elsewhere)
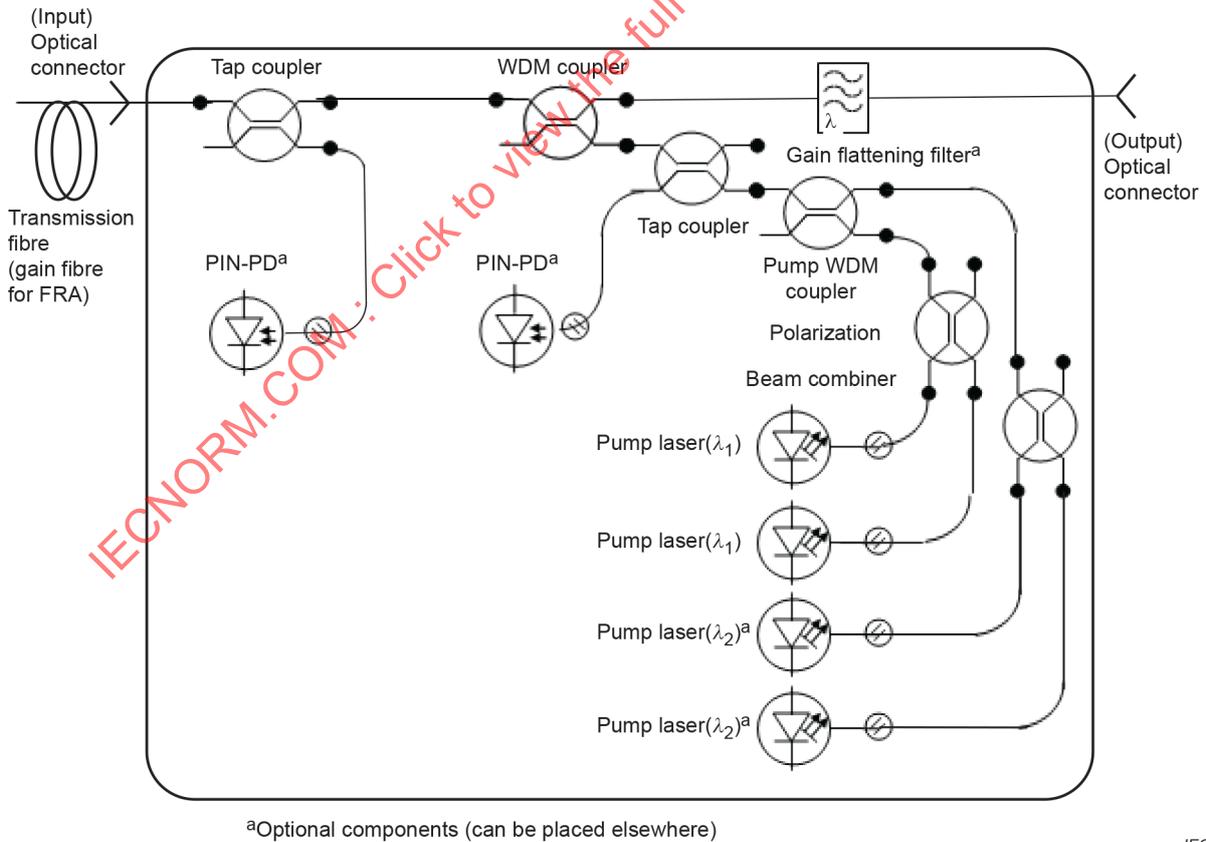
IEC

Figure 2 – Example of the component layout of a distributed Raman amplifier (DRA)

Figure 3 provides an example of the component layout of a lumped (or discrete) Raman amplifier.
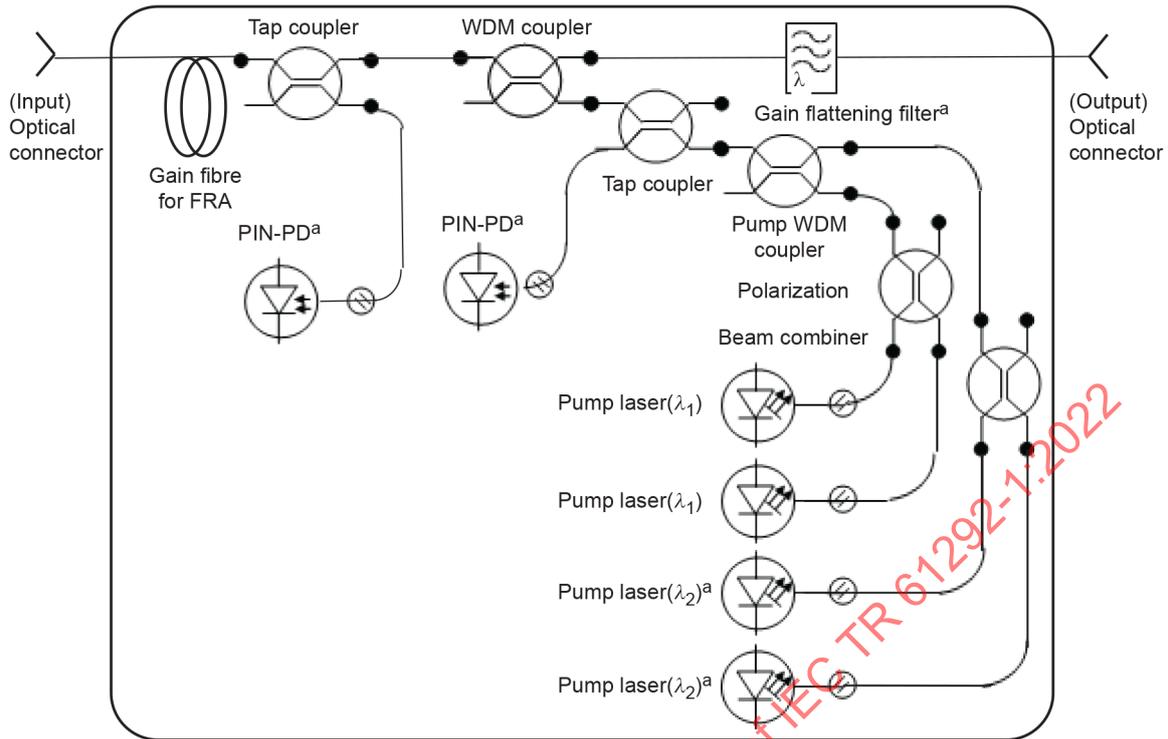
a Optional components (can be placed elsewhere)

IEC

**Figure 3 – Example of the component layout
of a lumped (or discrete) Raman amplifier**

5 Parameters of optical fibre amplifier components

5.1 Active fibre

5.1.1 Function and technical outline

The active fibre is used as the gain medium in OFAs. The core region of the optical fibre is usually doped with rare earth ions to produce signal amplification. Er^{3+} ions are generally used for 1 550 nm band OFAs, which are called erbium doped fibre amplifiers (EDFAs). An Erbium doped fibre (EDF) absorbs light at a wavelength of 980 nm and/or 1 480 nm for pumping, and emits infrared light with a wavelength in the 1 550 nm region. Optical amplification is realized utilizing stimulated emission of 1 530 nm luminescence. IEC TR 63309 provides more information on active fibres.

5.1.2 Parameters for active fibres

The following parameters apply to active fibres. Detailed definitions of these parameters are given in 3.1.1:

– maximum input signal power of active fibre (see 3.1.1.1);

– insertion loss at out-of-band wavelength of active fibre (see 3.1.1.2);

– polarization-dependent gain of active fibre (see 3.1.1.3);

– polarization mode dispersion (PMD) of active fibre (see 3.1.1.4);

– mode field diameter (MFD) of active fibre (see 3.1.1.5);

– cut-off wavelength of active fibre (see 3.1.1.6);

– cladding diameter of active fibre (see 3.1.1.7);

– cladding non-circularity of active fibre (see 3.1.1.8);

- mode field concentricity error of active fibre (see 3.1.1.9);
- active fibre composition (see 3.1.1.10);
- active fibre length (see 3.1.1.11);
- active fibre dopant distribution (see 3.1.1.12);
- slope efficiency (see 3.1.1.13);
- saturation pump power (see 3.1.1.14);
- threshold pump power (see 3.1.1.15).

5.2 Gain fibre for FRA

5.2.1 Function and technical outline

In FRAs, the signal light is amplified by stimulated Raman scattering in the fibre. The maximum gain occurs at a frequency about 13 THz below that of the pump for FRA, whereas for EDFAs the amplification gain is uniquely determined by the emission spectrum of Er^{3+}. For the distributed Raman amplifier, the gain fibre for FRA is the transmission fibre itself, which can be dispersion-unshifted SMF, DSF, or NZDSF. Lumped (discrete) Raman amplifiers typically use a highly non-linear fibre (e.g. a DCF) as the gain fibre for FRA. IEC TR 61292-6 provides more information on gain fibres for FRA.

5.2.2 Parameters for gain fibres of FRAs

To be specified (at this time, there are no IEC documents defining gain fibre parameters for FRAs).

5.3 Pump laser

5.3.1 Function and technical outline

A pump laser is used to provide excitation energy to the active fibre. The signal light is amplified by inserting a strong signal from the pump laser into the active fibre. In the case of rare-earth doped fibres (like EDFs), the signal light is amplified by stimulated emission from the rare-earth ions (e.g. Er^{3+}). In the case of FRAs, the signal light is amplified by stimulated Raman scattering, which is caused by pump-light induced excitation of the silica glass matrix to a higher (virtual) energy state.

5.3.2 Parameters for pump lasers

The following parameters apply to pump lasers. Detailed definitions of these parameters are given in 3.1.2:

- pumping wavelength (see 3.1.2.1);
- pumping scheme (see 3.1.2.2);
- pumping power (see 3.1.2.3);
- centroidal wavelength (see 3.1.2.4);
- peak wavelength (see 3.1.2.5);
- root mean square (RMS) spectral width (see 3.1.2.6);
- full-width at half maximum (FWHM) spectral width (see 3.1.2.7);
- wavelength stability (see 3.1.2.8);
- pumping spectral width (see 3.1.2.9);
- threshold current (see 3.1.2.10);
- maximum allowed current (see 3.1.2.11);
- pump LD chip temperature (see 3.1.2.12);
- pump LD case temperature (see 3.1.2.13);

– temperature dependence of threshold current (see 3.1.2.14);

– temperature dependence of wavelength (see 3.1.2.15);

– device reliability (see 3.1.2.16).

5.4 WDM coupler (for combining signal light and pump light)

5.4.1 Function and technical outline

A WDM coupler is used to combine pump light with signal light and to guide the combined light to the active fibre. Thin film technology or tapered fused coupler technology is commonly applied to manufacture WDM couplers.

5.4.2 Parameters for WDM couplers

The following parameters apply to WDM couplers. Detailed definitions of these parameters are given in 3.1.3:

– signal insertion loss of WDM coupler (see 3.1.3.1);

– pump insertion loss of WDM coupler (see 3.1.3.2);

– PDL of WDM coupler (see 3.1.3.3);

– signal reflectance of WDM coupler (see 3.1.3.4);

– pump leakage at the signal input port (see 3.1.3.5).

5.5 Pump WDM coupler

5.5.1 Function and technical outline

A pump WDM coupler combines two or more pump signals having different wavelengths to obtain high power pump light. Thin film technology or tapered fused coupler technology is commonly applied to manufacture pump WDM couplers as well as WDM couplers for combining signal and pump light.

5.5.2 Parameters for pump WDM couplers

The following parameters apply to pump WDM couplers. Detailed definitions of these parameters are given in 3.1.4:

– insertion loss of pump WDM coupler (see 3.1.4.1);

– PDL of pump WDM coupler (see 3.1.4.2);

– pump reflectance of pump WDM coupler (see 3.1.4.3).

5.6 Polarization beam combiner (PBC)

5.6.1 Function and technical outline

A PBC is an optical component that combines two optical signals having orthogonal linear polarization states. The two input ports of a PBC are usually connected to polarization maintaining fibres. With single-polarized pump light, the Raman gain in FRAs tends to be polarization-dependent. This polarization dependence can be mitigated by combining two orthogonally polarized pump signals in a PBC.

5.6.2 Parameters for PBC

To be specified (at this time, there are no IEC documents defining parameters for PBCs).