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Edition 4.0 2018-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical amplifiers –
Part 1: Generic specification

Amplificateurs optiques –
Partie 1: Spécification générique

IEC 61291-1:2018-02(en-fr)

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OPTICAL AMPLIFIERS –

Part 1: Generic specification

FOREWORD

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International Standard IEC 61291-1 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This fourth edition cancels and replaces the third edition published in 2012. This edition constitutes a technical revision.

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

a) terms have been added for parameters from IEC 61290-4-3 and IEC 61290-10-5;
b) Clause 4 Classification has been removed, since this system is judged to be unused;
c) the definition of polarization mode dispersion (PMD) has been simplified.

The text of this International Standard is based on the following documents:

CDV	Report on voting
86C/1460/CDV	86C/1498/RVC

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

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

A list of all parts in the IEC 61291 series, published under the general title *Optical amplifiers*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "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- withdrawn,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.

OPTICAL AMPLIFIERS –

Part 1: Generic specification

1 Scope

This part of IEC 61291 applies to all commercially available optical amplifiers (OAs) and optically amplified assemblies. It applies to OAs using optically pumped fibres (OFAs based either on rare-earth doped fibres or on the Raman effect), semiconductors (SOAs), and waveguides (POWAs).

The object of this document is

– to establish uniform requirements for transmission, operation, reliability and environmental properties of OAs, and
– to provide assistance to the purchaser in the selection of consistently high-quality OA products for his particular applications.

Parameters specified for OAs are those characterizing the transmission, operation, reliability and environmental properties of the OA seen as a "black box" from a general point of view. In the sectional and detail specifications a subset of these parameters will be specified according to the type and application of the particular OA device or assembly.

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 60050-731, *International Electrotechnical Vocabulary – Chapter 731: Optical fibre communication* (available at http://www.electropedia.org)

IEC 61290 (all parts), *Optical amplifiers – Test methods*

IEC 61290-1-1, *Optical amplifiers – Test methods – Part 1-1: Power and gain parameters – Optical spectrum analyzer method*

IEC 61290-1-2, *Optical amplifiers – Test methods – Part 1-2: Power and gain parameters – Electrical spectrum analyzer method*

IEC 61290-1-3, *Optical amplifiers – Test methods – Part 1-3: Power and gain parameters – Optical power meter method*

IEC 61290-3-1, *Optical amplifiers – Test methods – Part 3-1: Noise figure parameters – Optical spectrum analyzer method*

IEC 61290-3-2, *Optical amplifiers – Test methods – Part 3-2: Noise figure parameters – Electrical spectrum analyzer method*

IEC 61290-4-1, *Optical amplifiers – Test methods – Part 4-1: Gain transient parameters – Two wavelength method*

IEC 61290-4-2, *Optical amplifiers – Test methods – Part 4-2: Gain transient parameters – Broadband source method*

IEC 61290-4-3, *Optical amplifiers – Test methods – Part 4-3: Power transient parameters – Single channel optical amplifiers in output power control*

IEC 61290-5-1, *Optical amplifiers – Test methods – Part 5-1: Reflectance parameters – Optical spectrum analyzer method*

IEC 61290-5-2, *Optical amplifiers – Test methods – Part 5-2: Reflectance parameters – Electrical spectrum analyzer method*

IEC 61290-5-3, *Optical fibre amplifiers – Basic specification– Part 5-3: Test methods for reflectance parameters – Reflectance tolerance using an electrical spectrum analyzer*

IEC 61290-6-1, *Optical fibre amplifiers – Basic specification – Part 6-1: Test methods for pump leakage parameters – Optical demultiplexer*

IEC 61290-7-1, *Optical amplifiers – Test methods – Part 7-1: Out-of-band insertion losses – Filtered optical power meter method*

IEC 61290-10-1, *Optical amplifiers – Test methods – Part 10-1: Multichannel parameters – Pulse method using an optical switch and optical spectrum analyzer*

IEC 61290-10-2, *Optical amplifiers – Test methods – Part 10-2: Multichannel parameters – Pulse method using a gated optical spectrum analyzer*

IEC 61290-10-3, *Optical amplifiers – Test methods – Part 10-3: Multichannel parameters – Probe methods*

IEC 61290-10-4, *Optical amplifiers – Test methods – Part 10-4: Multichannel parameters – Interpolated source subtraction method using an optical spectrum analyzer*

IEC 61290-10-5, *Optical amplifiers – Test methods – Part 10-5: Multichannel parameters – Distributed Raman amplifier gain and noise figure*

IEC 61290-11-1, *Optical amplifiers – Test methods – Part 11-1: Polarization mode dispersion parameter – Jones matrix eigenanalysis (JME)*

IEC 61290-11-2, *Optical amplifiers – Test methods – Part 11-2: Polarization mode dispersion parameter – Poincaré sphere analysis method*

IEC 61291-5-2, *Optical amplifiers – Part 5-2: Qualification specifications – Reliability qualification for optical fibre amplifiers*

IEC TR 61931, *Fibre optic – Terminology*

3 Terms, definitions and abbreviated terms

3.1 Overview

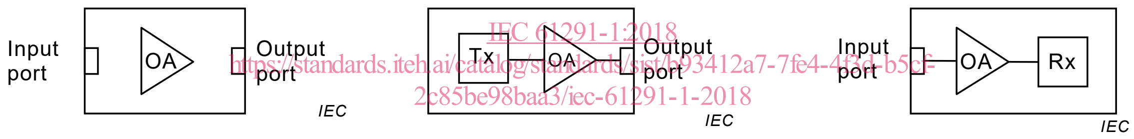
The definitions listed in 3.2 refer to the meaning of the terms used in the specifications of OAs. Only those parameters listed in the appropriate specification template, as in IEC 61291-2 and IEC 61291-4, are intended to be specified.

The list of parameter definitions of OAs, given in 3.2, is divided into two parts: the first part, 3.2.1, lists those parameters relevant for OA devices, namely power, pre-, line- and distributed amplifiers; the second part, 3.2.2, lists the parameters relevant for optically amplified, elementary assemblies, namely the optically amplified transmitter (OAT) and the optically amplified receiver (OAR).

In any case where the value of a parameter is given for a particular device, it will be necessary to specify certain appropriate operating conditions such as temperature, bias current, pump optical power. In Clause 3, two different operating conditions are referred to: nominal operating conditions, which are those suggested by the manufacturer for normal use of the OA, and limit operating conditions, in which all the parameters adjustable by the user (e.g. temperature, gain, pump laser injection current) are at their maximum values, according to the absolute maximum ratings stated by the manufacturer.

The OA shall be considered as a "black box", as shown in Figure 1. The OA device shall have two optical ports, namely an input and an output port (Figure 1 a)). The OAT and OAR shall be considered as an OA integrated on the transmitter side or on the receiver side, respectively. Both kinds of integration imply that the connection between the transmitter or the receiver and the OA is proprietary and not to be specified. Consequently, only the optical output port can be defined for the OAT [after the OA, as shown in Figure 1 b)] and only the optical input port can be defined for the OAR [before the OA, as shown in Figure 1 c)]. The optical ports may consist of unterminated fibres or optical connectors. Electrical connections for power supply (not shown in Figure 1) are also necessary. Following this "black box" approach, the typical loss of one connection and the corresponding uncertainty will be included within the values of gain, noise figure and other parameters of the OA device.

NOTE 1 For distributed amplifiers, as described in Clause 4, this black-box configuration can be simulated for test purposes, for example by attaching a reference fibre to test a Raman pump unit.



a) – OA device b) – OAT c) – OAR

Figure 1 – OA device and assemblies

The OA amplifies signals in a nominal operating wavelength region. In addition, other signals outside of the band of operating wavelength can in some applications, also cross the OA. The purpose of these out-of-band signals and their wavelength, or wavelength region, can be specified in the detail specifications.

When signals at multiple wavelengths are incident on the OA, as is the case in multichannel systems, suitable adjustment of the definitions of some existing relevant parameters is needed together with the introduction of definitions of new parameters relevant to this different application.

A typical configuration of an OA in a multichannel application is shown in Figure 2. At the transmitting side, m signals, coming from m optical transmitters, Tx_1, Tx_2, . . . Tx_m, each with a unique wavelength, λ_1, λ_2, . . . λ_m, respectively, are combined by an optical multiplexer (OM). At the receiving side, the m signals at λ_1, λ_2, . . . λ_m, are separated with an optical demultiplexer (OD) and routed to separate optical receivers, Rx_1, Rx_2, . . . Rx_m, respectively. To characterize the OA in this multichannel application, an input reference plane and an output reference plane are defined at the OA input and output ports, respectively, as shown in Figure 2.

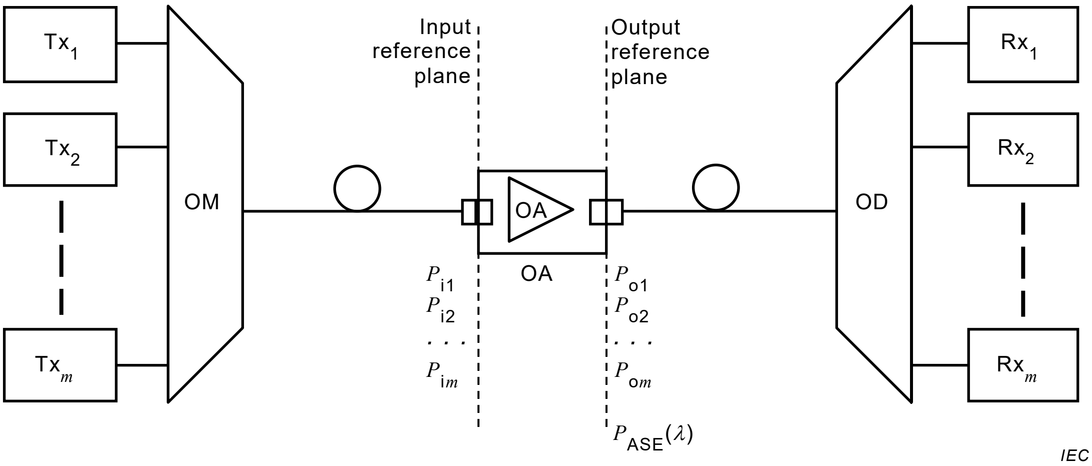


Figure 2 – Optical amplifier in a multichannel application

At the input reference plane, m input signals at the m wavelengths are considered, each with a unique power level, P_{i1}, P_{i2}, . . . P_{im}, respectively. At the output reference plane, m output signals at the m wavelengths, resulting from the optical amplification of the corresponding m input signals, are considered, each with power level P_{o1}, P_{o2}, . . . P_{om}, respectively. Moreover, the amplified spontaneous emission, ASE, with a noise power spectral density, $P_{ASE}(\lambda)$, is also to be considered at the OA output port.

Most definitions of relevant single-channel parameters can be suitably extended to multichannel applications. When this extension is straightforward, the word "channel" will be added to the pertinent parameter. In particular, the noise figure and the signal-spontaneous noise figure may be extended to multichannel applications, channel by channel, by considering the value of $P_{ASE}(\lambda)$ at each channel wavelength and the channel signal bandwidth. For each channel wavelength there will be a unique value of noise figure that will be a function of the input power level of all signals. In this case the parameters, channel noise figure and channel signal-spontaneous noise figure, are introduced. However, some additional parameters also need to be defined. For each parameter, the particular multichannel configuration, including the full set of channel signal wavelengths and input powers, needs to be specified.

The parameters defined in 3.2.1 will in general depend on temperature and polarization state of input channels. The temperature and state of polarization should be kept constant or controlled or be measured and reported together with the measured parameter.

NOTE 2 Except where noted, the optical powers mentioned in 3.2.1 are intended as average powers.

NOTE 3 The measured optical powers are open beam powers: this can result in differences of about 0,18 dB in the measurement of absolute power levels.

NOTE 4 In the case of the distributed amplifier, all the parameters are related to a suitable reference fibre used to emulate the transmission fibre in conjunction with the pumping assembly.

3.2 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-731 and IEC TR 61931 and the following 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

3.2.1 OA devices and distributed amplifiers

NOTE The terms and definitions in 3.2.1 also apply, in general, to optical amplifiers under IEC 61290 (all parts) and IEC 61291 (all parts).

3.2.1.1
gain
increase of signal optical power from the output end of the jumper fibre to the OA output port in an OA which is externally connected to an input jumper fibre

Note 1 to entry: The gain includes the connection loss between the input jumper fibre and the OA input port.

Note 2 to entry: It is assumed that the jumper fibres are of the same type as the fibres used as input and output port of the OA.

Note 3 to entry: Care should be taken to exclude the amplified spontaneous emission power from the signal optical powers.

Note 4 to entry: Gain is expressed in dB.

3.2.1.2
small-signal gain
gain of the amplifier, when operated in linear regime, where it is essentially independent of the input signal optical power, at a given signal wavelength and pump optical power level

Note 1 to entry: This property can be described at a discrete wavelength or as a function of wavelength.

3.2.1.3
reverse gain
gain measured using the input port of the OA as output port and vice versa

3.2.1.4
reverse small-signal gain
small-signal gain measured using the input port of the OA as output port and vice versa

3.2.1.5
maximum gain
highest gain that can be achieved when the OA is operated within the stated nominal operating conditions

3.2.1.6
maximum small-signal gain
highest small-signal gain that can be achieved when the OA is operated within the stated nominal operating conditions

3.2.1.7
maximum gain wavelength
wavelength at which the maximum gain occurs

3.2.1.8
maximum small-signal gain wavelength
wavelength at which the maximum small-signal gain occurs

3.2.1.9
gain wavelength variation
peak-to-peak variation of the gain over a given wavelength range

3.2.1.10
small-signal gain wavelength variation
peak-to-peak variation of the small-signal gain over a given wavelength range

3.2.1.11
gain-slope under single wavelength operation
<for analogue operation> derivative of the gain of a small probe versus wavelength, at the signal wavelength, in the presence of a signal of given wavelength and input power

Note 1 to entry: The probe total average power level shall be at least 20 dB below the input signal level, to minimize the effect on the gain wavelength-profile.

3.2.1.12
polarization-dependent gain
PDG
the maximum variation of the OA gain due to a variation of the state of polarization of the input signal, at nominal operating conditions

Note 1 to entry: A source of PDG in OAs is the polarization dependent loss of the passive components used inside.

Note 2 to entry: This note applies to the French language only.

3.2.1.13
channel gain
<for multichannel operation> gain for each channel (at wavelength λ_j) in a specified multichannel configuration

Note 1 to entry: Channel gain, G_j, can be expressed as $G_j = P_{\mathrm{o}j} - P_{\mathrm{i}j}$, where $P_{\mathrm{i}j}$ and $P_{\mathrm{o}j}$ are respectively the input and output power levels, in dBm, of the j-th channel and j = 1, 2, ... n; n total number of channels.

Note 2 to entry: Since the amplifier saturation power level is determined by the combined effect of the input signals at all wavelengths, the channel gain is dependent on the input power level of all signals.

Note 3 to entry: Channel gain is expressed in dB.

3.2.1.14
multichannel gain variation
interchannel gain difference
<for multichannel operation> difference between the channel gains of any two of the channels in a specified multichannel configuration

Note 1 to entry: Multichannel gain variation can be expressed as $\Delta G_{jl} = G_j - G_l$, where G_j and G_l are respectively the channel gains of j-th and l-th channel and j, l = 1, 2, ... n; $j \neq l$; n total number of channels):

Note 2 to entry: Normally, this parameter is specified as the maximum multichannel gain variation, intended as the maximum absolute value of multichannel gain variation, considering all possible combinations of channel pairs. The input power levels would normally be set to their minimum and maximum specified values. Input power levels may also be specified to achieve certain gain values or total output power levels. Maximum multichannel gain variation can be expressed as $\Delta G_{\mathrm{MAX}} = MAX_{j,l}\,\{|\Delta G_{jl}|\}$.

Note 3 to entry: Maximum multichannel gain variation is expressed in dB.

Note 4 to entry: This parameter is often referred to as "gain flatness".

3.2.1.15
gain cross-saturation
<for multichannel operation> ratio of the change in channel gain of one channel, ΔG_j, to a given change in the input power level of another channel, ΔP_l, while the input power levels of all other channels are kept constant, in a specified multichannel configuration

Note 1 to entry: Gain cross-saturation can be expressed as follows (j, l = 1, 2, . . . , n; $j \neq l$; n total number of channels):

$$GXS_{jl} = \Delta G_j / \Delta P_l$$

Note 2 to entry: Gain cross-saturation is expressed in dB per dB.

Note 3 to entry: Normally, this parameter is specified for an initial input power distribution among channels in which each channel is at the minimum allowed power level. Other distributions may be indicated in the appropriate product specification.

3.2.1.16
multichannel gain-change difference
interchannel gain-change difference
<for multichannel operation> difference of change in gain in one channel, for a specified channel allocation, with respect to the change in gain of another channel for two specified sets of channel input powers

Note 1 to entry: Multichannel gain-change difference can be expressed as follows ($G_j^{(1)}$, $G_j^{(2)}$ and $G_l^{(1)}$, $G_l^{(2)}$ being the channel gains of the j-th and l-th channel at each of the two specified sets of channel input power (1) and (2) respectively, and j, l = 1, 2, . . . n; n total number of channels):

$$GD_{jl} = [G_j^{(1)} - G_j^{(2)}] - [G_l^{(1)} - G_l^{(2)}]$$

Note 2 to entry: Multichannel gain-change difference is expressed in dB.

Note 3 to entry: The two specified sets of channel input power are in general: (1) all input power levels set to the minimum value and (2) all input power levels set to the maximum value.

Note 4 to entry: Normally, the maximum multichannel gain-change difference will be specified. Different sets of input conditions could be defined in the appropriate product specification.

Note 5 to entry: Forward ASE power level can be relevant for OAs used as pre-amplifiers or line amplifiers. In this case the channel input power will include the forward ASE contribution coming from previous OAs.

Note 6 to entry: This parameter can be used instead of the multichannel gain tilt when the definition of the gain tilt cannot be applied.

3.2.1.17
multichannel gain tilt
interchannel gain-change ratio
dynamic gain tilt
DGT

<for multichannel operation> ratio of the changes in gain in each channel to the change in gain at a reference channel as the input conditions are varied from one set of input channel powers to a second set of input channel powers

Note 1 to entry Multichannel gain tilt can be expressed as follows ($G_j^{(1)}$, $G_j^{(2)}$ and $G_r^{(1)}$, $G_r^{(2)}$ being respectively the channel gains of the j-th and the reference channel at each of the two specified sets of channel input power and j = 1, 2, . . . n; n total number of channels):

$$GT_j = [G_j^{(1)} - G_j^{(2)}] / [G_r^{(1)} - G_r^{(2)}]$$

Note 2 to entry: Multichannel gain tilt is expressed in dB per dB.

Note 3 to entry: Multichannel gain tilt is normally used to predict the gains for each channel for various sets of input channel powers based on observed changes in the reference channel.

Note 4 to entry: The sets of input channel powers are generally those in which (1) all power levels are set equal to the maximum allowed and (2) all powers are set equal to the minimum allowed.

Note 5 to entry: The reference channel should be specified in the appropriate product specification. The multichannel gain tilt of the reference channel is by definition equal to 1 dB/dB.

Note 6 to entry: Application of multichannel gain tilt to prediction of channel gain in different conditions could be impaired in the case of hybrid multistage amplifiers, in homogeneous gain media and in particular for amplifiers with automatic gain control.

Note 7 to entry: This note applies to the French language only.

3.2.1.18
on-off gain
effective gain
<only applicable to distributed amplifier> increase in signal optical power from the output of an optical fibre providing distributed amplification when the pumping is active compared to when the pumping is disabled

Note 1 to entry: The on-off gain differs from gain in that it does not compare the output signal power with the input signal power, since this includes the attenuation of the fibre and this loss can be associated with the transmission system rather than the amplifier. The value for on-off gain is thus higher than for gain by the amount of passive loss between the input and output.

Note 2 to entry: On-off gain is expressed in dB.

3.2.1.19
net on-off gain
<only applicable to distributed amplifier> increase in signal optical power from the output of an optical fibre providing distributed amplification when the pumping is active compared to when no additional fibre optic equipment is installed to the fibre for the purpose of providing distributed amplification

3.2.1.20
wavelength band
wavelength range within which the OA output signal power is maintained in the specified output power range, when the corresponding input signal power lies within the specified input power range

3.2.1.21
available signal wavelength band
<for pre-amplifiers with optical filter(s) only> resulting pre-amplifier wavelength band including the effect of optical filter(s)

3.2.1.22
tunable wavelength range
<for pre-amplifiers with tuneable optical filter(s) only> wavelength range, of the wavelength band, within which the tuneable optical filter(s) inside the pre-amplifier can be tuned

3.2.1.23
channel allocation
<for multichannel operation> channel allocation is given by the number of channels, the nominal central frequencies/wavelengths of the channels and their central frequency/wavelength tolerance

3.2.1.24
gain stability
degree of gain fluctuation expressed by the ratio of the maximum and minimum gain, for a certain specified test period, under nominal operating conditions

Note 1 to entry: Gain stability is expressed in dB.

3.2.1.25
small-signal gain stability
degree of small-signal gain fluctuation expressed by the ratio of the maximum and minimum small-signal gain, for a certain specified test period, under nominal operating conditions

Note 1 to entry: Small-signal gain stability is expressed in dB.

3.2.1.26
maximum gain variation with temperature
change in gain for temperature variation within a specified range

Note 1 to entry: Maximum gain variation with temperature is expressed in dB.

3.2.1.27
maximum small-signal gain variation with temperature
change in small-signal gain for temperature variation within a specified range

Note 1 to entry: Maximum small-signal gain variation with temperature is expressed in dB.

3.2.1.28
large-signal output stability
degree of output optical power fluctuation expressed by the ratio of the maximum and minimum output signal optical powers, for a certain specified test period, under nominal operating conditions and a specified large input signal optical power

Note 1 to entry: Large-signal output stability is expressed in dB.

3.2.1.29
saturation output power
gain compression power
optical power level associated with the output signal above which the gain is reduced by N dB with respect to the small-signal gain at the signal wavelength

Note 1 to entry: The wavelength at which the parameter is specified should be stated.

Note 2 to entry: N = 3 is typically used.

3.2.1.30

nominal output signal power
minimum output signal optical power for a specified input signal optical power, under nominal operating conditions

3.2.1.31
maximum output signal power
highest optical power associated with the output signal that can be obtained from the OA at nominal operating conditions

3.2.1.32
input power range
range of optical power levels such that, for any input signal power of the OA which lies in this range, the corresponding output signal optical power lies in the specified output power range, where the OA performance is ensured

3.2.1.33
output power range
range of optical power levels in which the output signal optical power of the OA lies when the corresponding input signal power lies in the specified input power range, where the OA performance is ensured

3.2.1.34
noise figure
NF
decrease of the signal-to-noise ratio (SNR), at the output of an optical detector with unitary quantum efficiency and zero excess noise, due to the propagation of a shot noise-limited signal through the OA

Note 1 to entry: The operating conditions at which the noise figure is specified should be stated.

Note 2 to entry: This property can be described as a discrete wavelength or as a function of wavelength.

Note 3 to entry: The noise degradation due to the OA, is attributable to different factors, for example signal-spontaneous beat noise, spontaneous-spontaneous beat noise, internal reflections noise, signal shot noise,