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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Optical amplifiers – Test methods –
Part 3: Noise figure parameters

Amplificateurs optiques – Méthodes d'essais –
Partie 3: Paramètres du facteur de bruit

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OPTICAL AMPLIFIERS –
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FOREWORD

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International Standard IEC 61290-3 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

This second edition cancels and replaces the first edition, published in 2000, and constitutes a technical revision. It includes updates to specifically address additional types of optical amplifiers and to highlight that the IEC 61290-3 series pertains to single-channel amplifiers. References have been added to the documents pertaining to multichannel amplifiers.

The text of this standard is based on the following documents:

FDIS	Report on voting
86C/842/FDIS	86C/854/RVD

Full information on the voting for the approval of this standard 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- withdrawn,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.

INTRODUCTION

This International Standard is devoted to the subject of optical amplifiers. The technology of optical amplifiers is still evolving, hence amendments to and new editions of this standard can be expected. Each abbreviation introduced in this standard is explained in the text at least the first time it appears. However, for an easier understanding of the whole text, a list of all abbreviations used in this standard is given in Clause 3.

OPTICAL AMPLIFIERS – TEST METHODS –

Part 3: Noise figure parameters

1 Scope and object

This International Standard applies to all commercially available optical amplifiers (OAs), including OAs using optically pumped fibres (OFAs based on either rare-earth doped fibres or on the Raman effect), semiconductor optical amplifiers (SOAs) and planar waveguide optical amplifiers (PWOAs).

The object of this standard is to provide the general background for OA noise figure parameters measurements and to indicate those IEC standard test methods for accurate and reliable measurements of the following OA parameters, as defined in IEC 61291-1:

a) noise figure (NF);
b) noise factor (F);
c) multiple path interference (MPI) figure of merit;
d) signal-spontaneous noise figure;
e) (equivalent) spontaneous-spontaneous optical bandwidth (B_{sp-sp});
f) forward amplified spontaneous emission (ASE) power level;
g) reverse ASE power level;
h) ASE bandwidth.

This standard addresses measurement of OAs that are to be used for amplifying single channels, that is signals from a single transmitter. Testing of OAs for multichannel use involves additional considerations, such as: the number, wavelengths and relative power of the signals, the ability to measure signals simultaneously and to measure the ASE between channels.

NOTE Methods for measurement of OAs for multichannel use are included in the IEC 61290-10 series.

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

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

IEC 61291-1, *Optical amplifiers – Part 1: Generic specification*

3 Acronyms and abbreviations

ASE	amplified spontaneous emission
B_{sp-sp}	(equivalent) spontaneous-spontaneous optical bandwidth

ESA	electrical spectrum analyzer
F	noise factor
FWHM	full width half maximum
MPI	multiple path interference
NF	noise figure
OA	optical amplifiers
OFA	optical fibre amplifier
OSA	optical spectrum analyzer
PWOA	planar waveguide optical amplifiers
SOA	semiconductor optical amplifiers
SNR	signal-to-noise ratio

4 Noise figure generalities

The noise figure is one of the most important parameters of an OA. Following the definition in IEC 61291-1, the noise factor, i.e. the linear form of the noise figure, can be expressed by:

$$F = \frac{SNR_{\text{input}}}{SNR_{\text{output}}} = \frac{< i_{\text{signal}}{}^2 >_{\text{in}}}{< i_{\text{noise}}{}^2 >_{\text{in}}} \times \frac{< i_{\text{noise}}{}^2 >_{\text{out}}}{< i_{\text{signal}}{}^2 >_{\text{out}}}$$

$$F = \frac{1}{G^2} \frac{< i_{\text{noise}}{}^2 >_{\text{out}}}{< i_{\text{noise}}{}^2 >_{\text{in}}} \qquad (1)$$

where

SNR denotes signal-to-noise ratios;

i denotes photocurrents in an ideal photodetector with a quantum efficiency of 1;

G denotes the optical signal gain.

The input noise current is, by definition, the shot noise current caused by the optical input signal. This excludes other noise sources on the input side.

The output noise current is the sum of five contributions. Each of these contributions can be expressed by a partial noise factor:

a) signal shot noise factor, $F_{\text{shot,sig}}$, from shot noise from amplified input signal;

b) ASE shot noise factor, $F_{\text{shot,ase}}$, from shot noise from amplified spontaneous emission;

c) signal-spontaneous noise factor, $F_{\text{sig-sp}}$, from signal beating with ASE;

d) spontaneous-spontaneous noise factor, $F_{\text{sp-sp}}$, from ASE beating with itself;

e) noise factor from multiple path interference (MPI), F_{mpi}.

The total noise factor (in linear, not logarithmic units) is:

$$F_{\text{total}} = F_{\text{shot,sig}} + F_{\text{shot,ase}} + F_{\text{sig-sp}} + F_{\text{sp-sp}} + F_{\text{mpi}} \qquad (2)$$

The noise figure can be calculated using:

$$NF = 10\log(F_{\text{total}}) \tag{3}$$

Equation (2) can be used for optical noise figure measurements, as well as for estimating the influence of various parameters in electrical noise figure measurements. It represents a complete noise figure model of an OA.

5 Noise figure contributions

The signal shot noise factor is:

$$F_{\text{shot,sig}} = \frac{1}{G}, \tag{4}$$

where G is the gain at the signal wavelength.

The ASE shot noise factor is:

$$F_{\text{shot,ase}} = \frac{P_{\text{ase}}}{G^2 P_{\text{in}}} \tag{5}$$

where

P_{ase} is the wavelength-integrated ASE power;

P_{in} is the optical input signal power.

The signal-spontaneous noise factor is:

$$F_{\text{sig-sp}} = 2\frac{\rho_{\text{ase,p}}}{G\text{h}\nu_{\text{sig}}} \tag{6}$$

where

$\rho_{\text{ase,p}}$ is the optical power density of spontaneous emission, in the same polarization state as the output signal, at the signal wavelength, in W/Hz;

h is Planck's constant;

$\nu_{\text{sig}} = c/\lambda_{\text{sig}}$ is the optical signal frequency, in Hz.

The spontaneous-spontaneous noise factor is:

$$F_{\text{sp-sp}} = \frac{\rho_{\text{ase}}{}^2 B_{\text{sp-sp}}}{2\text{h}\nu_{\text{sig}} G^2 P_{\text{in}}} \tag{7}$$

where

ρ_{ase} is the optical power density of total (unpolarized) spontaneous emission, at the signal wavelength, in W/Hz;

$B_{\text{sp-sp}}$ is the equivalent spontaneous-spontaneous optical bandwidth defined in IEC 61291-1; it depends on power and wavelength of input signal.

NOTE When $B_{\text{sp-sp}}$ is known, there is no need for separate measurement of $F_{\text{sp-sp}}$ because it can be calculated from the signal spontaneous noise factor and the input power. Since ASE in any polarization state contributes to

$F_{sp\text{-}sp}$, this calculation also needs additional information if the ASE is not unpolarized, as is typical for example for SOAs.

Multiple path interference (MPI) noise is generated by beating between the output signal and one or more doubly reflected replica of the output signal. Two or more reflection points inside the OA are necessary to generate MPI noise. When all reflection points are separated by more than the coherence length of the optical source, then the MPI noise factor is as follows:

$$F_{mpi} = \frac{2P_{in}}{h\nu\pi} \frac{\Delta\nu}{f^2 + \Delta\nu^2} \sum_i \left(p_i G_{cav,i}\right) \tag{8}$$

where

$G_{cav,i}$ is the cavity gain (gain in the i^{th} parasitic cavity in the OA) = gain in forward direction × reflectivity in forward direction × gain in backward direction × reflectivity in backward direction;

p_i is the polarization alignment factor, and expresses the matching of polarization states between the direct and doubly reflected signal in the i^{th} cavity (between 0 and 1, p = 1 for perfect alignment);

$p_i\, G_{cav,i}$ is the effective cavity gain of the i^{th} cavity;

Σ is meant to collect all possible cavity gains in the OA;

$\Delta\nu$ is the FWHM of the source linewidth (Lorentzian model);

f is the baseband frequency.

When two or more light beams are coherent with each other, i.e. generated by closely spaced reflection points, MPI cannot be considered as noise, but rather as slow power fluctuations. In these cases, MPI does not contribute to the NF. The MPI contribution to the noise factor depends on the linewidth of the source, $\Delta\nu$, a parameter of the transmission system or measurement apparatus but not on the OA. To remove this parameter from the OA noise factor, it is suggested to integrate the MPI noise factor and denote the integration result a figure of merit, I_{mpi}, for the MPI characteristics of the OA. I_{mpi} represents the area under the F_{mpi} curve; it does not depend on the linewidth of the source or the baseband frequency:

$$I_{mpi} = \int_{f=0}^{\infty} F_{mpi}\, df = \frac{P_{in}}{h\nu} \sum_i \left(p_i G_{cav,i}\right) \quad [\text{Hz}] \tag{9}$$

where the MPI noise factor can be calculated from the figure of merit using:

$$F_{mpi} = \frac{2\, I_{mpi}}{\pi} \frac{\Delta\nu}{f^2 + \Delta\nu^2} \tag{10}$$

A special form of MPI known as double-Rayleigh scattering can be a significant factor in Raman fibre amplifiers, where long spans of fibre can provide gain for the small amount of signal that is backscattered by the Rayleigh effect in fibre, rather than due to reflections.

6 Noise figure test methods

Two qualitatively different and commonly practised procedures for quantifying the noise figure of an OA are considered in this standard.

The aim of the first procedure (see IEC 61290-3-1) is to determine the signal-spontaneous noise figure. This method uses an optical spectrum analyzer to determine gain and spectrally resolved ASE; the signal-spontaneous noise figure is calculated from these two quantities as outlined in Clause 5. Except for the noise contribution from multiple path interference (MPI),