IEC TR 61292-9

Edition 3.0 2023-01
REDLINE VERSION

TECHNICAL REPORT

colour inside

Optical amplifiers –
Part 9: Semiconductor optical amplifiers (SOAs)



IEC TR 61292-9:2023-01 RLV(en)



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2023 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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 It also gives information on projects, replaced and withdrawn publications.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 61292-9

Edition 3.0 2023-01
REDLINE VERSION

TECHNICAL REPORT

colour inside

Optical amplifiers –
Part 9: Semiconductor optical amplifiers (SOAs)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.160.10; 33.180.30

ISBN 978-2-8322-6367-9

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 4
INTRODUCTION 6
1 Scope 7
2 Normative references 7
3 Terms, definitions, abbreviated terms and symbols 7
3.1 Terms and definitions 7
3.2 Abbreviated terms 8
3.3 Symbols 9
4 Specific features of SOAs 10
4.1 SOA chips 10
4.2 Gain ripple 13
4.2.1 General 13
4.2.2 Theoretical calculation of gain ripple 14
4.3 Polarization dependent gain (PDG) 18
4.3.1 General 18
4.3.2 Polarization insensitive SOAs 18
4.4 Noise figure (NF) 18
4.5 Lifetime of carriers 19
4.6 Nonlinear effects 19
5 Measurement of SOA output power and PDG 19
5.1 Narrow-band versus broadband light source 19
~~5.2 Recommended set-up for output power and PDG measurements .....~~
5.2 Examples of measurement results ~~obtained by using the recommended set-up~~ 21
Annex A (informative) Applications of SOAs 26
A.1 General 26
A.2 Polarization mode of SOAs 26
A.3 Reach extender for GPON 26
A.4 Pre-amplifier in transceivers for 100 Gbit Ethernet 26
A.5 Monolithic integration of SOAs 27
A.6 Reflective SOAs (RSOAs) 28
Bibliography 30

Figure 1 – Schematic diagram of the typical SOA chip 10
Figure 2 – Example of gain dependency of an SOA chip on forward current 11
Figure 3 – Schematic top view of a typical SOA chip with and without an angled waveguide structure 12
Figure 4 – Schematic top view of a typical SOA module 13
Figure 5 – Schematic diagram of the optical feedback inside the SOA chip 13
Figure 6 – Schematic diagram of gain ripple 14
Figure 7 – Illustrated model of a Fabry-Perot type SOA 15
Figure 8 – Illustrated model of ASE output from an SOA 16
~~Figure 8 – Recommended measurement set-up for optical power and PDG of SOA modules .....~~
~~Figure 9 – Recommended measurement set-up for optical power and PDG of SOA chips .....~~

Figure 9 – SOA output power and PDG dependence on wavelength 20
Figure 10 – Optical power spectra of three different SOA chips..... 22
Figure 11 – Output power and PDG of SOA chip sample 1 as a function of I_F..... 23
Figure 12 – Output power and PDG of SOA chip sample 2 as a function of I_F..... 23
Figure 13 – Output power and PDG of SOA chip sample 3 as a function of I_F..... 24
Figure A.1 – Schematic diagram of the receiver section of SOA-incorporated CFP transceivers 27
Figure A.2 – Schematic diagram of the DFB-LDs-array type wavelength tuneable LD 28
Figure A.3 – Schematic diagram of a seeded WDM-PON system 29

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

OPTICAL AMPLIFIERS –

Part 9: Semiconductor optical amplifiers (SOAs)

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.

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC TR 61292-9:2017. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC TR 61292-9 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 2017. This edition constitutes a technical revision.

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

a) revised definitions for SOAs in 3.1;
b) added more theoretical background on gain ripple measurements using amplified spontaneous emission (ASE) spectrum in 4.3;
c) removed the formerly preferred set-up for output power and PDG measurements in Clause 5.

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

Draft	Report on voting
86C/1820/DTR	86C/1830/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.

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.

A list of all parts in the IEC 61292 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 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.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

~~Optical amplifiers (OAs) are necessary components as booster, line and pre-amplifiers for current optical network systems. IEC TC 86/SC 86C has published many standards for OAs, and most of them are focused on optical fibre amplifiers (OFAs), which are commonly deployed in commercial optical network systems. Recently, semiconductor optical amplifiers (SOAs) have attracted attention for applications in gigabit passive optical network (GPON) and 100 Gbit Ethernet (GbE) systems. This is because SOA chips are as small as laser diodes (LDs) and only require an electrical current.~~

~~Although SOAs for the 1 310 nm or 1 550 nm bands have been extensively studied since the 1980s, the use of SOAs is still limited to laboratories or field trials. This is due to specific performance features of SOAs such as gain ripple and polarization dependent gain (PDG). Thus, there are very few IEC standards addressing SOAs. One example is IEC TR 61292-3, which is a Technical Report for classification, characteristics and applications of OAs including SOAs. However, it only deals with general information on SOAs and does not contain the detail information on test methods that are necessary to measure precisely the particular parameters of SOAs.~~

~~This part of IEC 61292 provides a better understanding of specific features of SOAs as well as information on measuring gain and PDG. It is anticipated that future standards will address performance and test methodology.~~

Optical amplifiers (OAs) are essential components for fibre optic communication systems, where they serve as booster amplifiers, in-line amplifiers, and pre-amplifiers. Numerous standards have been published for OAs (e.g., the IEC 61290 series and IEC 61291 series). However, most of these standards focus on optical fibre amplifiers (OFAs) because these are commonly deployed in commercial fibre optic networks. Recently, semiconductor optical amplifiers (SOAs) have attracted attention for applications in Gbit passive optical networks (GPONs) and Gbit Ethernet (GbE) systems, which operate at line rates of 100 Gbit/s and beyond. SOA chips are as small as laser diodes (LDs) and are directly driven by an electrical current.

Although SOAs operating in the 1 310 nm or 1 550 nm wavelength bands have been extensively studied since the 1980s, SOAs have mostly been used in laboratories or in field trials. This is due to certain performance limitations of SOAs, such as gain ripple and polarization dependent gain (PDG). As a result, there are few IEC documents addressing SOAs. One exception is IEC TR 61292-3, which is a Technical Report on classification, characteristics, and applications of OAs including SOAs. However, IEC TR 61292-3 presents only general information on SOAs and does not contain detailed information on test methods for measuring the particular performance parameters of SOAs.

IEC 61290-1-1:2020 describes test methods for power and gain parameters of OAs, which includes a method for gain ripple measurements on SOAs. This document has been revised to harmonize its content with IEC 61290-1-1 and with IEC 61291-2.

This document provides more detailed descriptions of the specific features of SOAs, including information on gain ripple and PDG.

OPTICAL AMPLIFIERS –

Part 9: Semiconductor optical amplifiers (SOAs)

1 Scope

This part of IEC 61292, which is a Technical Report, ~~focuses on semiconductor optical amplifiers (SOAs), especially the specific features and measurement of gain and polarization dependent gain (PDG)~~ describes the characteristic features of semiconductor optical amplifiers (SOAs), including the specific features of gain ripple and polarization dependent gain (PDG).

This document focuses on amplifying applications of SOAs. Other applications, such as modulation, switching and non-linear functions, are not covered.

Potential applications of SOAs, such as reflective SOAs (RSOAs) for the seeded wavelength division multiplexing passive optical network (WDM-PON), are reviewed in Annex A.

2 Normative references

~~There are no normative references in this document.~~

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, *Optical amplifiers – Part 1: Generic specification*

IEC 61291-2:2016, *Optical amplifiers – Part 2: Single channel applications – Performance specification template*

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 61291-1:2018, IEC 61291-2:2016, 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

3.1.1
SOA
semiconductor optical amplifier
~~semiconductor optical amplifier that includes the "SOA chip" and the "SOA module"~~

optical amplifier in which the active optical waveguide is formed by a semiconductor laser diode structure, which is electrically pumped

Note 1 to entry: SOAs have a similar structure to Fabry-Perot semiconductor laser diodes but with anti-reflection elements at the end surfaces. The optical signal is amplified through the stimulated emission phenomenon in the gain medium.

[SOURCE: IEC 61291-2:2016, 3.1.3, modified – Note 1 to entry has been added.]

3.1.2
SOA chip
semiconductor chip that is the active component of the SOA module

3.1.3
SOA module
fibre-pigtailed optical component that consists of the SOA chip, lenses, optical isolators (if necessary), a thermoelectric cooler (TEC), a thermistor, a package, and optical fibre(s)

3.1.4
population inversion factor
n_{sp}
ratio of the injected carrier density N to the subtraction of the carrier density N_0 where the stimulated emission is equal to the stimulated absorption from N

$$n_{sp} = \frac{N}{N - N_0}$$

Note 1 to entry: In the semiconductor optical amplifier (SOA) field, the population inversion factor is composed of not only carrier density parameters but also combination of the confinement factor Γ, the optical gain g, and internal optical losses α of the optical waveguide of SOA chip. It is defined as:

$$n_{sp} = \frac{N}{N - N_0} \times \frac{\Gamma \times g}{\Gamma \times g - \alpha}$$

Note 2 to entry: The carrier density N_0 at which the stimulated emission is equal to the stimulated absorption ~~may be~~ is often called "transparent carrier density".

3.2 Abbreviated terms

AR	anti-reflection
ASE	amplified spontaneous emission
BPF	band pass filter
CFP	100 G form factor pluggable
CW	continuous wave
DEMUX	demultiplexer
DFB	distributed feedback
EDFA	erbium-doped fibre amplifier
FWM	four-wave mixing
GbE	gigabit Ethernet
GPON	gigabit capable passive optical network
LD	laser diode
MSA	multi-source agreement
MMI	multi-mode interference
MQWs	multiple quantum wells
NF	noise figure
OA	optical amplifier

OFA optical fibre amplifier
OLT optical line termination
ONU optical network unit
~~OPM optical power meter~~
PC polarization controller
PD photodiode
PDCE polarization dependence of coupling efficiency
PDG polarization dependent gain
PIC photonic integrated circuit
POL polarizer
PON passive optical network
RSOA reflective semiconductor optical amplifier
~~SLD superluminescent diode~~
SMF single-mode fibre
SOA semiconductor optical amplifier
TE transverse electric
TEC thermoelectric cooler
TIA transimpedance amplifier
TM transverse magnetic
VOA variable optical attenuator
WDM wavelength division multiplexing
XGM cross gain modulation
XPM cross phase modulation

3.3 Symbols

G optical gain
I_F forward current
L chip length
n_{eff} effective refractive index
~~NF noise figure~~
n_{sp} population inversion factor
~~$PDCE$ polarization dependence of coupling efficiency~~
PDG_{active} polarization dependence of active layer gain
PDG_{total} total polarization dependence of single pass gain
R reflectivity
ΔG_{ripple} peak to peak amplitude of gain ripple
$\Delta\lambda_{ripple}$ period of gain ripple
Γ_{TE} TE mode confinement factor
Γ_{TM} TM mode confinement factor
λ wavelength