

Optical amplifiers —

Part 3: Classification, characteristics and applications

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National foreword

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Cross-references

The British Standards which implement international publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

Summary of pages

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**Partie 3:
Classification, caractéristiques
et applications**

Optical amplifiers –

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and applications**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL AMPLIFIERS –

Part 3: Classification, characteristics and applications

FOREWORD

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IEC 61292-3, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
86C/407/DTR	86C/480A/RVC

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

IEC 61292 consists of the following parts, under the new general title *Optical amplifiers*:

Part 1: Parameters of amplifier components

Part 2: Theoretical background for noise figure evaluation using the electrical spectrum analyzer

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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 2009. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

INTRODUCTION

The rapid maturity of erbium doped fibre amplifier, EDFA, is pulling many new types of optical amplifiers into the market place and it is also stimulating many new types of fibre and non-fibre based optical amplifier research in the laboratories. This has created a large number of abbreviations, sometimes used liberally in the literature. This report is to promote the consistent use of optical amplifier abbreviations and to establish a family tree for the classification of optical amplifiers, including those still being researched in laboratories, so that their similarities and differences can readily be identified. The report also includes a brief description of each amplifier family, highlighting their generic properties, performances and applications at the time of writing. However, it is important to point out that in such fast evolving technology, the reader should always refer to the latest conferences and publications for state-of-the-art results.

Optical fibre amplifiers can either be grouped by their fluorescent dopant or by their fibre host. The family tree described in this report is by fluorescent dopant simply because of historical reasons, i.e. the well established optical amplifier in the market place is called erbium doped fibre amplifier, EDFA, and not called silica fibre amplifier doped with erbium. As can be seen in this report, erbium can also be used as a dopant in other fibre hosts, such as fluoride and tellurite as well as a dopant or co-dopant in the silica fibre. With the rapid saturation of transmission capacity in the erbium window, there is a great deal of interest on the search of new active fibres, which can provide optical gain outside the erbium window. These new amplifiers operating together with existing EDFAs can realize the full potential of the silica fibre low-loss bandwidth, of the order of 150 nm to 200 nm, in future transmission systems.

All optical amplifiers in this report require an optical pump source for photon stimulation, with the exception of the SOA (semiconductor optical amplifier) where the stimulated photon emission is by current injection through the heterojunction of a compound semiconductor material. Other types of non-fibre based optical amplifiers, such as those using doped silica planar waveguide and doped polymer waveguide are achieving useful levels of performance. They may lead to an extra dimension in flexibility, leading to photonic integration and lossless optical network elements and functionalities. New products based on such technology are beginning to emerge and a numbers of abbreviations have been used in the literature such as POWA (planar optical waveguide amplifier), PWOA (planar waveguide optical amplifier) and EDWA (erbium doped waveguide amplifier). In this report, we have attempted to rationalize the use of these new abbreviations as shown in the amplifier family tree. No doubt other new types of optical amplifiers and new abbreviations will appear in future to be added to the list.

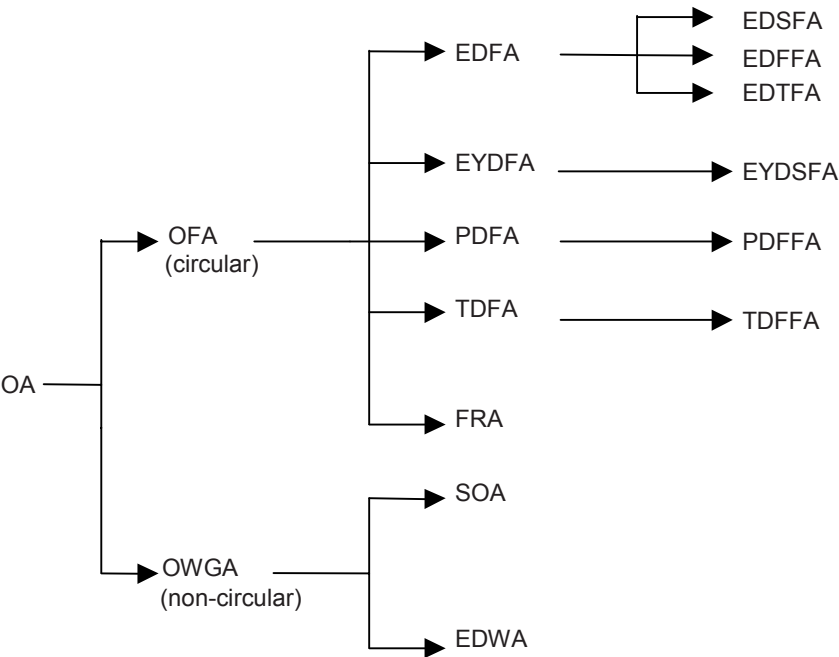
OPTICAL AMPLIFIERS –

Part 3: Classification, characteristics and applications

0 Scope

This part of IEC 61292 establishes a family tree for the classification of optical amplifiers, including those still being researched in laboratories, so that their similarities and differences can readily be identified. The report also includes a brief description of each amplifier family, highlighting their generic properties, performance and applications at the time of writing.

1 Optical amplifier family tree and abbreviations



OA	Optical amplifier
OFA	Optical fibre amplifier
EDFA	Erbium doped fibre amplifier
EDSFA	Erbium doped silica fibre amplifier (commonly known as EDFA)
EDFFA	Erbium doped fluoride fibre amplifier
EDTFA	Erbium doped tellurite fibre amplifier
EYDFA	Erbium ytterbium doped fibre amplifier
EYDSFA	Erbium Ytterbium doped silica fibre amplifier
PDFA	Praseodymium doped fibre amplifier

PDFFA	Praseodymium doped fluoride fibre amplifier (also known as PDFA)
TDFA	Thulium doped fibre amplifier
TDFFA	Thulium doped fluoride fibre amplifier (also known as TDFA)
FRA	Fibre Raman amplifier
OWGA	Optical wave guide amplifier
SOA	Semiconductor optical amplifier
EDWA	Erbium doped waveguide amplifier (also called POWA)

2 Optical amplifier operating bands

The first optical fibre amplifiers on the market were erbium doped silica fibre amplifiers, or EDFAs, operating in the 1,55 μm low loss transmission window of the silica transmission fibre. Although EDFAs have approximately 35 nm of optical bandwidth between approximately 1 528 nm and 1 563 nm, the gain is not flat across this window, or band. The first amplifiers were narrow band single wavelength amplifiers designed to take advantage of the natural gain peaks within this gain window, at approximately 1 533 nm and 1 557 nm. With the emerging WDM market, the inherent “flat” gain region of the EDFA at certain gain conditions between approximately 1 540 nm and 1 563 nm were used to support multi-channel applications. This flat gain region has been called the red-band by some manufacturers and has typically between 18 nm to 23 nm of bandwidth.

Research on erbium doped fluoride fibre amplifiers, EDFFAs, has demonstrated that they have a similar bandwidth as EDFAs but the gain is inherently flatter, thus have a wider useable WDM window than the EDFA red-band, able to support more WDM channels. However, with the introduction of gain flattening filter technologies, these filters were able to smooth out the EDFA gain peaks, especially the one at 1 533 nm, allowing EDFAs also to achieve a similar overall useable WDM window as EDFFAs. The EDFA and filter solution is currently the most commonly used solution in products. These amplifiers have been called full band amplifiers but more recently, for reasons to be explained later, C-band amplifiers, i.e. conventional band. The ITU-T considers that the C-band is defined over the 1 530 nm to 1 565 nm wavelength range for single-mode optical transmission systems. The lower half of the C-band is also sometimes called the blue-band. The precise boundary between blue and red band is vendor-dependent.

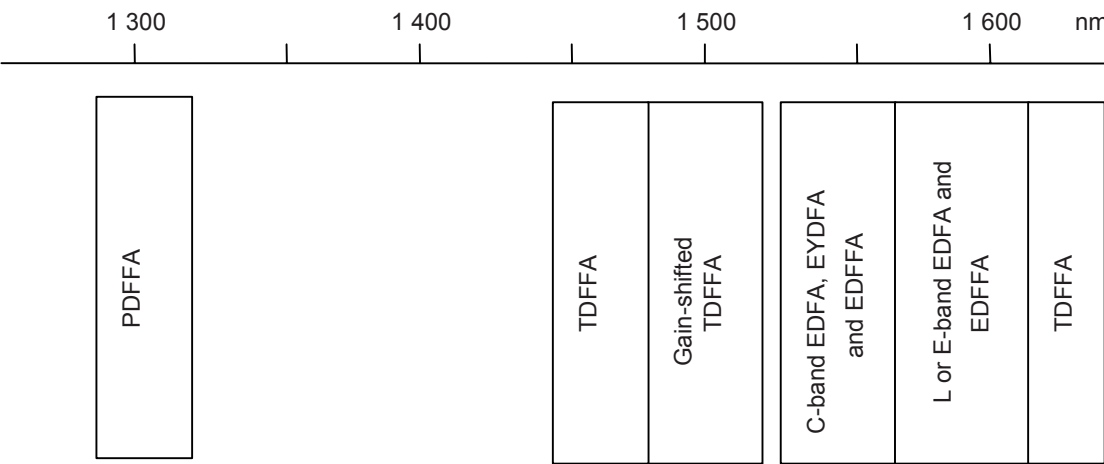
In the last few years, it was discovered that by taking advantages of the high power, low cost pumps, the low inversion region of the erbium fibre gain spectrum at the long wavelength end can be accessed for practical applications, opening up an entirely new amplification window. This window is approximately 1 570 nm to 1 620 nm. It is often referred to as the L-band because it operates in the longer wavelength than C-band. The ITU-T considers that the L-band is defined over 1 565 to 1 625 nm wavelength range for single-mode optical transmission systems. Amplifiers operating in this band often are called LWEDFAs, i.e. long wavelength EDFAs. This band is also sometimes called E-band, i.e. extended band. The combined C and L-band is also called the erbium band, reflecting the optical gain window obtainable from EDFAs.

Research on new materials had led to erbium doped tellurite fibre amplifiers, or EDTFAs. These amplifiers can give a very broad, continuous gain window from approximately 1 530 nm to 1 620 nm. It embraces both the C and L bands provided by EDFAs. Other material research had led to thulium doped fluoride fibre amplifiers, or TDFFAs. These amplifiers give gain between approximately 1 450 nm and 1 480 nm. This band is currently referred to as the S-band. Recent results indicate that amplifiers for the 1 480 nm to 1 528 nm window can also be obtained from this material system and this band has been called gain-shifted S-band. In some publications, the entire window below from approximately 1 520 nm to 1 450 nm is referred as S-band (ITU-T considers that the S-band is defined over the 1 460 nm to 1 530 nm wavelength range for single-mode optical transmission systems). Thulium doped fibre with terbium ions in its cladding have also demonstrated gain beyond L-band at 1 650 nm.

Outside the 1,55 μm transmission window, the praseodymium doped fluoride fibre amplifier, PDFFA, can provide gain in the 1,31 μm transmission window, as well as fibre Raman amplifiers, FRAs and semiconductor optical amplifiers, SOAs.

Both semiconductor optical amplifiers and simple, single pumped fibre Raman amplifiers can provide approximately 30 nm of bandwidth. The center wavelength of the gain window in the case of SOA is determined by the semiconductor material properties and in the case of Raman is determined by the pump wavelength and the Stoke shift of the fibre. Up to 100 nm of bandwidth has been reported from multi-pumped Raman amplifiers. Both amplifiers can in principle, provide gain anywhere in the silica fibre transmission window but reported work to date are mainly in the 1,55 μm and 1,31 μm windows.

The diagram below illustrates the operating windows, or bands, of the amplifiers described in this report.



← FRA and SOA in principle – reported operation in both 1,31 μm and 1,55 μm windows →