IEC TR 61292-8

Edition 1.0 2019-01

TECHNICAL REPORT

colour inside

Optical amplifiers –
Part 8: High-power amplifiers

IEC TR 61292-8:2019-01(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 33.160.10, 33.180.30

ISBN 978-2-8322-6421-8

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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IEC TR 61292-8, which is a technical report, has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics.

Optoelectronics Industry and Technology Development Association (OITDA), Technical Paper OITDA/TP 26/AM, *General information for high power optical amplifier* has served as the basis for the elaboration of this Technical Report.

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

Draft TR	Report on voting
86C/1534/DTR	86C/1549/RVDTR

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.

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

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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

Optical amplifiers (OAs) are necessary components as booster, line and pre-amplifiers for current optical network systems. IEC TC 86/SC 86C, therefore, has published many standards for OAs. Since the mid-2000s, high optical output power amplifiers have been used for applications in passive optical network (PON) and community access television (CATV) systems.

Although OAs with optical power greater than 500 mW are deployed in the field, there are very few documents addressing high optical power applications.

This document provides a better understanding of high-power amplifiers, especially those based on cladding pump technology, and addresses the handling of high optical power.

OPTICAL AMPLIFIERS –

Part 8: High-power amplifiers

1 Scope

This document deals with high-power optical amplifiers. It provides general information relating to high-power optical amplifiers with an output power greater than 500 mW for the fibre communication field. It covers the following aspects:

– general information;
– example of the optical amplifier's configuration realizing high optical output power;
– test method for optical output power and gain;
– considerations on high-power optical amplifiers.

Potential applications of high-power optical amplifiers are briefly reviewed in Annex A.

Informative IEC documents related to high optical power are listed in Annex B.

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, *Optical amplifiers – Part 1: Generic specification*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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 Abbreviated terms

For the purposes of this document, the abbreviated terms given in IEC 61291-1 and the following apply.

ASE	amplified spontaneous emission
CO	central office
DC	double-clad
DWDM	dense wavelength division multiplexing
EDF	erbium-doped fibre
EDFA	erbium-doped fibre amplifier

FTTH	fibre to the home
HP-EDFA	high-power erbium-doped fibre amplifier
MLFL	mode-locked fibre laser
MM	multi-mode
MUX	multiplexer
NA	numerical aperture
OA	optical amplifier
OFA	optical fibre amplifier
OLT	optical line termination
ONU	optical network unit
OSNR	optical signal-to-noise ratio
PCE	power conversion efficiency
PON	passive optical network
SM	single-mode
TV	television
V-OLT	video optical line termination
V-ONU	video optical network unit
WDM	wavelength division multiplexing

4 General

This document provides typical configuration and performance of high-power optical amplifiers and guidance of test method and special consideration. Potential applications of high-power optical amplifiers are also briefly reviewed in Annex A. Informative IEC documents related to high optical power are listed in Annex B.

5 Configuration

5.1 EDFAs using combined single-mode pump laser diodes

Figure 1 is a schematic diagram of an erbium-doped fibre amplifier (EDFA) using multiple single-mode pump lasers. Multiplexing many single-mode pump lasers within the 1 4xx-nm band is commonly used to obtain high power output, since EDF has a wide absorption spectrum in the 1 480-nm band compared to the 980-nm band. The closeness of 1 480-nm pumping and signal wavelengths also benefits power conversion efficiency and thus mean 1 480-nm pumps are used for high power.

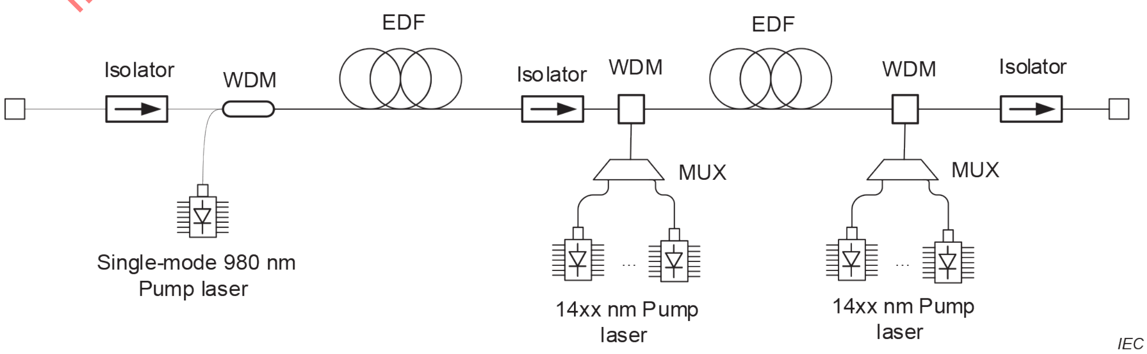

Figure 1 – Schematic diagram of EDFA using multiplexed single-mode pump lasers

Figure 2 shows an example of the output characteristics of a high-power EDFA.

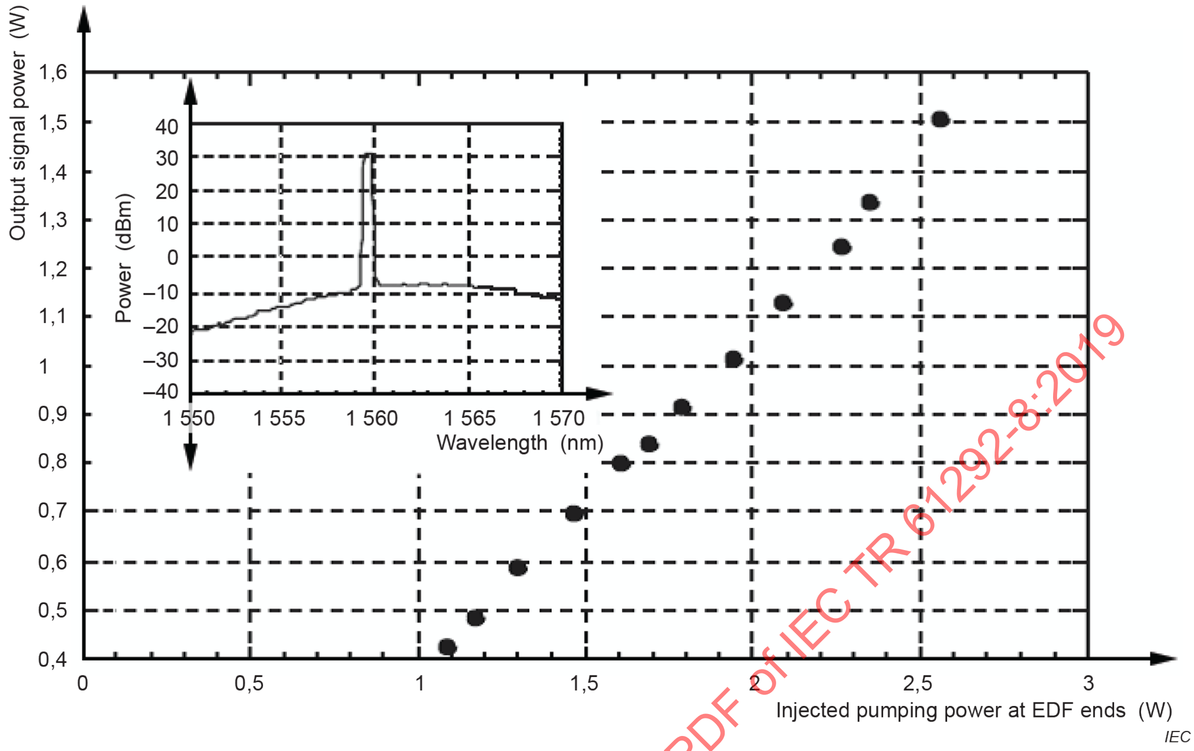

Figure 2 – Output characteristics of a high-power EDFA

In addition to the design of wavelength multiplexing, the concept of polarization multiplexing technologies, which combines two input pump light sources in orthogonal polarizations into one output, is also applicable to realize higher output power. By using a number of wavelengths in wavelength division multiplexing, it is possible to obtain high pump power although it is necessary to stabilize the wavelength. As the number of wavelengths increases, the insertion loss of the multiplexer increases. Thus, the optical power conversion efficiency gets worse. On the other hand, polarization multiplexing does not need to stabilize the wavelength, so it is useful way when there are a few pumping lasers to be multiplexed. If signals into EDF are polarized, polarization multiplexing can suffer from needing to balance the powers into the multiplexer to maintain low DOP in order to suppress the polarization dependent gain. It is also possible to utilize a combination of both multiplexing methods.

Several high-power pump sources are also utilized as a pump source, a 1 480-nm cascaded Raman resonator, for example. Figure 3 shows the schematic diagram of the EDFA by using a pump laser, which is a cascaded Raman resonator.

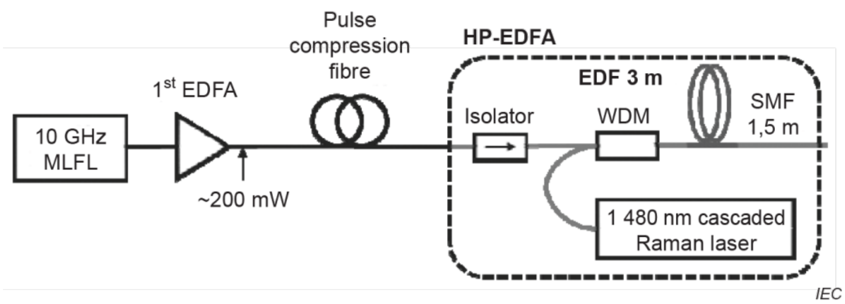

Figure 3 – Schematic diagram of an EDFA using a cascaded Raman resonator

5.2 Cladding pumped fibre amplifier

5.2.1 General

Figure 4 is a schematic diagram of a cladding-pumped fibre amplifier. In this example, an EDFA using a single-mode pump laser diode is used as pre-amplifier because the pre-amplifier stage needs high gain to achieve a low noise figure and thus requires a longer active fibre with higher absorption, but the length of cladding fibre is limited by the absorption of pump light. Also there is a parasitic effect, such as 1-µm ASE in erbium–ytterbium co-doped fibre. Therefore, the gain achieved in a cladding-pumped fibre amplifier is less than that of the conventional EDFA, and higher input power is required to obtain higher output power.

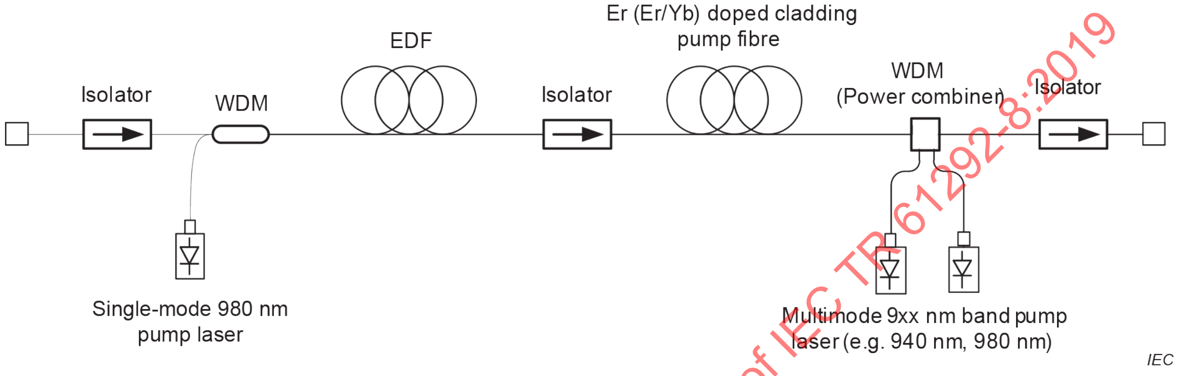

Figure 4 – Schematic diagram of a cladding-pumped fibre amplifier

5.2.2 Cladding-pumped methodology

5.2.2.1 General

Cladding-pumped technology utilizes a multi-layer fibre composed of an inner cladding around the rare-earth-element-doped fibre core for signal transmission that is surrounded by an outer cladding of a lower refractive index. The large area of the inner cladding with a large numerical aperture enables coupling of the high-power pump light from the multi-mode pump laser, which has higher electrical efficiency than a single-mode pump laser. Though the optical conversion efficiency of the cladding-pump method is generally worse than that of the core-pump method, the two approaches complement each other to achieve the highest output power.

In Figure 5, a signal light, shown by the red line, is launched into the core while the pump light, expressed as the green line, launched into the inner cladding also propagates into the fibre core, where it can be absorbed by laser-active ions. Note that the inner cladding is un-doped, so there is no pump absorption in this region. Only the overlap of pump light with the doped core is reduced, as much of the pump power travels in the un-doped inner cladding.

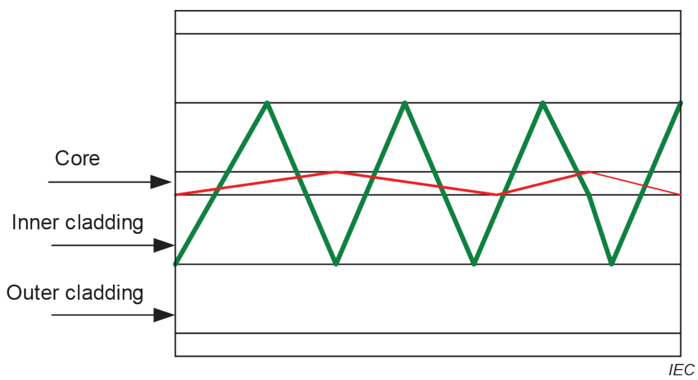

Figure 5 – Schematic of cladding pumping

5.2.2.2 Pumping methods

a) End-pumping

The pump light is launched into the same end of the fibre as the EDFA using a conventional single-mode erbium-doped fibre with filter-based passive device, as shown in Figure 6.

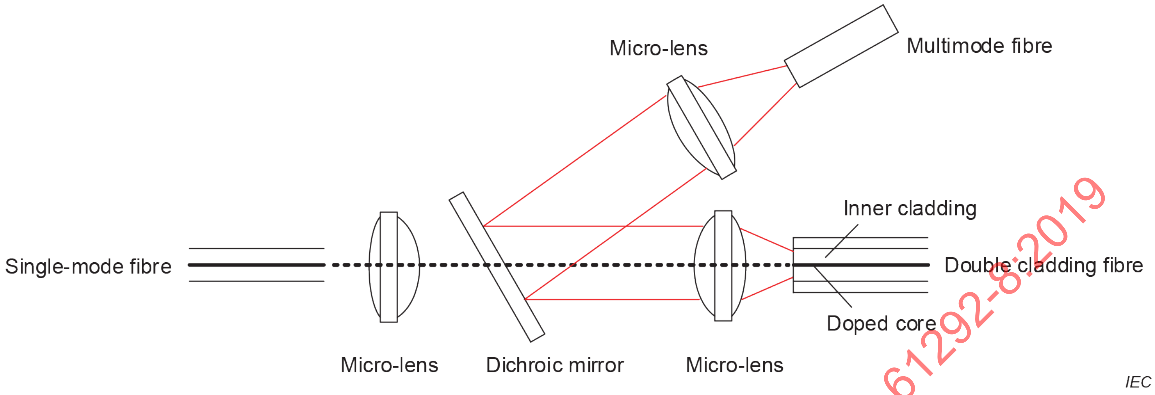

Figure 6 – Schematic structure of end-pumping

b) Fused bundled fibre pump combiner

In this method, several multi-mode fibres are bundled together, fused and drawn into a taper, fusion spliced to a double-clad (DC) fibre, and recoated with a low-index polymer. Figure 7 shows an example of this implementation.

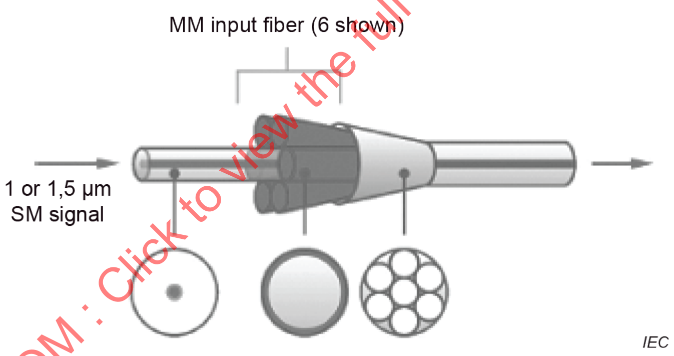

Figure 7 – Schematic structure of a fibre bundle power combiner

c) V-groove side pumping

In this approach, the double cladding fibre is stripped and bonded to a glass slide; a V-shaped notch is cut into the inner cladding, and the pump beam is launched by total internal reflection from the facet of the V-groove, as in Figure 8.

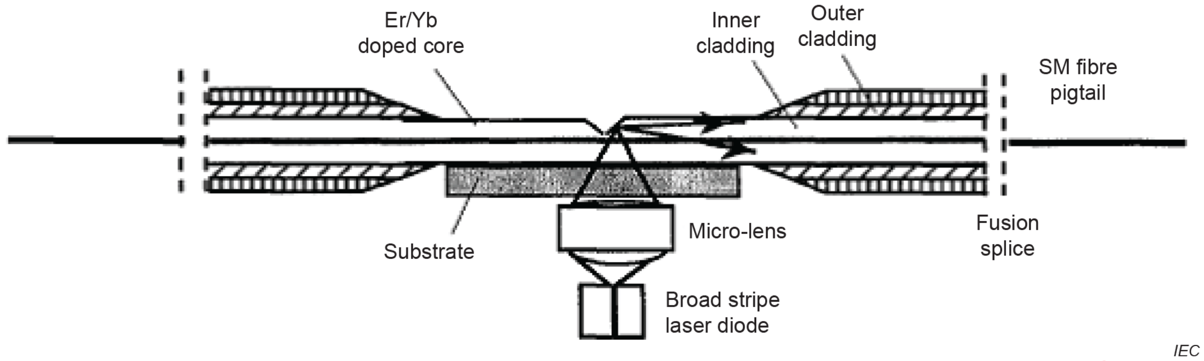

Figure 8 – V-groove side pumping arrangement

5.2.2.3 Key components

The key components for a cladding-pumped amplifier are as follows.

a) Active fibre

For the gain medium of the cladding-pumped amplifier, double cladding (DC) fibre is used. DC fibre is an optical fibre with a structure consisting of three layers of optical material instead of the usual two layers. Figure 9 is an illustration of a typical DC fibre. The innermost layer is called the core. It is surrounded by the inner cladding, which itself is surrounded by the outer cladding. The three layers are made of materials with different refractive indices. The core is doped with active dopant material, which both guides and amplifies the signal light. The inner cladding and core guide the pump light, which provides the energy to amplify the signal in the core. The core has the highest refractive index; the inner cladding has a lower refractive index than the core, and the outer cladding has the lowest. The inner cladding is typically not circular but uniform-shaped, with the aim of guiding efficiently by eliminating skew propagation that does not contribute to pumping the pumping light over the rare-earth-doped core. In most cases, the outer cladding is made of a polymer material rather than of glass.

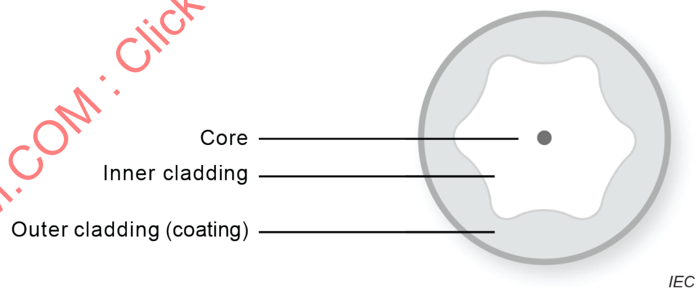

Figure 9 – Schematic diagram of a cross section of an example of double-cladding fibre

Figure 10 shows another example of double-cladding fibre. Here, the inner cladding for the pump laser is supported by very thin struts filled with an air hole. The air hole works to have a lower index than the inner cladding, and the pump light is captured by the inner cladding. Such a structure will have a very high numerical aperture (NA) for the pump light, which relaxes the requirements for pump beam quality.

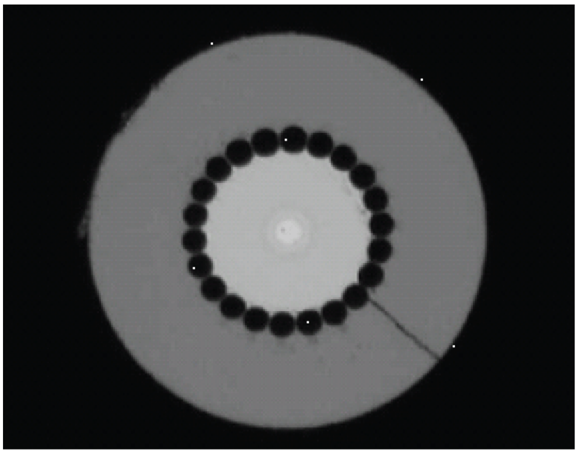

Figure 10 – Cross-section of the hole-assisted double cladding fibre

Co-doping ytterbium ions into an erbium-doped core is common in active fibre for high-power amplifiers. There are two advantages of ytterbium co-doping. One is broadening the 980-nm absorption region. Ytterbium has absorption in the 980-nm region and transfers pump photons into the erbium excited state. It helps reduce the pair-induced quenching effect and enables the use of multiple-pump laser wavelengths throughout the absorption band. The second advantage is preventing erbium ions from forming clusters, which makes high-concentration erbium doping possible and suppresses cooperative up-conversion, which depletes the useful excited erbium ion. An efficient energy transfer from ytterbium ions to erbium ions also makes this technique advantageous.

b) Power combiner

For pumping double-cladding fibre, a multiplexing device to combine high-power pump laser light into a single beam, as described in 5.2.2.2, is necessary.

c) Pump laser diode

Multimode 980-nm band (e.g. 940 nm, 980 nm) lasers with a more than 4,0 W fibre pigtail output are commercially available products and are reliable for use in telecommunications applications. Figure 11 shows the typical performance of uncooled multimode 980-nm laser diodes. Colourless design provides implified thermal and electrical management. The pump light is coupled to the fibre pigtail, which typically has a core diameter of 105 µm, and the numerical aperture is from 0,15 to 0,22.

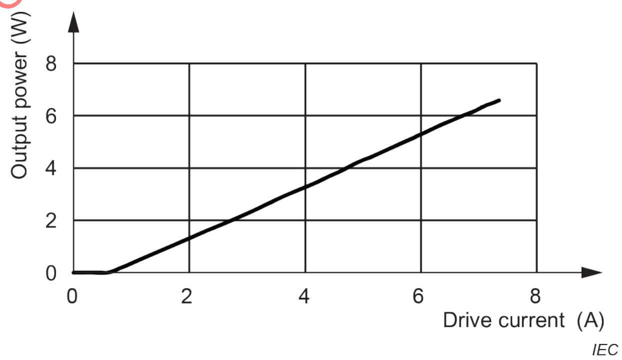

Figure 11 – Typical optical output power vs drive current on 980-nm multimode pump laser modules

5.2.2.4 Configuration of a cladding pumped amplifier

Figure 12 shows the configuration of a cladding pumped fibre amplifier to evaluate power conversion efficiency. Erbium and ytterbium co-doped DC fibre is utilized for the gain medium, and multiple multimode 980-nm band laser diodes are used for pumping.

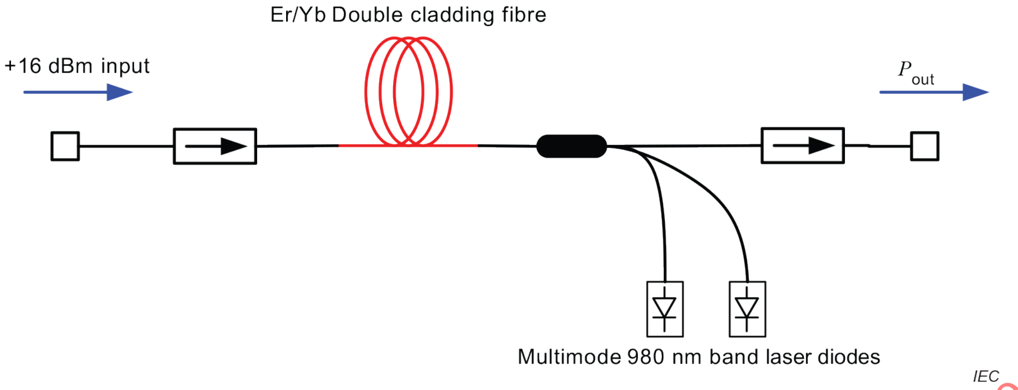

Figure 12 – Configuration of double-cladding pumped amplifier

5.2.2.5 Performance example

Figure 13 shows the power conversion efficiency of the cladding-pumped amplifier. Using multiple pump lasers, output power of up to 10 W is realized in commercial devices. Also, power conversion efficiency (PCE) of more than 30 % in cladding-pumped amplifiers achieves a radiating power of more than 3 W.

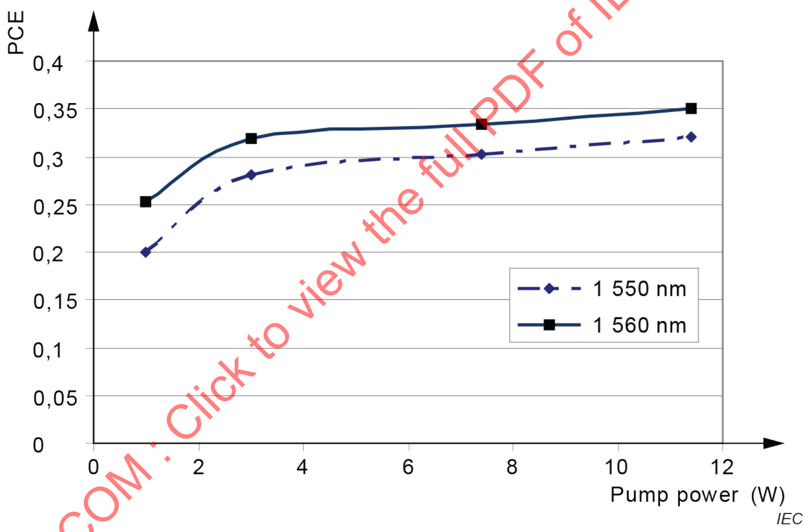

Figure 13 – Typical power conversion efficiency (PCE) of erbium - ytterbium co-doped double-clad (DC) fibre amplifier

6 Test method

Figure 14 shows a test setup for a high-power amplifier for measuring optical output power and gain. Most high-power optical amplifiers are designed as booster amplifiers; therefore, a high-power level input is also required (e.g. more than +13 dBm) to measure amplifier parameters (output power, gain, noise figure, etc.). Since the power of commercial laser sources is limited, manufacturers may use an amplified optical signal source with an additional OA. To ensure high measurement accuracy, a good OSNR (at least 35 dB) is recommended, because the amplified spontaneous emission (ASE) from the optional OA is also amplified by the OA under test. An optical spectrum analyzer may also be required to measure the OSNR.

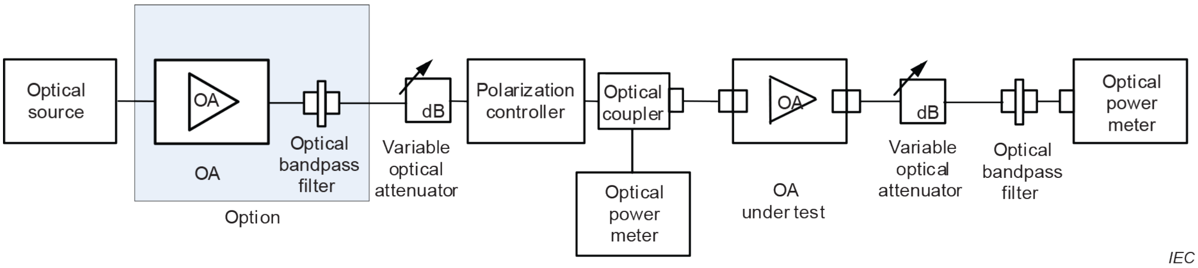

Figure 14 –Test setup to measure optical output power and gain

7 Special considerations for high-power optical amplifiers

7.1 Design considerations

The following are design considerations for a high-power amplifier:

a) Component selection

The insertion loss of components in high-power amplifiers should be as low as possible in order to avoid unexpected damage or degradation by the high optical power. In addition, it is important to reduce reflection at the connection points and components to avoid unexpected oscillation, which may lead to the fibre fuse phenomena.

b) Heat dissipation

As components transmit high optical power, the insertion loss causes heating, which can lead to deterioration and damage. It is necessary to consider adequate heat sinking.

c) Reliability qualification criteria

There is currently no IEC International Standard on the reliability of an amplifier and its components transmitting high optical power.

7.2 Handling and safety consideration

Laser products that have an optical output over 500 mW are categorized as Class 4 laser products in accordance with IEC 60825-1. Manufacturers and users should take safe operation into account.

Annex A
(informative)

Application of high-power OAs

A.1 General

High-power OAs, especially OFAs, are widely deployed in commercial optical networks. In Annex A, current applications of high-power OFAs are briefly introduced.

A.2 Power amplifier for FTTH PON systems

Since the mid-2000s, FTTH has been deployed using PON architecture. A PON system utilizes a passive splitter that splits one signal to broadcast signals to many users. This system substantially reduces the cost of the system by sharing one set of electronics.

Figure A.1 is a schematic diagram of the FTTH system adapted high-power OA. Most FTTH systems are so-called "triple play" systems providing voice (telephone), video (TV) and data (internet access). To provide all three services over one fibre, signals are sent bi-directionally over a single fibre using several wavelengths of light. Downstream digital signals from the central office (CO) through the splitter to the home are sent at 1 490 nm. This signal carries both voice and data to the home. The video signal broadcasts separately using a 1 550-nm laser, which is amplified by OFA to supply enough signal strength to overcome the loss of the optical splitter. Use of a high-power OA allows the system to reduce the number of amplifiers and controllers in the CO and reduces the equipment cost. Upstream digital signals for voice and data are sent back to the CO from the home using an inexpensive 1 310-nm laser. WDM couplers separate the signals at both the home and the CO.

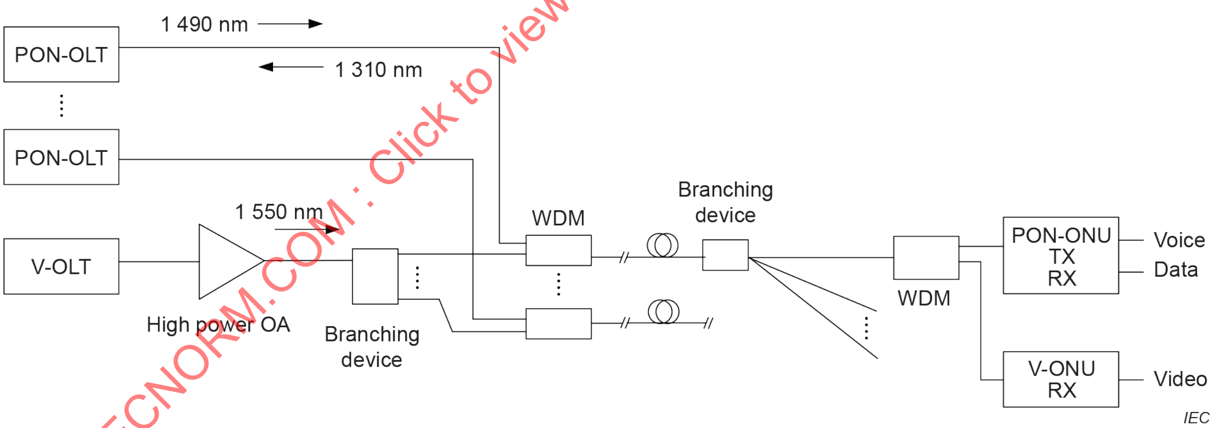

Figure A.1 – Schematic diagram of FTTH system adapted high-power OA

A.3 Ultra-long-haul DWDM transport system

The increased number of channels in transport systems requires higher power OAs. Notably, high-power OAs are deployed as boosters to long-span repeaterless links, for example, island-to-island, desert areas, and oil platforms.