IEC TR 61292-4

Edition 4.0 2023-01

TECHNICAL REPORT

colour inside

Optical amplifiers –
Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

IEC TR 61292-4:2023-01(en)

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FOREWORD

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IEC TR 61292-4 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 fourth edition cancels and replaces the third edition published in 2014. This edition constitutes a technical revision.

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

a) The technical information has been updated to reflect revisions of the relevant references.
b) In particular, the descriptions provided in Clause 5 and Clause 6 have been modified significantly to reflect changes in the cited references. Unnecessary formulas and explanations that overlap with the references have been removed to simplify the document.
c) New information has been added to Annex A on optical fibre burning when light enters an optical fibre with a bubble train formed by a fibre fuse.

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

Draft	Report on voting
86C/1821/DTR	86C/1832/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/standardsdev/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- withdrawn,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.

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INTRODUCTION

This document is dedicated to the subject of maximally permissible optical power for damage-free and safe use of optical amplifiers, including Raman amplifiers. Since the technology is quite new and still evolving, amendments and new editions to this document can be expected.

Many new types of optical amplifiers are entering the marketplace, and research is also stimulating the development of many new types of fibre and non-fibre based optical amplifiers. With the introduction of new technologies, such as long-haul, beyond 100 Gb/s, WDM transmission, digital coherent transmission and Raman amplification, some optical amplifiers employ optical pump sources with extremely high optical power – possibly up to several Watts. For example, erbium doped fibre amplifiers that provide extremely high output power are described in IEC TR 61292-8 [1][1], and Raman amplifiers in IEC TR 61292-6 [2].

Excessively high optical power can cause physical damage to the optical fibres, components and equipment, in addition to presenting a medical hazard to the human eye and skin.

The possibility of fibre damage caused by high optical intensity has been discussed at technical conferences and in technical reports for many years. The use of high intensity optical amplifiers can cause problems in optical fibres, which include fibre fuse, heating in the splice points (connection points), fibre endface damage due to dust, and fibre coat burning due to tight fibre bending. For example, IEC TR 62547 [3] provides guidelines for the measurement of high-power damage sensitivity of single-mode fibre to bends, and IEC TR 62627-01 [4] describes cleaning methods for fibre optic connectors to reduce the risk of fibre endface damage. In addition, other standard groups are discussing the risk of ignition of hazardous environments caused by high-power radiation from optical equipment.

The medical aspects of high-power optical radiation have also been addressed by standards. IEC 60825-2 defines the concept of hazard levels and corresponding labelling, which addresses the safety aspects of lasers specifically in relation to tissue damage.

In addition, IEC TR 60825-17 [5] describes safety measures to protect against effects caused exclusively by thermal, opto-mechanical and related effects in passive optical components and optical cables used in high power optical fibre communication systems. Moreover, ITU-T Recommendation G.664 [6] discusses the safety feature of automatic laser power reduction.

With the recently growing interest in high power fibre amplifiers and fibre Raman amplifiers, however, some difficulties have been identified among optical amplifier users and manufacturers in fully understanding the technical details and requirements across all such standards and agreements.

This document provides a simple informative guideline on the maximum optical power permissible for optical amplifiers for optical amplifier users and manufacturers.

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[1] Numbers in square brackets refer to the Bibliography.

OPTICAL AMPLIFIERS –

Part 4: Maximum permissible optical power for the damage-free and safe use of optical amplifiers, including Raman amplifiers

1 Scope

This part of IEC 61292, which is a Technical Report, applies to all commercially available optical amplifiers (OAs), including optical fibre amplifiers (OFAs) using active fibres as well as Raman amplifiers. Semiconductor optical amplifiers (SOAs) using semiconductor gain media are also included.

This document provides informative guidelines on the threshold of high optical power that can cause high-temperature damage of the fibre. Also discussed is optical safety for manufacturers and users of optical amplifiers by quoting parts of existing standards and agreements on eye and skin safety.

This document identifies the following values for maximum permissible optical power in the optical amplifier for damage-free and safe operation:

a) the optical power limit that causes thermal damage to the fibre, such as fibre fuse and fibre-coat burning;
b) the maximum permissible exposure (MPE) to which the eyes/skin can be exposed without consequent injury;
c) the optical power limit in the fibre that causes MPE on the eyes/skin after free-space propagation from the fibre;
d) the absolute allowable optical power level for damage-free and safe operation of the optical amplifier by comparing a) and c).

The objective of this document is to minimize potential confusion and misunderstanding in the industry that can cause unnecessary alarms and hinder the progress and acceptance of advancing optical amplifier technologies in the market.

It is important that the reader always refers to the latest international standards and agreements, because the technologies concerned are rapidly evolving.

The present document will be frequently reviewed and updated in a timely manner by incorporating the results of various studies related to OAs and OA-supported optical systems.

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 61291-1:2018, *Optical amplifiers – Part 1: Generic specification*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61291-1:2018 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 Abbreviated terms

ALS	automatic laser shutdown
APR	automatic power reduction
DSF	dispersion shifted fibre
LOS	loss of signal
MFD	mode field diameter
MPE	maximum permissible exposure
MPI-R	single channel receive main path Interface reference point
MPI-S	single channel source main path interface reference point
NOHD	nominal ocular hazard distance
NZ-DSF	non-zero dispersion shifted single-mode fibre
OA	optical amplifier
OFA	optical fibre amplifier
OFCS	optical fibre communication system
SMF	single-mode fibre
SOA	semiconductor optical amplifier

4 Maximum transmissible optical power to keep fibres damage-free

4.1 General

The use and reasonably foreseeable misuse of high intensity optical amplifiers can cause problems in the fibre such as

a) fibre fuse and its propagation,
b) heating in splice points/connection points,
c) fibre endface damage due to dust and other contamination, and
d) fibre coat burning and ignition of hazardous environments due to tight fibre bending or breakage.

Subclauses 4.2 to 4.5 introduce results concerning the above issues to give guidelines for the damage-free use of optical amplifiers. However, the following results are only valid under the conditions tested, and a higher power could be applied under different conditions.

4.2 Fibre fuse and its propagation

The safety of optical amplifiers is discussed from the viewpoint of laser hazard to the eyes and skin and from the viewpoint of fibre damage such as fibre-coat burning and fibre fusing. Subclause 4.2 experimentally analyses the fibre fuse and its propagation caused by high optical power and discusses the threshold power of fibre fuse propagation [7]. Fibre fuse is defined as the phenomenon in which an intense blue-white flash occurs and runs along the fibre toward the high-power light source while forming periodic and/or non-periodic voids.

Figure 1 shows a typical measurement set-up for measuring the threshold power of fibre fuse propagation. The fibre fuse is initiated by heating the optical fibre from outside of the fibre with an independent heat source, while light at high optical power is continuously launched into the fibre. Once the fibre fuse begins propagating, the optical source power is continuously reduced until the fuse propagation stops. Table 1 shows the threshold powers which were measured at various wavelengths of the high-power optical source and for various fibres. Although the threshold power depends on the wavelength of the high-power optical source, the power for the fuse propagation is less than 1,4 W and 1,2 W for a standard single-mode fibre (SMF) and a dispersion shifted fibre (DSF) respectively, which are used as the optical fibre for typical optical fibre communication systems.

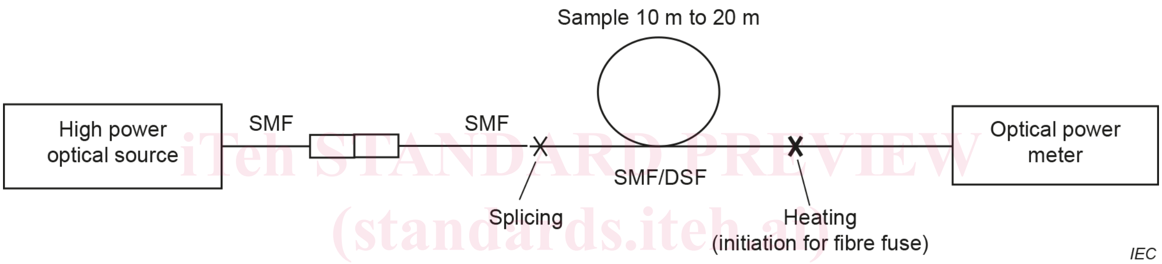

Figure 1 – Experimental set-up for fibre fuse propagation

Table 1 – Threshold power of fibre fuse propagation for various fibres

Fibre type	Measurement wavelength µm	Threshold power of fibre fuse propagation W
Standard single-mode fibre	1,064	1 [8]
	1,467	1,4 [8]
	1,48	~1,2 [9]
	1,55	1,39 [10]
Dispersion shifted fibre	1,064	1,2 [8]
	1,467	0,65 [8]
	1,55	~1,1 [11]
Dispersion compensation fibre	1,55	~0,7 [11]

The difference in fibre mode-field diameter has been identified as the major reason for the difference in the threshold powers because the fibre fuse depends on the power density [7], [8].

On the other hand, it is difficult to identify the threshold power for self-initiated fibre fuse (without any external cause) because it varies significantly. The threshold powers for self-initiated fibre fuse significantly exceed 1,4 W and 1,2 W for standard single-mode fibre (SMF) and dispersion shifted fibre (DSF) respectively.

Further information on the generating mechanism, the characteristics of fibre fuse and the prevention and termination of the fibre fuse are described in Annex A.

4.3 Loss-induced heating at connectors or splices

In extremely high-power optical amplifiers, the loss-induced heating at fibres and connectors or splices could lead to damage, including fibre-coat burning, fibre fuse, etc. Subclause 4.2 provides experimental data and considerations for the information of the thermal effects induced by connector and splice losses in high-power amplifiers [12].

Figure 2 shows temperature increase versus connection loss when measured by the conditions shown in Table 2. MU type optical connectors (IEC 61754-6 series [13]) for standard single-mode fibre (SMF) and dispersion shifted fibre (DSF) were used for this measurement. The connector loss was increased by optical fibre misalignment. The optical source used was a 2 W Raman pump at 1 480 nm. The connector temperature was measured by a thermocouple placed on the sleeve. Since the MU ferrule diameter was only 1,25 mm, the sleeve temperature was almost the same as that of the ferrule; ferrule temperature is the most important factor determining the long-term reliability of optical connectors [14].

Larger increases in temperature are observed in DSF rather than in SMF due to higher power density. The result suggests that the temperature increase could be within 10 °C under practical conditions of loss and power. A commercial dry-type connector cleaner was used in every test for cleaning the endface of the connectors.

During repeated connection-disconnection of the connectors, neither damage nor fibre fuse was observed. The experiments in which a cleaner was used identified no problems in terms of fibre/connector damage and reliability. Without the cleaner, however, the experiment with the DSF connector indicated that fibre fuse could occur after repeated connection-disconnection of more than 200 times.

Such temperature increase, and accordingly the danger of fibre fuse, will be worse for non-zero dispersion shifted single-mode fibre (NZ-DSF) connectors than for SMF connectors but better than for DSF connectors, because the effective area of SMFs is typically larger than that of NZ-DSFs, and the effective area of NZ-DSFs is larger than those of DSFs. Further quantitative studies are needed. Other types of physical contact (PC) connectors, like SC connectors (see IEC 61754-4 [15]), show similar temperature responses, because only their ferrule radii differ from MU type connectors.

In conclusion, it is shown that the thermal effects induced by connector and splice losses in high-power amplifiers could be acceptable under any practical conditions foreseeable at this moment. However, it is advisable to eliminate dust and contamination from the connector endfaces and splice points that could locally induce high temperature increases according to the power density absorbed.

Table 2 – Measurement conditions

Parameter	Conditions
Fibre	SMF, DSF
Connectors	MU type
Ferrule	Zirconia
Connector/splice loss	Imperfect alignment
Wavelength	Raman pump: 1 480 nm
Power	2 W
Temperature measurement	Thermocouple on the sleeve