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TECHNICAL REPORT

colour inside

Optical amplifiers –
Part 12: Fibre amplifiers for space division multiplexing transmission

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CONTENTS

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Part 12: Fibre amplifiers for space division multiplexing transmission

FOREWORD

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IEC TR 61292-12 has been prepared by subcommittee 86C: Fibre optic systems and active devices, of IEC technical committee 86: Fibre optics. It is a Technical Report.

External document OITDA/TP 33/AM [1] [1] has served as a basis for the elaboration of this document.

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1 Numbers in square brackets refer to the Bibliography.

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

Draft	Report on voting
86C/1807/DTR	86C/1819/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- withdrawn,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

Optical amplifiers (OAs) are essential components for designing long-haul optical transmission systems, for which many standards have been published. Recently, research has been conducted to develop higher data rate fibre optic transmission systems using space division multiplexing (SDM) with multi-core and few-mode optical fibres. A development effort is also underway to fabricate optical fibre amplifiers (OFAs) for SDM, which are necessary for extending the transmission distance. The OFAs varieties include multi-core optical fibre amplifiers, few-mode optical fibre amplifiers, and multi-core and few-mode optical fibre amplifiers. This document provides a better understanding of OFAs for SDM fibre transmission systems.

NOTE Few-mode fibres are special types of multimode fibres.

OPTICAL AMPLIFIERS –

Part 12: Fibre amplifiers for space division multiplexing transmission

1 Scope

This part of IEC 61292, which is a Technical Report, provides general information on optical fibre amplifiers for space division multiplexed transmission systems using multi-core, few-mode, and multi-core and few-mode optical fibres. This document describes the classification, concepts, configurations, and implementations of these amplifiers as well as state-of-the-art development technologies, specific features and measurement methods.

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 60050-731, *International Electrotechnical Vocabulary (IEV) – Part 731: Optical fibre communication*

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

IEC TR 61931, *Fibre optic – Terminology*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-731, IEC 61291-1, IEC TR 61931, 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
erbium doped fibre amplifier
EDFA
amplifier with rare earth-doped fibre of which core is doped with erbium ions

[SOURCE: IEC TR 61292-3:2020, 3.1.1]

3.1.2
space division multiplexing optical fibre amplifier
SDM OFA
optical fibre amplifier that is used for SDM (space division multiplexing) fibre transmission systems

3.1.3
multi-core optical fibre amplifier
multi-core OFA
optical fibre amplifier for multi-core fibre transmission

3.1.4
multi-core erbium doped fibre amplifier
multi-core EDFA
erbium-doped fibre amplifier for multi-core fibre transmission

3.1.5
multi-core fibre Raman amplifier
multi-core FRA
fibre Raman amplifier for multi-core fibre transmission

3.1.6
few-mode optical fibre amplifier
few-mode OFA
optical fibre amplifier for few-mode fibre transmission

3.1.7
few-mode erbium doped optical fibre amplifier
few-mode EDFA
erbium-doped fibre amplifier for few-mode fibre transmission

3.1.8
few-mode fibre Raman amplifier
few-mode FRA
fibre Raman amplifier for few-mode fibre transmission

3.1.9
multi-core and few-mode optical fibre amplifier
multi-core and few-mode OFA
optical fibre amplifier for multi-core and few-mode fibre transmission

3.1.10
multi-core and few-mode erbium doped optical fibre amplifier
multi-core and few-mode EDFA
erbium-doped fibre amplifier for multi-core and few-mode fibre transmission

3.1.11
multi-core and few-mode fibre Raman amplifier
multi-core and few-mode FRA
fibre Raman amplifier for multi-core and few-mode fibre transmission

3.2 Abbreviated terms

EDF	erbium-doped fibre
EDFA	erbium-doped fibre amplifier
FM	few-mode
FMF	few-mode fibre
FRA	fibre Raman amplifier
GFF	gain flattening filter
LD	laser diode
LP	linearly polarized
MC	multi-core

MCF	multi-core fibre
MC&FMF	multi-core fibre with few-mode cores
MDG	mode-dependent gain
MDL	mode-dependent loss
MDM	mode-division multiplexing
MIMO	multi-input multi-output
NF	noise figure
OA	optical amplifier
OAM	orbital-angular-momentum
OFA	optical fibre amplifier
OSNR	optical signal-to-noise ratio
ROPA	remote optically pumped amplifier
SDM	space division multiplexing
SNR	signal-to-noise ratio
VOA	variable optical attenuator
WDM	wavelength division multiplexing
XT	crosstalk

4 Classification of SDM OFAs

Fibre optic transmission systems using space division multiplexing (SDM) utilize multi-core fibre (MCF) transmission, few-mode fibre (FMF) transmission, or multi-core few-mode fibre (MC&FMF) transmission. These techniques are employed to overcome the capacity limits of conventional fibre transmission and can potentially achieve ultra-high transmission capacity per fibre (i.e., exabit/s). Long-haul transmission systems usually employ optical fibre amplifiers (OFAs) to maintain sufficiently high optical signal power along the fibre optic transmission line. SDM transmission systems typically use multi-core EDFAs (MC-EDFAs), few-mode EDFAs (FM-EDFAs), or multi-core few mode EDFAs (MC&FM-EDFAs). In contrast to conventional EDFAs, the input and output fibres of MC-EDFAs, FM-EDFAs and MC&FM-EDFAs are MCF, FMF and MC&FMF, respectively. Amplification media used for the above are multi-core erbium-doped fibres (MC-EDF), few-mode EDF (FM-EDF) and multi-core few-mode EDFs (MC&FM-EDF) [2] to [45]. Furthermore, MCFs, FMFs and MC-FMFs are used as Raman amplification media for multi-core fibre Raman amplifiers (MC-FRAs), few-mode fibre Raman amplifiers (FM-FRAs), and multi-core few-mode fibre Raman amplifiers (MC&FM-FRAs).

Figure 1 shows the classification scheme for SDM OFAs, which consists of MC-OFAs and FM-OFAs, as described in IEC TR 61292-3 [6]. MC-OFAs comprise MC-EDFAs and MC-FRAs, whereas FM-OFAs include FM-EDFAs and FM-FRAs. Furthermore, as various mode multiplexing techniques are under consideration for FMF transmission, FM-OFAs can have multiple mode types for amplification, such as linearly polarized (LP) modes, orbital-angular-momentum (OAM) modes, and coupled-core modes. MC&FM-OFAs can be made by combining MC and FM-OFA techniques.

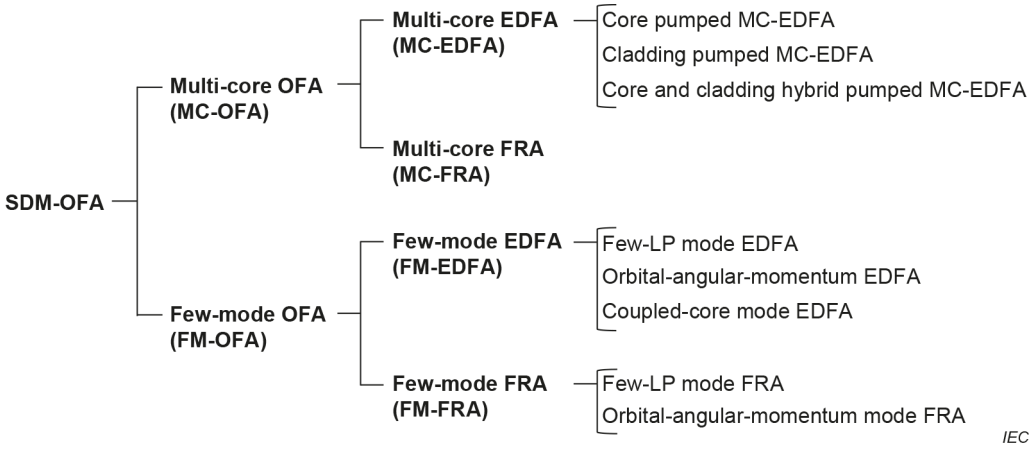

Figure 1 – Classification of SDM OFAs

5 Multi-core OFA technology

5.1 Outline of multi-core EDFAs

Figure 2 shows the concept of an MC-EDFA. In this case, the EDFA consists of an array of several conventional EDFAs (i.e., conventional gain blocks) with fan-out and fan-in elements for connecting the MC-EDFA to the output and input MCFs. Newer versions of MC-EDFAs are under development at the time of writing with the goal to improve performance through the integration of optical components (see IEC TR 61292-1 [7]) and EDF cores, without degradation in amplification properties and amplification efficiency. The amplification properties can be degraded, for example, by crosstalk (XT) between the optical signals propagating through the various amplifier cores.

Crosstalk characteristics are particularly important for MC-EDFAs, because several cores of EDFs need to be integrated with high density. Furthermore, it is important to achieve the same amplification characteristics for each core. It is expected that highly integrated MC-EDFA will lead to smaller amplifier systems, lower complexity/cost, and lower power consumption, compared with arrayed EDFAs.