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Optical fibres –
Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

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CONTENTS

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OPTICAL FIBRES –

Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

FOREWORD

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International Standard IEC 60793-2-10 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This seventh edition cancels and replaces the sixth edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant change with respect to the previous edition: revision of the naming convention for A1 multimode fibres, which better matches with those found in ISO/IEC standards. These changes are outlined in the scope of this document along with a cross reference table for the new names.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
86A/1932/FDIS	86A/1939/RVD

Full information on the voting for the approval of this International Standard 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 60793 series, published under the general title *Optical fibres*, 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

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- withdrawn,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

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OPTICAL FIBRES –

**Part 2-10: Product specifications –
Sectional specification for category A1 multimode fibres**

1 Scope

This part of IEC 60793 is applicable to optical fibre sub-categories ~~A1a, A1b~~ A1-OM1, A1-OM2, A1-OM3, A1-OM4, A1-OM5, and A1d. These fibres are used or can be incorporated in information transmission equipment and optical fibre cables.

~~Sub-category A1a applies~~ Sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 apply to 50/125 µm graded index fibre in four bandwidth grades ~~are defined as models A1a.1, A1a.2, A1a.3 and A1a.4~~. Each of these bandwidth grades is defined for two levels of macrobend loss performance that are distinguished by "a" or "b" suffix. Those ~~models~~ sub-categories with suffix "a" are specified to meet traditional macrobend loss performance levels. Those ~~models~~ sub-categories with suffix "b" are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels. ~~Model A1a.4 supports single wavelength or multi-wavelength transmission systems in the vicinity of 850 nm to 950 nm.~~

Sub-category A1-OM5 is specified to support single wavelength or multi-wavelength transmission systems in the vicinity of 850 nm to 950 nm. Although not normatively specified, bandwidth information covering this wavelength range is also included for A1-OM3 and A1-OM4.

Sub-category ~~A1b~~ A1-OM1 applies to 62,5/125 µm graded index fibre and sub-category A1d applies to 100/140 µm graded index fibre.

Other applications include, but are not restricted to, the following: short reach, high bit-rate systems in telephony, distribution and local networks carrying data, voice and/or video services; on-premises intra-building and inter-building fibre installations including data centres, local area networks (LANs), storage area networks (SANs), private branch exchanges (PBXs), video, various multiplexing uses, outside telephone cable plant use, and miscellaneous related uses.

Three types of requirements apply to these fibres:

- general requirements, as defined in IEC 60793-2;
- specific requirements common to the category A1 multimode fibres covered in this document and which are given in Clause 5;
- particular requirements applicable to individual fibre sub-categories and models, or specific applications, which are defined in the normative specification Annexes A to D.

Table 1 shows the cross reference between the IEC A1 multimode optical fibre designations used in this document compared to those used in IEC 60793-2-10:2017. The table also refers to the normative annexes A, B and C for the A1 sub-category multimode fibres in this document that contains the detailed specification.

Table 1 – Cross reference IEC A1 multimode fibre designations to IEC 60793-2-10:2017

Annex	Sub-category	Sub-category/Model	Core diameter (nominal)	ISO/IEC 11801-1:2017
	This document designations	IEC 60793-2-10:2017 designations		Usage of cabled OMx fibres
A	A1-OM2	A1a.1	50 µm [a]	OM2 [b]
	A1-OM3	A1a.2	50 µm	OM3
	A1-OM4	A1a.3	50 µm	OM4
	A1-OM5	A1a.4	50 µm	OM5
B	A1-OM1	A1b	62,5 µm [c]	OM1 [d]
C	A1d	A1d	100 µm	

[a] Historically, ISO/IEC 11801:2002 also defined OM2 cables made with 62,5/125 µm fibres having a minimum overfilled launch bandwidth of 500 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 62,5/125 µm fibre is not part of this document.

[b] OM2 cables are not supported for new installations within ISO/IEC 11801-1:2017.

[c] Historically, ISO/IEC 11801:2002 also defined OM1 cables made with 50/125 µm fibres having a minimum overfilled launch bandwidth of 200 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 50/125 µm fibre is not part of this document.

[d] OM1 cables are not supported for new installations within ISO/IEC 11801-1:2017.

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 60793-1-20, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

IEC 60793-1-21, *Optical fibres – Part 1-21: Measurement methods and test procedures – Coating geometry*

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

IEC 60793-1-30, *Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test*

IEC 60793-1-31, *Optical fibres – Part 1-31: Measurement methods and test procedures – Tensile strength*

IEC 60793-1-32, *Optical fibres – Part 1-32: Measurement methods and test procedures – Coating strippability*

IEC 60793-1-33, *Optical fibres – Part 1-33: Measurement methods and test procedures – Stress corrosion susceptibility*

~~IEC 60793-1-34, *Optical fibres – Part 1-34: Measurement methods and test procedures – Fibre curl*~~

IEC 60793-1-40, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-1-41, *Optical fibres – Part 1-41: Measurement methods and test procedures – Bandwidth*

IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement*

IEC 60793-1-46, *Optical fibres – Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance*

IEC 60793-1-47, *Optical fibres – Part 1-47: Measurement methods and test procedures – Macrobending loss*

IEC 60793-1-49, *Optical fibres – Part 1-49: Measurement methods and test procedures – Differential mode delay*

IEC 60793-1-50, *Optical fibres – Part 1-50: Measurement methods and test procedures – Damp heat (steady state) tests*

IEC 60793-1-51, *Optical fibres – Part 1-51: Measurement methods and test procedures –Dry heat (steady state) tests*

IEC 60793-1-52, *Optical fibres – Part 1-52: Measurement methods and test procedures – Change of temperature tests*

IEC 60793-1-53, *Optical fibres – Part 1-53: Measurement methods and test procedures – Water immersion tests*

IEC 60793-2~~:2015~~, *Optical fibres – Part 2: Product specifications – General*

IEC 61280-4-1:2009, *Fibre-optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement*

3 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

4 Abbreviated terms

CPR	coupled power ratio
DMD	differential mode delay
EF	encircled flux
EMB	effective modal bandwidth
EMB_c	calculated effective modal bandwidth
LAN	local area network
MMF	multimode fibre
NA	numerical aperture
OFL	overfilled launch
OMB_c	overfilled launch modal bandwidth calculated from differential mode delay (also known as OFL_c)
PBX	private branch exchange
PMD	physical medium dependent
ROFL	radial overfilled launch
SAN	storage area network

5 Specifications

5.1 General

The fibre consists of a glass core with a graded index profile and a glass cladding in accordance with IEC 60793-2~~:2015, 5.1~~.

The term "glass" usually refers to material consisting of non-metallic oxides.

5.2 Dimensional requirements

Dimensional attributes and measurement methods are given in Table 2.

Requirements common to all fibres in category A1 are indicated in Table 3.

Table 4 lists additional attributes that shall be specified by each sub-category specification.

Table 2 – Dimensional attributes and measurement methods

Attributes	Measurement methods
Cladding diameter	IEC 60793-1-20
Core diameter [a, b]	IEC 60793-1-20
Cladding non-circularity	IEC 60793-1-20
Core non-circularity	IEC 60793-1-20
Core-cladding concentricity error	IEC 60793-1-20
Primary coating diameter	IEC 60793-1-21
Primary coating non-circularity	IEC 60793-1-21
Primary coating-cladding concentricity error	IEC 60793-1-21
Fibre length	IEC 60793-1-22

[a] Core diameter is specified at 850 nm ± 10 nm with a test specimen length of 2,0 m ± 0,2 m and a threshold value, k_{CORE}, of 0,025 for A1 fibres except ~~A1a.1b/2b/3b/4b~~ A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

[b] Core diameter is specified at 850 nm ± 10 nm with a test specimen length of 100 m ± 5 % and a threshold value, k_{CORE}, of 0,025 for ~~A1a.1b/2b/3b/4b~~ A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

Table 3 – Dimensional requirements common to category A1 fibres

Attributes	Unit	Limits
Core non-circularity	%	≤ 6
Primary coating diameter – uncoloured [a]	µm	245 ± 10
Primary coating diameter – coloured [a]	µm	250 ± 15
Primary coating-cladding concentricity error	µm	≤ 12,5
Fibre length	km	[b]

[a] The limits on primary coating diameter are most commonly used in telecommunications cables. There are other applications, which use other primary coating diameters, several of which are listed below.

Alternative nominal primary coating diameters and tolerance (µm):

400 ± 40

500 ± 50

700 ± 100

900 ± 100

[b] Length requirements vary and should be agreed between supplier and customer.

Table 4 – Additional dimensional attributes required in sub-category specifications

Attributes
Cladding diameter
Cladding non-circularity
Core diameter
Core-cladding concentricity error

5.3 Mechanical requirements

Mechanical attributes and measurement methods are given in Table 5.

Requirements common to all fibres in category A1 are in Table 6.

Table 5 – Mechanical attributes and measurement methods

Attributes	Test methods
Proof test	IEC 60793-1-30
Tensile strength	IEC 60793-1-31
Primary coating strippability	IEC 60793-1-32
Stress corrosion susceptibility	IEC 60793-1-33
~~Fibre curl~~	~~IEC 60793-1-34~~

Table 6 – Mechanical requirements common to category A1 fibres

Attributes	Unit	Limits
Proof stress level	GPa	≥ 0,69 [a]
Average strip force[b]	N	$1,0 \leq F_{avg} \leq 5,0$
Peak strip force[b]	N	$1,0 \leq F_{peak} \leq 8,9$
Tensile strength (median) for 0,5 m specimen length	GPa	≥ 3,8
Stress corrosion susceptibility constant, n_d	-	≥ 18

[a] The proof test value of 0,69 GPa equals about 1 % strain or about 8,8 N force, for ~~A1a and A1b~~ A1-OM1 to A1-OM5 fibres. For the relation between these different units, see IEC TR 62048:2014, 8.4.

[b] Either average strip force or peak strip force, which are defined in the test procedure, may be specified by agreement between supplier and customer.

5.4 Transmission requirements

Transmission attributes and measurement methods are given in Table 7.

Table 8 lists additional attributes that shall be specified by each sub-category specification.

Table 7 – Transmission attributes and measurement methods

Attributes	Measurement methods
Attenuation coefficient	IEC 60793-1-40
Modal bandwidth [a,b]	IEC 60793-1-41
Numerical aperture [c,d]	IEC 60793-1-43
Chromatic dispersion	IEC 60793-1-42
Change of optical transmission	IEC 60793-1-46
Macrobending loss	IEC 60793-1-47
Differential mode delay [e]	IEC 60793-1-49

[a] For modal bandwidth, either overfilled launch (OFL) or overfilled launch modal bandwidth calculated from differential mode delay (OMB_c) can be used. OMB_c is the reference test method for ~~A1a.1/2/3~~ A1-OM2, A1-OM3 and A1-OM4 fibres at 850 nm and is the required method for ~~A1a.4~~ A1-OM5 fibres at 850 nm and 953 nm.

[b] 850 nm modal bandwidth is specified with a test specimen length of 1 000 m ± 5 % for ~~A1a.2/3/4~~ A1-OM3 to A1-OM5 fibres. For ~~A1a.2~~ A1-OM3 fibres, the 850 nm modal bandwidth is measured at 850 nm ± 10 nm. For ~~A1a.3~~ A1-OM4 and ~~A1a.4~~ A1-OM5 fibres, the 850 nm modal bandwidth is measured at 850 nm ± 2 nm. For ~~A1a.4~~ A1-OM5 fibre, the modal bandwidth is also measured at 953 nm ± 6 nm.

[c] Numerical aperture is specified at 850 nm ± 10 nm with a test specimen length of 2 m ± 0,2 m and a threshold value, k_{NA}, of 0,05 for A1 fibres except ~~A1a.1b/2b/3b/4b~~ A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

[d] Numerical aperture is specified at 850 nm ± 10 nm with a test specimen length of 100 m ± 5 % and a threshold value, $k_{NA,}$ of 0,05 for ~~A1a.1b/2b/3b/4b~~ A1-OM2b, A1-OM3b, A1-OM4b and A1-OM5b fibres.

[e] Differential mode delay is specified with a test specimen length of 1 000 m ± 5 % for ~~A1a.2/3/4~~ A1-OM3, A1-OM4 and A1-OM5 fibres. For ~~A1a.2~~ A1-OM3 fibres, the DMD is measured at 850 nm ± 10 nm. For ~~A1a.3~~ A1-OM4 and ~~A1a.4~~ A1-OM5 fibres, the DMD is measured at 850 nm ± 2 nm. For ~~A1a.4~~ A1-OM5 fibre, the DMD is also measured at 953 nm ± 6 nm.

Specification compliance of chromatic dispersion can be assured by compliance to the numerical aperture (NA) specification for A1 fibre.

Table 8 – Additional transmission attributes required in sub-category specifications

Attributes
Attenuation coefficient
Modal bandwidth
Chromatic dispersion
Numerical aperture
Macrobending loss

For attenuation coefficient and modal bandwidth, the sub-category specifications may contain ranges of specifiable values instead of fixed limits. In this case, the actual values of the maximum attenuation coefficient and minimum modal bandwidth, at both 850 nm and 1 300 nm (or just at one of these wavelengths) ~~are to~~ shall be agreed between supplier and customer. For commercial purposes, the modal bandwidth is linearly normalized to 1 km.

~~For guidance purposes, Table H.1 shows a number of standardised applications supported by A1 fibres, and Table H.2 provides a cross reference between the cabled optical fibre categories of ISO/IEC 11801-1[1] and fibre sub-categories A1a and A1b of this document.~~

~~[1] Under preparation. Stage at the time of publication: ISO/IEC RFDIS 11801-1:2017.~~

For guidance purposes, Annex H shows a number of standardised applications supported by A1 fibres and Annex I shows transmission capabilities for these fibres.

The indicated maximum attenuation ~~values~~ coefficients apply to uncabled optical fibres; for the maximum cabled attenuation ~~values~~ coefficients, reference is made to IEC 60794-1-1, which can be used in conjunction with this document. Tighter specifications for the fibre may be requested to account for added attenuation in the cabling process.

Remarks on the specification of modal bandwidth:

Care should be taken in writing dual wavelength bandwidth specifications. It is understood that for category A1 fibres, the bandwidth at 850 nm may be related to the bandwidth at 1 300 nm in a way shown in Figure 1, depending on the refractive index parameter, g (see IEC 60793-2~~:2015, 5.1~~). See [1][2], page 50, and [2], page 255, for similar figures. The shaded region under the curve of Figure 1 can be defined as the dual window area. In this area, regions X, Y, and Z are examples of where a fibre manufacturer may choose to optimise the process. That is, centre the production bandwidth peak at 850 nm, 1 300 nm, or between these two wavelengths.

Due to this optimisation of the manufacturing process, there will be combinations of bandwidth that are not possible (i.e., outside the shaded region).

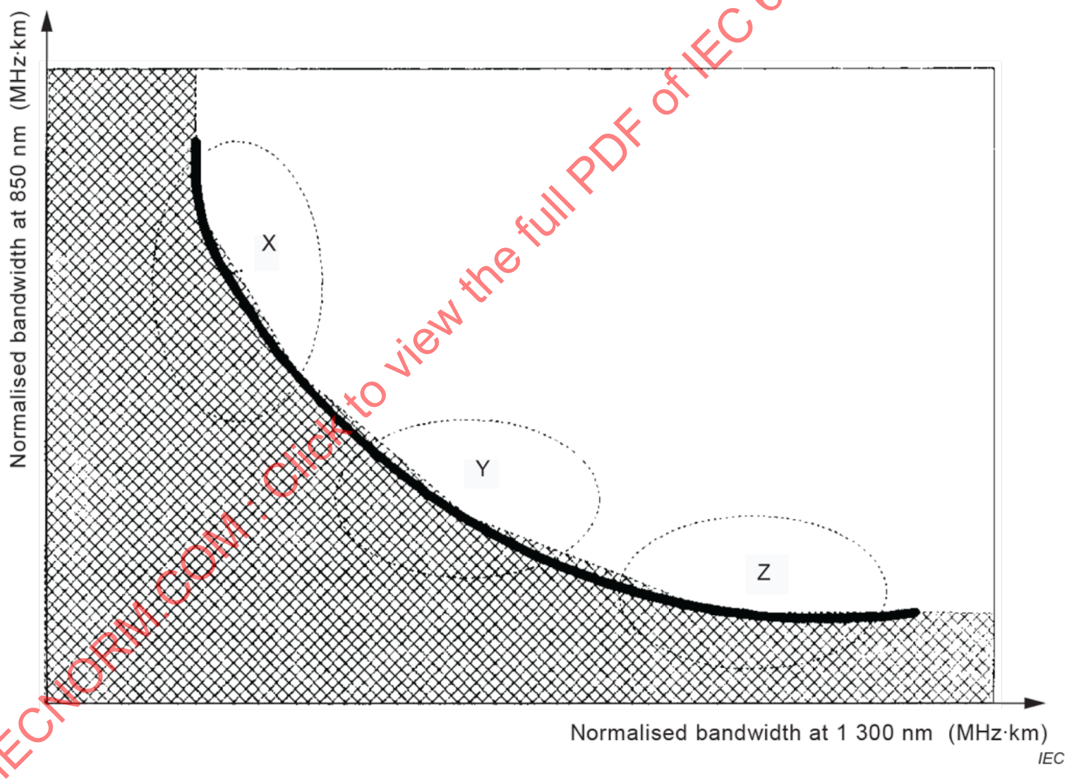

Figure 1 – Relation between bandwidths at 850 nm and 1 300 nm

5.5 Environmental requirements

5.5.1 General

Environmental exposure tests and measurement methods are documented in two forms:

- relevant environmental attributes and test procedures are given in Table 9;

2 Numbers in square brackets refer to the Bibliography.

- measurements of a particular mechanical or transmission attribute that may change on the application of the environment are listed in Table 10.

Table 9 – Environmental exposure tests

Environmental exposure	Test
Damp heat	IEC 60793-1-50
Dry heat	IEC 60793-1-51
Change of temperature	IEC 60793-1-52
Water immersion	IEC 60793-1-53

Table 10 – Attributes measured for environmental tests

Attribute	Measurement method
Change in optical transmission	IEC 60793-1-46
Attenuation	IEC 60793-1-40
Strip force	IEC 60793-1-32
Tensile strength	IEC 60793-1-31
Stress corrosion susceptibility	IEC 60793-1-33

These tests are normally conducted periodically as type-tests for a fibre and coating design. Unless otherwise indicated, the recovery period allowed between the completion of the environmental exposure and performing the attribute measurements shall be as stated in the particular environmental test method.

5.5.2 Mechanical environmental requirements (common to all fibres in category A1)

5.5.2.1 General

These tests are, in practice, the most severe requirements amongst the environments defined in Table 9.

Tables 11, 12, and 13 give the prescriptions for strip force, tensile strength and stress corrosion susceptibility respectively.

5.5.2.2 Strip force

The following attributes shall be verified following removal of the fibre from the particular environment.

Table 11 – Strip force for environmental tests

Environment	Average strip force N	Peak strip force N
Damp heat	$1,0 \leq F_{avg} \leq 5,0$	$1,0 \leq F_{peak} \leq 8,9$
Water immersion	$1,0 \leq F_{avg} \leq 5,0$	$1,0 \leq F_{peak} \leq 8,9$

5.5.2.3 Tensile strength

The following attribute shall be verified following removal of the fibre from the environment.

Table 12 – Tensile strength for environmental tests

Environment	Median tensile strength specimen length: 0,5 m GPa	15th percentile tensile strength specimen length: 0,5 m GPa
Damp heat	≥ 3,03	≥ 2,76
NOTE These requirements do not apply to hermetically coated fibre.		

5.5.2.4 Stress corrosion susceptibility

The following attribute shall be verified following removal of the fibre from the environment.

Table 13 – Stress corrosion susceptibility for environmental tests

Environment	Stress corrosion susceptibility constant, n_d
Damp heat	≥ 18
NOTE This requirement does not apply to hermetically coated fibre.	

5.5.3 Transmission environmental requirements

Change in attenuation from the initial value shall be less than the values in Table 14. Attenuation shall be measured periodically during the entire exposure to each environment and after removal.

Table 14 – Change in attenuation for environmental tests

Environment	Wavelength nm	Attenuation increase dB/km
Damp heat	850	≤ 0,20
	1 300	≤ 0,20
Dry heat	850	≤ 0,20
	1 300	≤ 0,20
Change of temperature	850	≤ 0,20
	1 300	≤ 0,20
Water immersion	850	≤ 0,20
	1 300	≤ 0,20

Annex A
(normative)

Specifications for ~~sub-category A1a~~ sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 multimode fibres

A.1 General

Annex A contains particular requirements applicable to ~~A1a~~ sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres. Common requirements, repeated here for ease of reference from the main body of this document, are noted by a clause entry in the "Reference" column. The "Reference" column also refers to other annexes containing relevant information on the attribute. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

~~Sub-category A1a is a~~ Sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 are 50/125 µm graded index multimode fibres in four bandwidth grades ~~are defined as models A1a.1, A1a.2, A1a.3 and A1a.4~~. All are specified using overfilled bandwidth metrics, while ~~models A1a.2, A1a.3~~ sub-categories A1-OM3, A1-OM4 and ~~A1a.4~~ A1-OM5 also apply differential mode delay measurements to deliver laser-optimised performance near 850 nm. ~~Model A1a.4~~ Sub-category A1-OM5 also specifies both overfilled and differential mode delay bandwidth metrics at 953 nm to deliver laser-optimized performance over a wavelength range in the vicinity of 850 nm to 950 nm. ~~A1a.2~~ A1-OM3 complies with ~~A1a.1~~ A1-OM2 specifications. ~~A1a.3~~ A1-OM4 complies with ~~A1a.2~~ A1-OM3 specifications. ~~A1a.4~~ A1-OM5 complies with ~~A1a.3~~ A1-OM4 specifications.

~~A1a.1, A1a.2, A1a.3 and A1a.4~~ Sub-category A1-OM2, A1-OM3, A1-OM4 and A1-OM5 are also specified for two levels of macrobend loss performance that are distinguished by "a" or "b" suffix. Those with suffix "a" (i.e. ~~A1a.1a, A1a.2a, A1a.3a, A1a.4a~~ models A1-OM2a, A1-OM3a, A1-OM4a and A1-OM5a) are specified to meet traditional macrobend loss performance levels. Those with suffix "b" (i.e. ~~A1a.1b, A1a.2b, A1a.3b and A1a.4b~~ models A1-OM2b, A1-OM3b, A1-OM4b and A1-OM5b) are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels, and thereby also comply with traditional macrobend loss performance.

The nomenclature for the ~~A1a sub-category~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 sub-categories establishes a coding hierarchy that permits designation of fibres with increasing specificity. For example, purchase orders for ~~A1a fibres~~ A1-OM3 may be filled by ~~any of the models specified in Annex A, while purchase orders for A1a.2 may be filled by A1a.2a~~ A1-OM3a or ~~A1a.2b~~ A1-OM3b. As a result, where specifications and descriptions apply to all models at lower hierarchical levels, only the common portion of the name is stated.

The dimensional, mechanical and environmental requirements are common to all and specified in Tables A.1 and A.2. The common and distinguishing transmission requirements are specified in Table A.3.

A.2 Dimensional requirements

Table A.1 contains dimensional requirements specific to ~~A1a~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.1 – Dimensional requirements specific to ~~A1a~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	125 ± 1	
Cladding non-circularity	%	≤ 1	
Core diameter SS	µm	50 ± 2,5	
Core-cladding concentricity error	µm	≤ 2	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

A.3 Mechanical requirements

Table A.2 contains the mechanical requirements specific to ~~A1a~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.2 – Mechanical requirements specific to ~~A1a~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Peak strip force SS	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
SS See notes in the main body of this document.			

A.4 Transmission requirements

Table A.3 contains transmission requirements specific to ~~A1a~~ A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.3 – Transmission requirements specific to A1a A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes	Unit	Limits				Reference
Fibre model		A1a.1	A1a.2	A1a.3	A1a.4	
Targeted operational wavelength(s) [a]	nm	850			850 to 950	Annex E
Maximum attenuation coefficient at 850 nm	dB/km	2,5				
Maximum attenuation coefficient at 953 nm	dB/km	Not specified			1,8	
Maximum attenuation coefficient at 1 300 nm	dB/km	0,8				
Minimum modal bandwidth-length product for overfilled launch at 850 nm [SS]	MHz·km	500	1 500	3 500	3 500 Meet Clause D.5	
Minimum modal bandwidth-length product for overfilled launch at 953 nm [SS]	MHz·km	Not specified			1 850 Meet Clause D.5	
Minimum modal bandwidth-length product for overfilled launch at 1 300 nm	MHz·km	500				
Minimum effective modal bandwidth-length product at 850 nm [SS]	MHz·km	Not specified	2 000 Meet Clause D.1 or Clause D.2	4 700 Meet Clause D.3 or Clause D.4	4 700 Meet Clause D.5	Annexes D, E, F, G
Minimum effective modal bandwidth-length product at 953 nm [SS]	MHz·km	Not specified			2 470 Meet Clause D.5	Annexes D, E, F, G
Numerical aperture [SS]	Dimensionless	0,200 ± 0,015				
Maximum macro-bending loss [b] – Bending radius / Number of turns	dB	A1a.1a	A1a.2a	A1a.3a	A1a.4a	
		Max at 850 nm / 1 300 nm				
37,5 mm / 100		0,5 / 0,5				
15 mm / 2		1,0 / 1,0				
Bending radius / Number of turns	dB	A1a.1b	A1a.2b	A1a.3b	A1a.4b	
		Max at 850 nm / 1 300 nm				
37,5 mm / 100		0,5 / 0,5				
15 mm / 2		0,1 / 0,3				
7,5 mm / 2		0,2 / 0,5				
Zero dispersion wavelength, λ_0	nm	$1\,295 \leq \lambda_0 \leq 1\,340$ [c]			$1\,297 \leq \lambda_0 \leq 1\,328$ [d]	
Zero dispersion slope, S_0	ps/nm²·km	$S_0 \leq 0,105$ from $1\,295$ nm $\leq \lambda_0 \leq 1\,310$ nm, and $\leq 0,000\,375\,(1\,590 - \lambda_0)$ from $1\,310$ nm $\leq \lambda_0 \leq 1\,340$ nm [c]			$S_0 \leq 4\,(-103) / (840\,(1 - (\lambda_0/840)^4))$ [d]	

[a] Targeted operational wavelength(s) is informative.

[b] The launch condition for the macrobending loss measurement shall fulfil that described in IEC 61280-4-1.

[c] The worst case chromatic dispersion coefficient at 850 nm (e.g. S_0 = 0,093 75 ps/nm²·km at λ_0 = 1 340 nm or S_0 = 0,101 25 ps/nm²·km at λ_0 = 1 320 nm) is –104 ps/nm·km.

[d] The coordinate that generates the worst-case dispersion for operating wavelengths from 840 nm to 1 000 nm is λ_0 = 1 328 nm, S_0 = 0,093 477 ps/nm²·km. The worst case chromatic dispersion coefficient at 850 nm is –98,5 ps/nm·km.

[SS] See notes in the main body of this sectional specification.

Attributes	Unit	Limits				Reference
Fibre sub-category		A1-OM2	A1-OM3	A1-OM4	A1-OM5	
Targeted operational wavelength(s) [a]	nm	850			850 to 950	Annex E
Maximum attenuation coefficient at 850 nm	dB/km	2,5				
Maximum attenuation coefficient at 953 nm	dB/km	Not specified			1,8	
Maximum attenuation coefficient at 1 300 nm	dB/km	0,8				
Minimum modal bandwidth-length product for overfilled launch at 850 nm [SS]	MHz·km	500	1 500	3 500	3 500	Clause D.6
Minimum modal bandwidth-length product for overfilled launch at 953 nm [SS]	MHz·km	Not specified			1 850	Clause D.6
Minimum modal bandwidth-length product for overfilled launch at 1 300 nm	MHz·km	500				
Minimum effective modal bandwidth-length product at 850 nm [SS]	MHz·km	Not specified	2 000 Meet Clause D.1 or Clause D.2	4 700 Meet Clause D.3 or Clause D.4	4 700 Meet Clause D.5	Annexes D, E, F, G
Minimum effective modal bandwidth-length product at 953 nm [SS]	MHz·km	Not specified			2 470 Meet Clause D.5	Annexes D, E, F, G
Numerical aperture [SS]	Dimen-sionless	0,200 ± 0,015				
Fibre model		A1-OM2a	A1-OM3a	A1-OM4a	A1-OM5a	
Maximum macro-bending loss [b] – Bending radius / Number of turns	dB	Max at 850 nm / 1 300 nm				
37,5 mm / 100		0,5 / 0,5				
15 mm / 2		1,0 / 1,0				
Fibre model		A1-OM2b	A1-OM3b	A1-OM4b	A1-OM5b	
Maximum macro-bending loss [b] – Bending radius / Number of turns	dB	Max at 850 nm / 1 300 nm				
37,5 mm / 100		0,5 / 0,5				
15 mm / 2		0,1 / 0,3				
7,5 mm / 2		0,2 / 0,5				
Zero dispersion wavelength, λ_0	nm	$1\,295 \le \lambda_0 \le 1\,340$ [c]			$1\,297 \le \lambda_0 \le 1\,328$ [d]	
Zero dispersion slope, S_0	ps/(nm²·km)	$S_0 \le 0{,}105$ from $1\,295\ \text{nm} \le \lambda_0 \le 1\,310\ \text{nm}$, and $\le 0{,}000\,375\,(1\,590 - \lambda_0)$ from $1\,310\ \text{nm} \le \lambda_0 \le 1\,340\ \text{nm}$ [c]			$S_0 \le 4\,(-103) / (840\,(1 - (\lambda_0/840)^4))$ [d]	

[a] Targeted operational wavelength(s) is informative.

[b] The launch condition for the macrobending loss measurement shall fulfil that described in IEC 61280-4-1.

[c] The worst case chromatic dispersion coefficient at 850 nm (e.g. S_0 = 0,093 75 ps/(nm²·km) at λ_0 = 1 340 nm or S_0 = 0,101 25 ps/(nm²·km) at λ_0 = 1 320 nm) is –104 ps/(nm·km).

[d] The coordinate that generates the worst-case dispersion for operating wavelengths from 840 nm to 1 000 nm is λ_0 = 1 328 nm, S_0 = 0,093 477 ps/(nm²·km) The worst case chromatic dispersion coefficient at 850 nm is –98,5 ps/(nm·km)

[SS] See notes in the main body of this document.

A.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex B
(normative)

Specifications for sub-category A1b A1-OM1 multimode fibres

B.1 General

Annex B contains particular requirements applicable to A1b A1-OM1 fibres. Common requirements, repeated here for ease of reference from the main body of this document, are noted by a clause entry in the "Reference" column. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

Sub-category A1b A1-OM1 fibre is a 62,5/125 µm graded index fibre.

B.2 Dimensional requirements

Table B.1 contains dimensional requirements specific to A1b A1-OM1 fibres.

Table B.1 – Dimensional requirements specific to A1b A1-OM1 fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	125 ± 2	
Cladding non-circularity	%	≤ 2	
Core diameter SS	µm	62,5 ± 3	
Core-cladding concentricity error	µm	≤ 3	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length SS	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

B.3 Mechanical requirements

Table B.2 contains the mechanical requirements specific to A1b A1-OM1 fibres.

Table B.2 – Mechanical requirements specific to A1b A1-OM1 fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	$1{,}0 \le F_{avg} \le 5{,}0$	5.3
Peak strip force SS	N	$1{,}0 \le F_{peak} \le 8{,}9$	5.3
SS See notes in the main body of this document.			

B.4 Transmission requirements

Table B.3 contains transmission requirements specific to ~~A1b~~ A1-OM1 fibres.

Table B.3 – Transmission requirements specific to ~~A1b~~ A1-OM1 fibres

Attributes	Unit	Limits	Reference
Maximum attenuation coefficient at 850 nm	dB/km	3,0	
Maximum attenuation coefficient at 1 300 nm	dB/km	1,0	
Minimum modal bandwidth-length product at 850 nm	MHz·km	200	
Minimum modal bandwidth-length product at 1 300 nm	MHz·km	500	
Numerical aperture [SS]	Dimensionless	0,275 ± 0,015	
Maximum macrobending loss 100 turns on bending radius of 37,5 mm at wavelengths 850 nm and 1 300 nm [a]	dB	0,5	
Zero dispersion wavelength, λ_0	nm	1 320 ≤ λ_0 ≤ 1 365 [b]	
Zero dispersion slope S_0 – from 1 320 nm ≤ λ_0 ≤ 1 348 nm – from 1 348 nm ≤ λ_0 ≤ 1 365 nm	ps/(nm²·km)	 ≤ 0,11 [b] ≤ 0,001 (1 458 – λ_0) [b]	

[a] The launch condition for the macrobending loss measurement shall fulfil that described in IEC 61280-4-1.

[b] The worst case chromatic dispersion coefficient at 850 nm (S_0 = 0,11 ps/(nm²·km) at λ_0 = 1 348 nm) is –125 ps/(nm·km).

[SS] See notes in the main body of this document.

B.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex C
(normative)

Specifications for sub-category A1d multimode fibres

C.1 General

Annex C contains particular requirements for A1d fibres. Common requirements, repeated here for ease of reference from this document, are noted by an entry in the "Reference" column. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

Sub-category A1d fibre is a 100/140 µm graded index fibre.

C.2 Dimensional requirements

Table C.1 contains dimensional requirements specific to A1d fibres.

Table C.1 – Dimensional requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	140 ± 4	
Cladding non-circularity	%	≤ 4	
Core diameter SS	µm	100 ± 5	
Core-cladding concentricity error	µm	≤ 6	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length SS	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

C.3 Mechanical requirements

Table C.2 contains the mechanical requirements specific to A1d fibres.

Table C.2 – Mechanical requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	1,0 ≤ F_{avg} ≤ 5,0	5.3
Peak strip force SS	N	1,0 ≤ F_{peak} ≤ 8,9	5.3
SS See notes in the main body of this document.			

C.4 Transmission requirements

Table C.3 contains transmission requirements specific to A1d fibres.

Table C.3 – Transmission requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Maximum attenuation coefficient at 850 nm [a]	dB/km	3,5 to 7,0	
Maximum attenuation coefficient at 1 300 nm [a]	dB/km	1,5 to 4,5	
Minimum modal bandwidth-length product at 850 nm [a]	MHz·km	10 to 200	
Minimum modal bandwidth-length product at 1 300 nm [a]	MHz·km	100 to 300	
Numerical aperture [SS]	Dimensionless	0,26 ± 0,03 or 0,29 ± 0,03	
Maximum macrobending loss	dB	For further study	
Zero dispersion wavelength, λ_0	nm	1 330 ≤ λ_0 ≤ 1 385 [b]	
Zero dispersion slope S_0 – from 1 330 nm ≤ λ_0 ≤ 1 365 nm – from 1 365 nm ≤ λ_0 ≤ 1 385 nm	ps/(nm²·km)	 ≤ 0,105 [b] ≤ 0,000 5 (1 575 – λ_0) [b]	

[a] The limit column forms a range of values that may be specified.

[b] The worst case chromatic dispersion coefficient at 850 nm (S_0 = 0,105 ps/(nm²·km) at λ_0 = 1 365 nm) is –126 ps/(nm·km).

[SS] See notes in the main body of this document.

C.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex D
(normative)

Fibre differential mode delay (DMD), calculated effective modal bandwidth (EMB_c) and calculated overfilled modal bandwidth (OMB_c) requirements

D.1 ~~A1a.2~~ A1-OM3 fibre DMD requirements

D.1.1 General

~~A1a.2~~ A1-OM3 fibres selected using the DMD mask method shall meet the requirements of D.1.2 and D.1.3. The radial limits, R_{INNER} and R_{OUTER}, were established for transmitters meeting the requirements of Clause E.4.

Refer to Annex E for information regarding effective modal bandwidth (EMB).

D.1.2 DMD templates

~~A1a.2~~ A1-OM3 fibres shall meet at least one of the six templates in Table D.1, each of which includes an inner and outer mask requirement, when measured according to IEC 60793-1-49.

Table D.1 – DMD templates for ~~A1a.2~~ A1-OM3 fibres

Template number	Inner mask DMD (ps/m) for R_{INNER} = 5 µm to R_{OUTER} = 18 µm	Outer mask DMD (ps/m) for R_{INNER} = 0 µm to R_{OUTER} = 23 µm
1	≤ 0,23	≤ 0,70
2	≤ 0,24	≤ 0,60
3	≤ 0,25	≤ 0,50
4	≤ 0,26	≤ 0,40
5	≤ 0,27	≤ 0,35
6	≤ 0,33	≤ 0,33

The DMD requirements in ~~D.1.2~~ Table D.1 are illustrated in Figure D.1. In this figure, the allowable DMD (as measured according to IEC 60793-1-49) is plotted versus the radial offset position of the single mode probe. There is a trade-off between the tightness of the inner mask and the outer mask to ensure a sufficient amount of the baud energy from a transmitter (meeting the launch specifications) arrives within the required time period (defined by the baud rate of the transmission system).

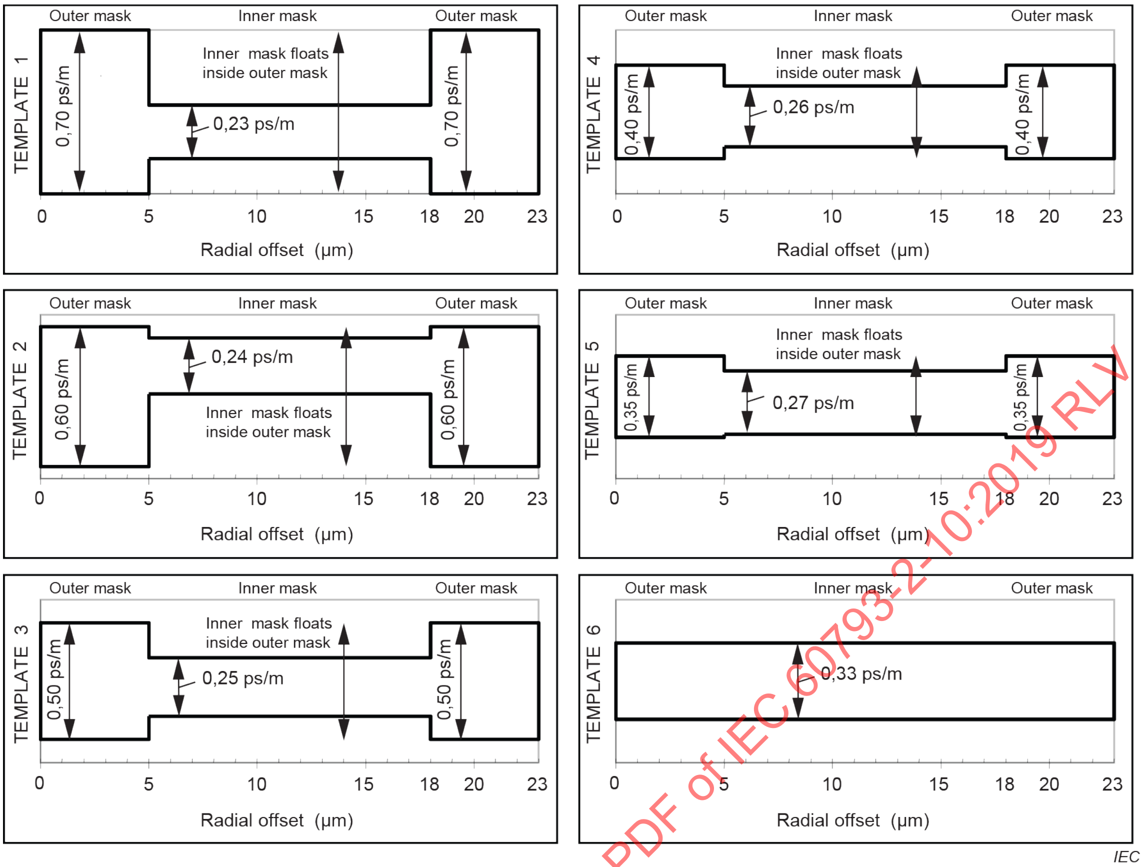

Figure D.1 – DMD template requirements

The "floating" characteristic of the inner mask is also illustrated in Figure D.1. In this figure, the inner mask (5 µm to 18 µm) may be positioned vertically (temporally) anywhere within the outer mask (0 µm to 23 µm). The DMD is more tightly constrained in the inner mask to allow for looser tolerances on the outer mask providing for improved ability to manufacture fibre conforming to this requirement. In the case of the 0,33 ps/m mask, the requirement is the same over the whole range from 0 µm to 23 µm creating a "flat" mask.

IEC 60793-1-49 can be used to ensure a minimum effective modal bandwidth-length product, when using sources meeting appropriate restrictions. When the launch condition requirements on the transmitters are coupled to the DMD requirements on the fibre, a balance can be achieved between fibre tolerance and transmitter tolerance. A careful study, using fibres contributed by several different fibre manufacturers and laser transmitters from several different source manufacturers, and including extensive and detailed simulations, shows that the above coupled specifications on fibre and sources will yield a minimum effective modal bandwidth-length product of 2 000 MHz·km [3] to [14].

The use of a template on the values of DMD achieves an effective trade-off between transmitter and fibre properties. The transmitter launch condition is bounded by encircled flux requirements at 4,5 µm and 19 µm as discussed in Clause E.4. The limitation on the transmitter encircled flux at the 4,5 µm radius assures that very little energy is carried by the lowest order modes of the fibre, allowing the relaxed tolerance on modal structure excited at small radii. The limitation on the transmitter encircled flux at the 19 µm radius assures that very little energy is carried by the highest order modes of the fibre, allowing the relaxed tolerance on modal structure excited at high radii.

D.1.3 DMD interval masks

The ~~A1a.2~~ A1-OM3 fibre DMD shall not exceed 0,25 ps/m for any of the radial offset intervals given in Table D.2.

Table D.2 – DMD interval masks for ~~A1a.2~~ A1-OM3 fibres

Interval number	R_{INNER} µm	R_{OUTER} µm
1	7	13
2	9	15
3	11	17
4	13	19

These interval masks screen out fibres having DMD that change too rapidly over short radial ranges. Fibres passing this screen have lower inter-symbol interference than those that do not.

D.2 ~~A1a.2~~ A1-OM3 fibre EMB_c requirements

D.2.1 General

~~A1a.2~~ A1-OM3 fibres selected using the EMB_c method shall meet the requirements of D.2.2.

D.2.2 Calculated effective bandwidth

The DMD optical pulse shapes can be weighted by a set of launch distributions to determine a corresponding set of EMB_c values. The minimum EMB_c ($minEMB_c$) within this set shall meet the requirement of Equation (D.1):

$$minEMB_c \geq 1\,770 \text{ MHz·km} \tag{D.1}$$

where

$minEMB_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

NOTE 1 Minimum EMB_c is a fibre parameter, and it is possible that its value is not optimal for use in system models. Refer to Annex E for information regarding the corresponding system parameter called the "effective modal bandwidth" (EMB) and its relationship to EMB_c.

NOTE 2 Refer to Annex F for additional explanation of bandwidth nomenclature.

Weightings within Table D.3 are provided for DMD measured at 1 µm radial intervals starting from the centre of the core (r = 0) for ten simulated lasers with encircled flux (EF) metrics that correspond to those of ten actual lasers. The DMD weightings in Table D.3 are specific to sources meeting the specifications of Clause E.4.

Table D.3 – DMD weightings

Radial position	Laser ID				
r (µm)	1	2	3	4	5
0	0	0	0	0	0
1	0,033 023	0,023 504	0	0	0
2	0,262 463	0,188 044	0	0	0
3	0,884 923	0,634 634	0	0	0
4	2,009 102	1,447 235	0,007 414	0,005 637	0,003 034
5	3,231 216	2,376 616	0,072 928	0,055 488	0,029 856
6	3,961 956	3,052 908	0,262 906	0,200 05	0,107 634
7	3,694 686	3,150 634	0,637 117	0,483 667	0,258 329
8	2,644 369	2,732 324	1,197 628	0,896 95	0,458 494
9	1,397 552	2,060 241	1,916 841	1,402 833	0,661 247
10	0,511 827	1,388 339	2,755 231	1,957 805	0,826 035
11	0,110 549	0,834 722	3,514 797	2,433 247	1,000 204
12	0,004 097	0,419 715	3,883 317	2,639 299	1,294 439
13	0,000 048	0,160 282	3,561 955	2,397 238	1,813 982
14	0,001 111	0,047 143	2,617 093	1,816 953	2,506 95
15	0,005 094	0,044 691	1,480 325	1,296 977	3,164 213
16	0,013 918	0,116 152	0,593 724	1,240 553	3,572 113
17	0,026 32	0,219 802	0,153 006	1,700 02	3,618 037
18	0,036 799	0,307 088	0,012 051	2,240 664	3,329 662
19	0,039 465	0,329 314	0	2,394 077	2,745 395
20	0,032 152	0,268 541	0	1,952 429	1,953 241
21	0,019 992	0,166 97	0	1,213 833	1,137 762
22	0,008 832	0,073 514	0	0,534 474	0,494 404
23	0,002 612	0,021 793	0	0,158 314	0,146 517
24	0,000 282	0,002 679	0	0,019 738	0,018 328
25	0	0	0	0	0

Radial position	Laser ID				
r (µm)	6	7	8	9	10
0	0	0	0	0	0
1	0,015 199	0,016 253	0,022 057	0,010 43	0,015 681
2	0,120 91	0,129 011	0,176 39	0,083 496	0,124 978
3	0,407 702	0,434 844	0,595 248	0,281 802	0,421 548
4	0,925 664	0,987 184	1,351 845	0,650 28	0,957 203
5	1,488 762	1,587 6	2,174 399	1,130 599	1,539 535
6	1,825 448	1,94 661 4	2,666 278	1,627 046	1,887 747
7	1,702 306	1,815 285	2,486 564	2,044 326	1,762 955
8	1,218 378	1,299 241	1,780 897	2,291 72	1,292 184
9	0,643 911	0,686 635	0,945 412	2,280 813	0,790 844
10	0,238 557	0,255 85	0,360 494	1,937 545	0,559 38
11	0,098 956	0,131 429	0,163 923	1,383 006	0,673 655
12	0,204 274	0,327 091	0,318 712	0,878 798	1,047 689
13	0,529 982	0,848 323	0,778 983	0,679 756	1,589 037
14	1,024 948	1,567 513	1,383 174	0,812 36	2,138 626
15	1,611 695	2,224 027	1,853 992	1,074 702	2,470 827
16	2,210 689	2,555 06	1,914 123	1,257 323	2,361 764
17	2,707 415	2,464 566	1,511 827	1,255 967	1,798 213
18	2,938 8	2,087 879	0,908 33	1,112 456	1,059 264
19	2,739 32	1,577 111	0,386 991	0,879 309	0,444 481
20	2,090 874	1,056 343	0,111 76	0,608 183	0,123 304
21	1,261 564	0,595 102	0,014 829	0,348 921	0,012 552
22	0,552 14	0,256 718	0,001 818	0,151 12	0
23	0,163 627	0,076 096	0,000 54	0,044 757	0
24	0,020 443	0,009 446	0	0,005 639	0
25	0	0	0	0	0

D.3 ~~A1a.3~~ A1-OM4 DMD requirements

D.3.1 General

~~A1a.3~~ A1-OM4 fibres selected using the DMD mask method shall meet the requirements of D.3.2 and D.3.3. See Clause D.1 for supporting information. The radial limits, R_{INNER} and R_{OUTER}, were established for transmitters meeting the requirements of Clause E.4.

Refer to Annex E for information regarding effective modal bandwidth (EMB).

D.3.2 DMD templates

~~A1a.3~~ A1-OM4 fibres shall meet at least one of the three templates in Table D.4, each of which includes an inner and outer mask requirement, when measured according to IEC 60793-1-49.

Table D.4 – DMD templates for ~~A1a.3~~ A1-OM4 fibres

Template number	Inner mask DMD (ps/m) for R_{INNER} = 5 µm to R_{OUTER} = 18 µm	Outer mask DMD (ps/m) for R_{INNER} = 0 µm to R_{OUTER} = 23 µm
1	≤ 0,10	≤ 0,30
2	≤ 0,11	≤ 0,17
3	≤ 0,14	≤ 0,14

D.3.3 DMD interval masks

The ~~A1a.3~~ A1-OM4 fibre DMD shall not exceed 0,11 ps/m for any of the radial offset intervals given in Table D.5 when measured according to IEC 60793-1-49.

Table D.5 – DMD interval masks for ~~A1a.3~~ A1-OM4 fibres

Interval number	R_{INNER} µm	R_{OUTER} µm
1	7	13
2	9	15
3	11	17
4	13	19

D.4 ~~A1a.3~~ A1-OM4 fibre EMB$_c$ requirements

D.4.1 General

~~A1a.3~~ A1-OM4 fibres selected using the EMB$_c$ method shall meet the requirements of D.4.2. See the introductory text for Table D.3 in D.2.2 for supporting information.

D.4.2 Calculated effective bandwidth

The DMD optical pulse shapes can be weighted by a set of launch distributions to determine a corresponding set of EMB$_c$ values. The minimum EMB$_c$ (minEMB$_c$) within this set shall meet the requirement of Equation (D.2):

$$\text{minEMB}_c \geq 4\ 160\ \text{MHz·km} \qquad \text{(D.2)}$$

where

minEMB$_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

D.5 ~~A1a.4~~ A1-OM5 fibre modal bandwidth requirements

D.5.1 General

~~A1a.4~~ A1-OM5 fibres shall meet the requirements of D.5.2 and D.6. See the introductory text for Table D.3 in D.2.2 for supporting information.

D.5.2 Calculated effective modal bandwidth

The DMD optical pulse shapes shall be weighted by a set of launch distributions to determine a corresponding set of EMB_c values. The minimum EMB_c ($minEMB_c$) within this set shall meet the requirement of Equations (D.3) and (D.4):

$$minEMB_c \geq 4\,160 \text{ MHz·km at 850 nm} \tag{D.3}$$

$$minEMB_c \geq 2\,190 \text{ MHz·km at 953 nm} \tag{D.4}$$

where

$minEMB_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

D.6 A1-OM2, A1-OM3, A1-OM4 and A1-OM5 calculated overfilled modal bandwidth

The DMD optical pulse shapes shall be weighted for A1-OM2, A1-OM3 and A1-OM4 fibres by the launch distribution of Table D.6 to determine a corresponding OMBc value at 850 nm. For A1-OM5 fibres, the launch distribution of Table D.6 shall be used to determine a corresponding value at 850 nm and 953 nm. The weights of Table D.6 are the same as those in IEC 60793-1-41 for method C.

Table D.6 – DMD weighting for OMB_c

Radial position, *r* µm	**OFL weighting**
0	0
1	0,000 73
2	0,001 57
3	0,002 53
4	0,003 62
5	0,004 87
6	0,006 31
7	0,007 95
8	0,009 83
9	0,011 98
10	0,014 43
11	0,017 25
12	0,020 46
13	0,024 14
14	0,028 36
15	0,033 17
16	0,038 69
17	0,045 00
18	0,052 21
19	0,060 47
20	0,069 92
21	0,080 73
22	0,093 10
23	0,107 25
24	0,123 45
25	0,141 97

Annex E
(informative)

System, modal bandwidth, and transmitter considerations

E.1 Background

When a multimode fibre is used with laser transmitters, the bandwidth of the combination may vary widely, depending on the details of the modal structure of the lasers, the modal delay structure of the fibre, and the coupling between the laser and the fibre modes. More precisely, modal bandwidth is the –3 dB bandwidth of the impulse response produced from the modal delays of a particular fibre weighted by the mode power distribution excited by a particular laser. To generate a robust bandwidth estimate when the impulse response is non-Gaussian, the 3 dB bandwidth is replaced by an extrapolation of the 1,5 dB bandwidth.

Knowledge of the modal structure of a fibre, as determined by IEC 60793-1-49, allows a lower limit to be placed on the range of bandwidths which will be experienced when using a given fibre with various laser transmitters. The $minEMB_c$ technique reviewed in Clause E.3 screens the fibre with 10 simulated lasers that explore the observed mode power distribution; the set of 10 simulated lasers is believed to be conservative compared to commercially available lasers but narrower than the set of theoretical lasers in the original TIA model shown in Figure E.2 [13]. The chosen lasers exhibit a variety of coupled mode power distribution characteristics: some with power more concentrated in lower order modes, some with power more concentrated in higher order modes, and some with both low order and high order mode power concentrations.

By using lasers which couple primarily into modes with well bounded delays, minimum modal bandwidth can be ensured. IEC 61280-1-4 can be used to measure the launch condition of laser transmitters into multimode fibre [15]. Appropriately selected launch condition specifications can restrict the modes of the fibre used by the transmitters primarily to those with appropriately limited differential mode delays.

A minimum modal bandwidth-length product can be ensured by combining a transmitter meeting the specifications in Clause E.4 below with a 50 µm fibre meeting the specifications in Annex D.

E.2 System considerations

E.2.1 ~~A1a.2~~ A1-OM3 and ~~A1a.3~~ A1-OM4 fibres

Refer to Clause E.3.

E.2.2 ~~A1a.4~~ A1-OM5 fibre

Fibre specifications for high data systems have been developed using link models [16]. The 10 Gb/s and 25 Gb/s models build on the 1 Gb/s link model [16] which includes both a requirement that the power penalty or margin be positive and that the inter-symbol interference (ISI) be less than 3,6 dB.

The ~~A1a.4~~ A1-OM5 fibre specifications were developed using the Excel link models for IEEE 100GBASE-SR4 (Example MMF Link Model.xls [17]) and Fibre Channel 32GFC (T11-12-376v0.xlsx [18]). The link models were used to determine the bandwidth requirements over the wavelength range from 840 nm to 953 nm. The wavelengths were varied within this range in the models. In the link models, the dispersion parameters U0 (zero dispersion wavelength) and S0 (zero dispersion slope) were adjusted to new values of 1 328 nm and 0,093 477 ps/(nm2·km) based on round-robin results, and the cabled fibre attenuation was decreased from 3,5 dB/km to 3,0 dB/km. Both link models are margin-limited over the 840 nm to 953 nm wavelength range (unlike the IEEE P802.3ae 10GBASE-S model [19] used for OM3, which is inter-symbol interference limited to less than or equal to 3,6 dB), and the EMB in the link model was adjusted to achieve a margin of 0,000 dB. For setting the EMB specification, it was agreed to use the 32GFC link model with zero margin because the EMB requirements are higher than for the 100GBASE-SR4 model (that is, bandwidth requirements were chosen that met requirements of both system link models). The normative EMB specifications are 4 700 MHz·km at 850 nm and 2 470 MHz·km at 953 nm. These are marked with circles in Figure E.1. With these requirements fulfilled, the expected worst-case EMB lies on or above the system requirements, as explained in Clause E.3.

E.3 Effective modal bandwidth (EMB)

During the development of fibre ~~model A1a.2~~ sub-category A1-OM3, a detailed time-domain Monte-Carlo simulation was used to assess the performance-screening ability of various DMD mask and DMD weighting proposals for transmitters meeting the specifications of Clause E.4 [3] to [14]. The proposals were judged based on their ability to pass fibres that did not cause inter-symbol interference (ISI) to exceed a specific value more often than a 0,5 % rate [13]. The specific ISI value was established via the IEEE 802.3ae link budget spreadsheet [19] for a channel that included the effects of transmitter rise time, receiver bandwidth, and a fibre with 2 000 MHz·km modal bandwidth. Thus, through the use of the Monte-Carlo simulation, fibres meeting the requirements of ~~model A1a.2~~ sub-category A1-OM3 provide a minimum EMB of 2 000 MHz·km.

The minimum EMB value is aligned with the assumptions of the IEEE 802.3ae link budget spreadsheet. Of particular relevance is the fact that, in the spreadsheet, the ISI impairment is modelled under Gaussian waveform assumptions for the transmitter and fibre outputs. According to the results of the Monte-Carlo simulation for fibres passing the requirements, the spreadsheet relationship between ISI and minimum fibre modal bandwidth is pessimistic. Therefore, the calculation of EMB from weighted DMD included a factor of 1,13 to align the fibre requirements developed with the time-domain Monte-Carlo simulation with the spreadsheet model as shown in Equation (E.1).

$$\mathrm{EMB} = 1{,}13 \times \mathrm{minEMB_c} \qquad \text{(E.1)}$$

The EMB derived by Equation (E.1) also applies to the Fibre Channel link models. If other models are used, then a different EMB may be appropriate.

Fibres passing the requirements of Clauses D.3 and D.4 (i.e. ~~A1a.3~~ A1-OM4 fibres) provide a minimum modal bandwidth at 850 nm that is 2,35 times higher than the minimum modal bandwidth of those passing the requirements of Clauses D.1 and D.2 (i.e. ~~A1a.2~~ A1-OM3 fibres). As such, their minimum EMB is also 2,35 times higher under the same link budget spreadsheet assumptions as stated by Equation (E.2).

$$\mathrm{EMB} \geq 2{,}35 \times 2\,000\ \mathrm{MHz{\cdot}km} \geq 4\,700\ \mathrm{MHz{\cdot}km} \qquad \text{(E.2)}$$

System performance studies with actual fibres and laser sources support this relationship [20] to [22]. Applications have emerged which will utilize multiple wavelengths in the vicinity of 850 nm to 950 nm. To support these applications, guidance which characterizes the minimum EMB for A1-OM3, A1-OM4, and A1-OM5 is provided in the form of Equations (E.3) through (E.9) and Figures E.1 through E.3. These equations should not be extrapolated without due consideration.

The population of A1-OM3 subcategory fibres generally exhibit estimated minimum EMB meeting Equations (E.3) and (E.4) which are depicted as two curves from (a) 840 nm to 850 nm and (b) 850 nm to 953 nm as depicted in Figure E.1. The unit of EMB in the two equations is MHz·km.

For 840 nm ≤ λ_c ≤ 850 nm:

$$EMB \geq 1\,826 + (2\,000 - 1\,826) \times (\lambda_c - 840) / (850 - 840) \quad (E.3)$$

For 850 nm ≤ λ_c ≤953 nm:

$$EMB \geq 2\,000 \times (1{,}001\,0 - 0{,}980\,9x + 0{,}807\,3x^2 - 0{,}430\,4x^3 + 0{,}119\,4x^4) \quad (E.4)$$

where

x = (λ_c – 850) / (953 – 850)

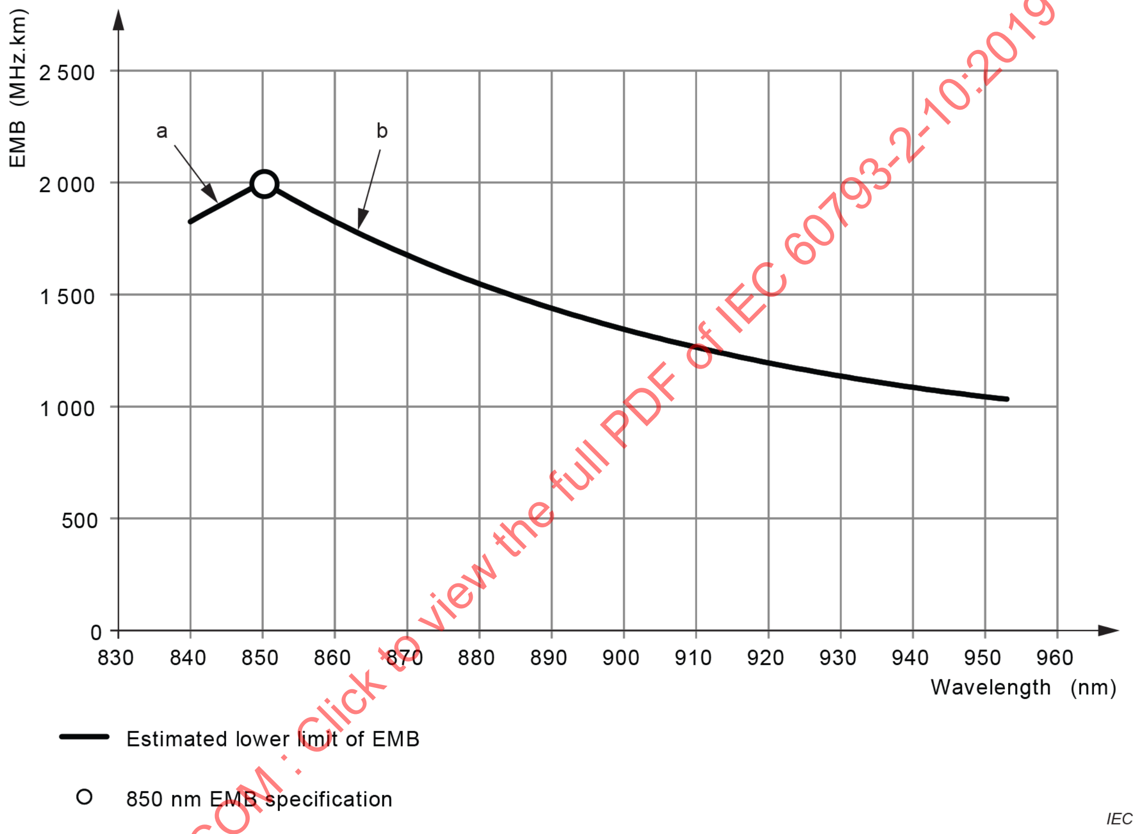

Figure E.1 – Estimated minimum wide band EMB versus wavelength for A1-OM3

The population of A1-OM4 subcategory fibres generally exhibit estimated minimum EMB meeting Equations (E.5) and (E.6) which are depicted as two curves from (a) 840 nm to 850 nm and (b) 850 nm to 953 nm in Figure E.2. The unit of EMB in the two equations is MHz·km.

For 840 nm ≤ λ_c ≤ 850 nm:

$$EMB \geq 3\,840 + (4\,700 - 3\,840) \times (\lambda_c - 840) / (850 - 840) \quad (E.5)$$

For 850 nm ≤ λ_c ≤ 953 nm:

$$EMB \geq 4\,700 \times (1{,}000\,2 - 2{,}154\,9x + 3{,}270\,0x^2 - 2{,}732\,8x^3 + 0{,}928\,0x^4) \quad (E.6)$$

where

x = (λ_c – 850) / (953 – 850)

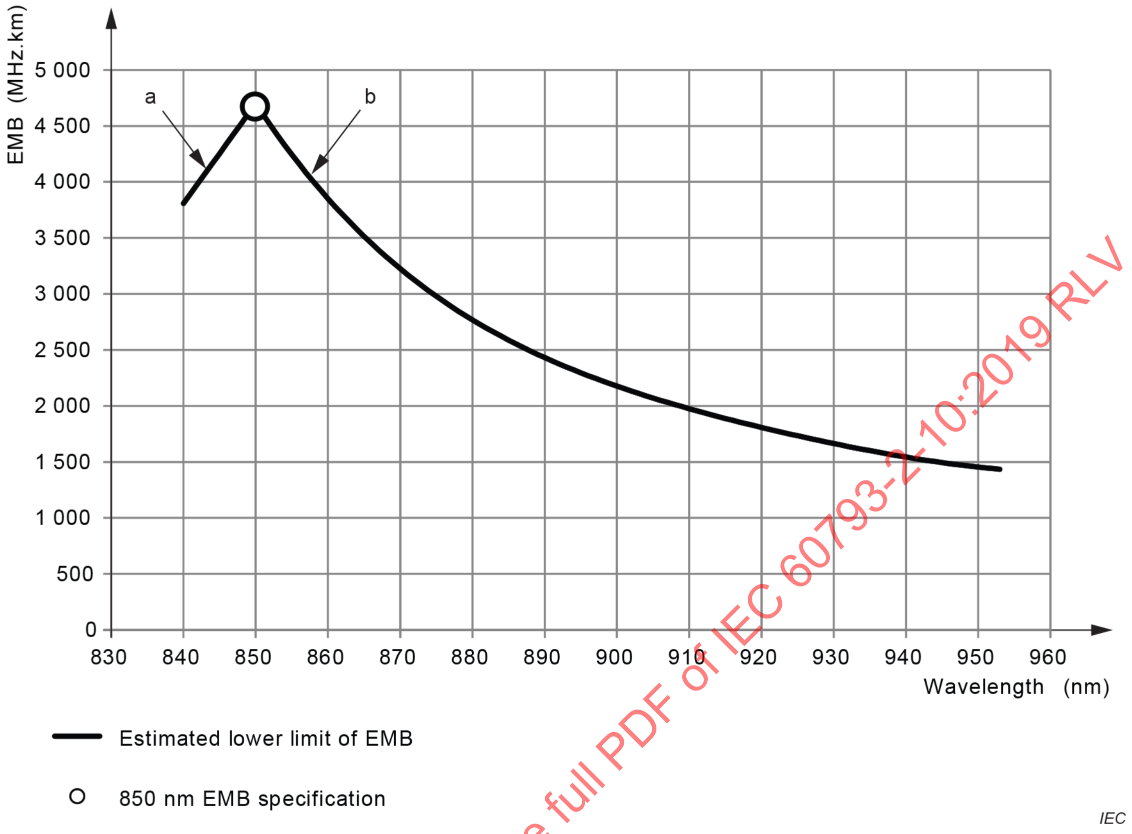

Figure E.2 – Estimated minimum wide band EMB versus wavelength for A1-OM4

Fibres passing the requirements of Clause D.5 (i.e. ~~A1a.4~~ A1-OM5 fibres) generally exhibit estimated EMB meeting Equations (E.7), (E.8) and (E.9), which are depicted as three straight-line segments from (a) 840 nm to 850 nm, (b) 850 nm to 930 nm, and (c) 930 nm to 953 nm in Figure E.3. The unit of EMB in all three equations is MHz·km.

For 840 nm ≤ λ_c ≤ 850 nm:

$$\text{EMB} \geq 3\,840 + (4\,700 - 3\,840) \times (\lambda_c - 840) / (850 - 840) \quad \text{(E.7)}$$

For 850 nm ≤ λ_c ≤ 930 nm:

$$\text{EMB} \geq 4\,700 + (2\,565 - 4\,700) \times (\lambda_c - 850) / (930 - 850) \quad \text{(E.8)}$$

For 930 nm ≤ λ_c ≤ 953 nm:

$$\text{EMB} \geq 2\,565 + (2\,470 - 2\,565) \times (\lambda_c - 930) / (953 - 930) \quad \text{(E.9)}$$

Equations (E.7), (E.8), and (E.9) describe three straight line segments between the minimum EMB indicated by the 32GFC link model at 840 nm and the two minimum EMBs at the nominal measurement wavelengths of 850 nm and 953 nm. Equations (E.7), (E.8) and (E.9) are plotted in Figure E.3 along with values of EMB that close the 32GFC link model. The straight line segments from 840 nm to 953 nm were carefully established as providing a minimum EMB guidance over the wavelength range while not intentionally introducing special fibre design dependence.

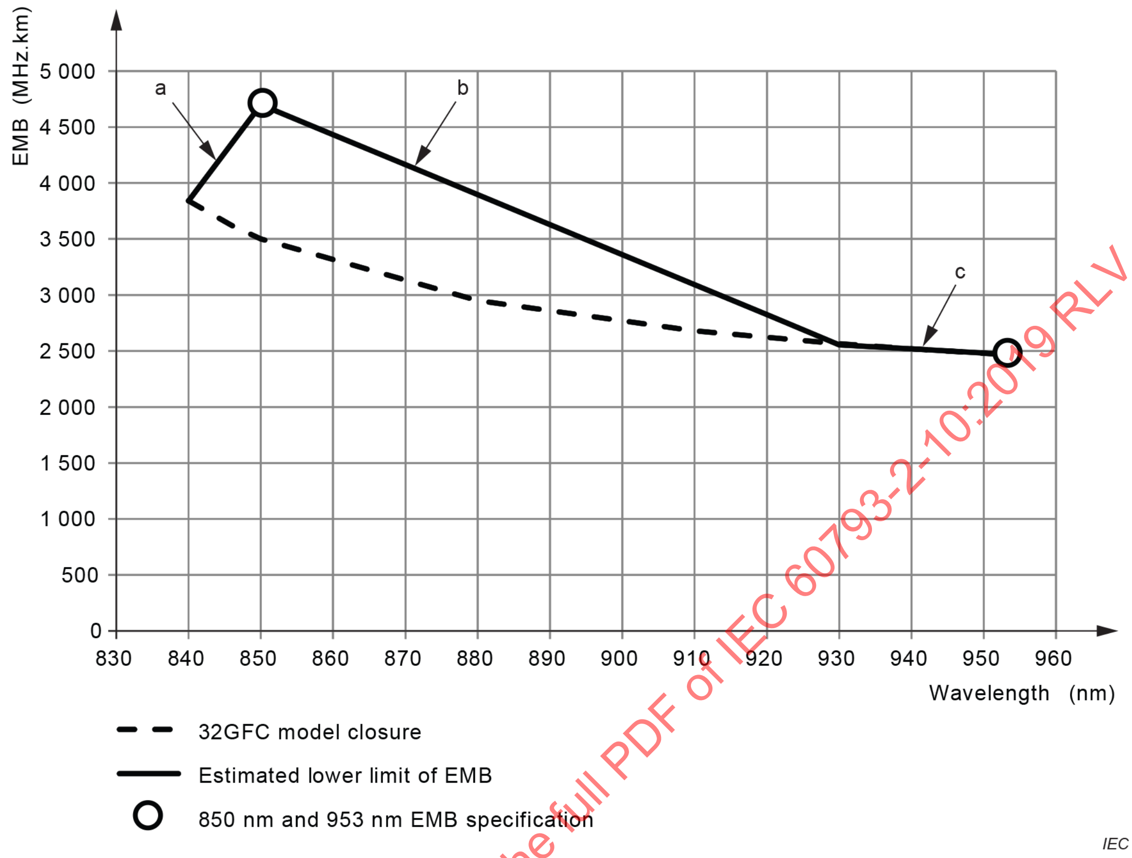

Figure E.3 – Estimated minimum wide band EMB versus wavelength for A1-OM5

E.4 Transmitter encircled flux (EF) and centre wavelength requirements

E.4.1 Encircled flux

The DMD radial limits of the inner, outer and interval masks specified in Clauses D.1 and D.3, and the DMD weightings specified in Clauses D.2, D.4 and D.5, were established in conjunction with the particular bounded range of laser launch conditions specified in Equations (E.10) and (E.11). The minimum modal bandwidth for launch conditions outside of this range has not been determined, but will be lower than for launch conditions within this range.

The transmitter launch condition power distribution should meet the requirements of Equations (E.10) and (E.11) when measured according to IEC 61280-1-4 [15] with the transmitter coupled into a 50-µm fibre meeting the specifications of this document.

$$\text{EF at radius } 4{,}5\ \mu\text{m} \leq 30\ \% \qquad (E.10)$$

$$\text{EF at radius } 19\ \mu\text{m} \geq 86\ \% \qquad (E.11)$$

The approximate positions of the DMD weightings specified in Table D.3 are depicted in the Figure E.4 below, relative to the boundaries given in Equations (E.10) and (E.11) [2].

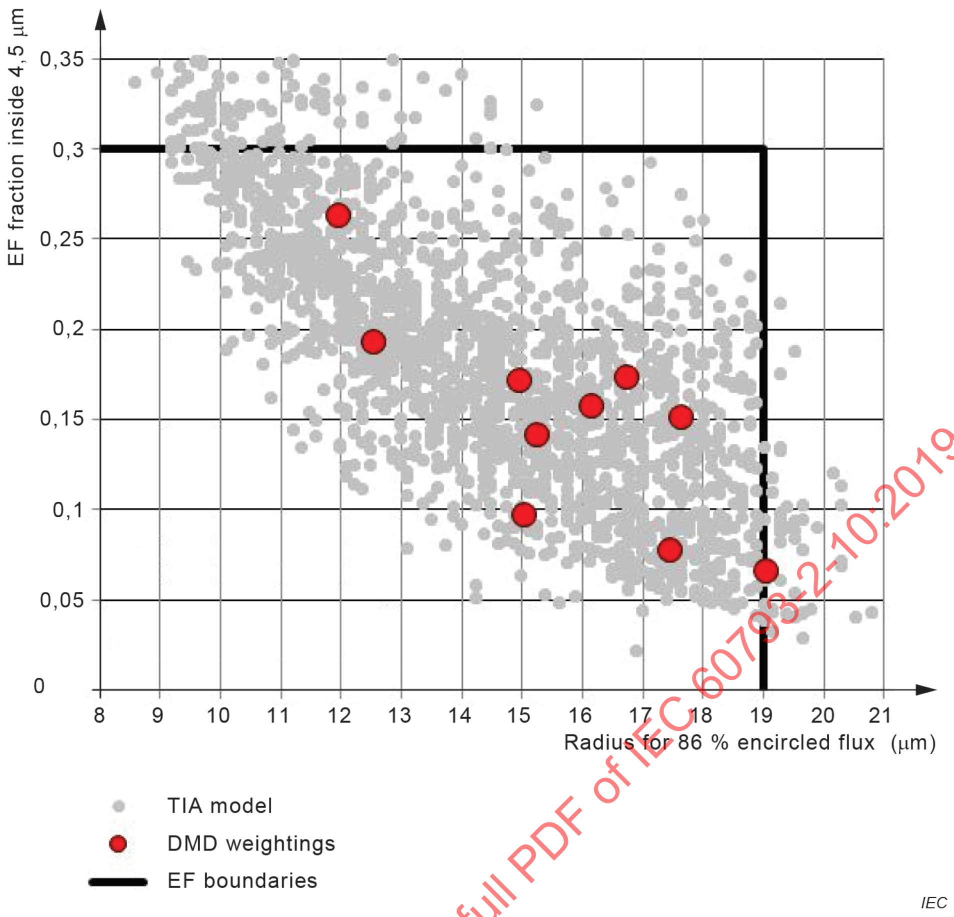

Figure E.4 – Approximate position of DMD weightings relative to the EF boundaries of Equations (E.10) and (E.11)

Several published application standards meet the requirements of E.4.1 and E.4.2 [23] to [26].

E.4.2 Centre wavelength for ~~A1a.2~~ A1-OM3 and ~~A1a.3~~ A1-OM4 fibres

Because the fibre's modal delays change with wavelength, the transmitter centre wavelength should be kept close to the nominal DMD measurement wavelength of 850 nm to achieve the highest modal bandwidth performance over the population of passing fibres. It may be appropriate to de-rate the modal bandwidth when the transmitter is not operating at 850 nm [8]. See [~~14~~27] for an illustration of bandwidth roll-off for fibres with bandwidth similar to fibre model ~~A1a.3~~ A1-OM4.

The laser transmitter centre wavelength (λ_c) should meet the requirements of Equation (E.12) when tested according to IEC 61280-1-3 [28].

$$840 \text{ nm} \leq \lambda_c \leq 860 \text{ nm} \qquad \text{(E.12)}$$

E.4.3 Centre wavelength for ~~A1a.4~~ A1-OM5 fibre

Because the fibre's modal delays change with wavelength, the highest modal bandwidth performance is attained when the laser transmitter centre wavelength is between the DMD measurement wavelengths. When the laser transmitter's centre wavelength is outside this range, the modal bandwidth may degrade. See Equation (E.7), (E.8) and (E.9) for advice on bandwidth values between the DMD measurement wavelengths.

The laser transmitter centre wavelength (λ_c) should meet the requirements of Equation (E.13) when tested according to IEC 61280-1-3 [28].

$$840 \text{ nm} \leq \lambda_c \leq 953 \text{ nm} \tag{E.13}$$

Annex F
(informative)

Bandwidth nomenclature explanation

Table F.1 provides explanations of bandwidth parameters that have similar names and abbreviations.

Table F.1 – Bandwidth nomenclature explanation

Parameter name and abbreviation	Parameter description
Calculated effective modal bandwidth (EMB_c)	The calculated modal bandwidth resulting from a particular weighting of a particular DMD.
Minimum calculated effective modal bandwidth (minimum EMB_c or $minEMB_c$)	The minimum calculated modal bandwidth resulting from a particular set of weightings of a particular DMD.
Effective modal bandwidth (EMB)	The modal bandwidth that results from multiplying the minimum calculated effective modal bandwidth by 1,13 to arrive at a value aligned with the assumptions of the IEEE 802.3ae link model for transmitters compliant to Clause E.2.
Calculated overfilled modal bandwidth (OMB_c)	The calculated modal bandwidth resulting from weighting a particular DMD to simulate an overfilled launch condition.

Annex G
(informative)

Preliminary indications for items needing further study

G.1 Effective modal bandwidth (EMB) at 1 300 nm

Chromatic dispersion properties allow DMD measured at one wavelength to be transformed to DMD at another wavelength. Thus, 850 nm DMD may be used to predict minimum effective modal bandwidth-length product at 1 300 nm. Preliminary engineering analysis indicates that fibres meeting the requirements of Annex D for ≥ 2 000 MHz·km EMB at 850 nm will also provide ≥ 500 MHz·km EMB at 1 300 nm.

Some 1 300 nm laser-based transmitters are defined to operate into both multimode fibre and single mode fibre. In order to provide better assurance that multimode fibres, with bandwidth performance specified only on the basis of overfilled launch conditions, deliver at least their minimum overfilled bandwidth-length product for 1 300 nm transmitters designed to launch into single mode fibre (e.g. 1000BASE-LX), IEEE Std 802.3™ specifies the use of offset-launch mode-conditioning patch cords when connecting such transmitters to this type of multimode fibre.

The offset-launch is implemented by joining a single mode fibre to a multimode fibre within the patch cord using a specified range of single mode-to-multimode radial offset. By launching significantly off-centre from the single mode fibre into the multimode fibre, many modes are excited that produce a mode power distribution closer to that of an overfilled launch than that of the native launch, which typically strongly excites only low-order modes.

Because overfilled-launch bandwidth measurements are heavily dominated by high-order mode behaviour, they are insensitive to the behaviour of low-order modes. Therefore, by avoiding strong excitation of the low-order modes, the offset-launch patch cord eliminates dependence on the behaviour of these poorly-characterized modes, and improves the correlation between minimum system bandwidth and the overfilled launch bandwidth-length measurement.

However, because the DMD test procedure does measure low-order mode behaviour, it is capable of bounding the lower limit of bandwidth-distance product for the native launches of these 1 300 nm transmitters. Fibres meeting ~~A1a.2~~ A1-OM3 and ~~A1a.3~~ A1-OM4 specifications are optimised for peak bandwidth at 850 nm, and have specifically limited low-order mode DMD.

Operating at wavelengths different from the peak wavelength introduces a systematic increase in DMD. The largest increase in DMD occurs for the highest order modes. Thus the overfilled bandwidth, which is dominated by high-order mode DMD, is a conservative indicator of lowest effective modal bandwidth for native 1 300 nm launches that concentrate power in the low order modes. Therefore, ~~A1a.2~~ A1-OM3 and ~~A1a.3~~ A1-OM4 fibres are expected to provide EMB at least as high as their 500 MHz·km minimum overfilled bandwidth-length product at 1 300 nm without the use of mode conditioning patch cords.

G.2 Scaling of EMB with DMD

Different effective modal bandwidth-length products can be derived from the templates and interval masks defined in Clauses D.1 and D.3 simply by scaling EMB in inverse proportion to DMD temporal width, provided the following three conditions are met:

1) the fibre is used with transmitters meeting the specifications in E.4.1;
2) the radial offset limits of the templates are not changed; and
3) the overfilled modal bandwidth-length product requirements are scaled in direct proportion to the EMB.

This scaling ability is substantiated by the following relationships. From the waveguide theory, the mode power distribution of the transmitter relates directly to the radial extents of the inner and outer DMD masks. The operating wavelength range constrains operation in close proximity to the nominal DMD measurement wavelength to minimise modal bandwidth changes due to wavelength. With the mode power distribution and the radial extent of the DMD masks fixed, and the operating wavelength range unchanged, scaling is supported by the inverse proportionality between RMS pulse width and bandwidth [29] [30]. In this case, the RMS pulse width equates to the DMD temporal width. Scaling the overfilled bandwidth in direct proportion to the desired EMB maintains the established proportionality between the DMD and overfilled bandwidth.

For example, an effective modal bandwidth-length product at 850 nm of ≥ 1 000 MHz·km (one-half of 2 000 MHz·km) can be provided with fibre meeting any of the six DMD templates given in Clause D.1, with each template having double the DMD temporal width in both the inner and outer masks, and an overfilled bandwidth-length product of ≥ 750 MHz·km.

Annex H
(informative)

Applications and cabling categories supported by A1 fibres

H.1 Standardised applications

Table H.1 shows various internationally standardised applications, as well as other recommended applications, which are supported by A1 fibres. It is not an exhaustive list, and many other applications not specifically listed may also be supported.

Table H.1 – Some standardised applications supported by A1a A1-OM2, A1-OM3, A1-OM4, A1-OM5 fibres and in some cases A1b A1-OM1 fibres

Application	Source	Name
1GFC	ISO/IEC 14165-115	1-Gigabit Fibre Channel
2GFC	ISO/IEC 14165-115	2-Gigabit Fibre Channel
4GFC	ANSI/INCITS 479	4-Gigabit Fibre Channel
8GFC	ANSI/INCITS 479	8-Gigabit Fibre Channel
10GFC	ISO/IEC 14165-116	10-Gigabit Fibre Channel
16GFC	ANSI/INCITS 479	16-Gigabit Fibre Channel
32GFC	ANSI/INCITS 512	32-Gigabit Fibre Channel
1000BASE-SX	ISO/IEC/IEEE 8802-3	Gigabit Ethernet
1000BASE-LX	ISO/IEC/IEEE 8802-3	Gigabit Ethernet
10GBASE-S	ISO/IEC/IEEE 8802-3	10-Gigabit Ethernet
25GBASE-SR	ISO/IEC/IEEE 8802-3	25-Gigabit Ethernet
40GBASE-SR4	ISO/IEC/IEEE 8802-3	40-Gigabit Ethernet
100GBASE-SR10	ISO/IEC/IEEE 8802-3	100-Gigabit Ethernet
100GBASE-SR4	ISO/IEC/IEEE 8802-3	100-Gigabit Ethernet

H.2 Cross reference of cabled optical fibre performance categories in ISO/IEC 11801-1 to fibres of this document

Table H.2 provides a cross reference between the cabled optical fibre categories of ISO/IEC 11801-1 and the fibre sub-categories of this document.

Table H.2 – Cross reference between ISO/IEC 11801-1 and this document

ISO/IEC 11801-1 cabled optical fibre performance category	IEC 60793-2-10 fibre sub-category or model
OM1 [a]	A1b [b]
OM2 [c]	A1a.1 [d]
OM3	A1a.2
OM4	A1a.3
OM5	A1a.4

[a] OM1 cables are not supported for new installations within ISO/IEC 11801-1.

[b] Historically, ISO/IEC 11801:2002 also defined OM1 cables made with 50/125 µm fibres having a minimum overfilled launch bandwidth of 200 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 50/125 µm fibre is not part of this document.

[c] OM2 cables are not supported for new installations within ISO/IEC 11801-1.

[d] Historically, ISO/IEC 11801:2002 also defined OM2 cables made with 62.5/125 µm fibres having a minimum overfilled launch bandwidth of 500 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 62.5/125 µm fibre is not part of this document.

Annex I
(informative)

1-Gigabit, 10-Gigabit, 25-Gigabit, 40-Gigabit and 100-Gigabit Ethernet applications

Annex I is intended to outline a summary of category A1a and A1b A1-OM2, A1-OM3, A1-OM4, A1-OM5 and A1-OM1 fibre requirements and related transmission capabilities for the 1-Gigabit, 10-Gigabit, 25-Gigabit, 40-Gigabit, and 100-Gigabit Ethernet application standards developed within IEEE 802.3. All the Ethernet applications at 1 Gb/s or higher are considered as "laser launch" applications.

Table I.1 shows a summary of 1 Gb/s, 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities. The rows of Table I.1 are grouped by fibre sub-category and model and listed by increasing data rate. For each line item, there is an indication of the application link length and the requirements on transmitter launch characteristics. The requirements of the transmitter launch characteristics are of three types.

- Offset-launch mode-conditioning patch cord for 1 300 nm operations, defined in IEEE 802.3.
- Coupled power ratio (CPR) > 9 dB and avoidance of radial overfilled launch (ROFL) for 1 Gb/s 850 nm operations on fibres characterised solely by overfilled launch (OFL) bandwidth. CPR is defined in IEC 61280-4-1:2009; ROFL is defined in IEEE 802.3.
- Encircled Flux (EF) requirements for 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s 850 nm operation on fibre models A1a.2, A1a.3 A1-OM3, A1-OM4 and A1a.4 A1-OM5 with effective modal bandwidth ensured by DMD measurement. The EF requirements are: EF at 4,5 µm radius ≤ 30 % and EF at 19,0 µm radius ≥ 86 %. For EF measurements, see IEC 61280-1-4.

Table I.1 – Summary of 1 Gb/s, 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
~~A1b~~ A1-OM1	1	160 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	220	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
~~A1b~~ A1-OM1	1	200 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	275	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
~~A1b~~ A1-OM1	10	160 for OFL	n.s.	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	26	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
~~A1b~~ A1-OM1	10	200 for OFL	n.s.	10GBASE-S	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	33	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
~~A1b~~ A1-OM1	10	160 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
~~A1b~~ A1-OM1	10	200 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220
~~A1a.1~~ A1-OM2	1	400 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	500	400 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
~~A1a.1~~ A1-OM2	1	500 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	550	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
~~A1a.1~~ A1-OM2	10	400 for OFL	n.s.	10GBASE-S	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	66	400 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	240
~~A1a.1~~ A1-OM2	10	500 for OFL	n.s.	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	82	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
~~A1a.1~~ A1-OM2	10	400 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	100
~~A1a.1~~ A1-OM2	10	500 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220
~~A1a.2~~ A1-OM3	10	1 500 for OFL	2 000	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	300	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
~~A1a.2~~ A1-OM3	10	1 500 for OFL	2 000	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
~~A1a.2~~ A1-OM3	25	1 500 for OFL	2 000	25GBASE-SR	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	70	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.2~~ A1-OM3	40	1 500 for OFL	2 000	40GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.2~~ A1-OM3	100	1 500 for OFL	2 000	100GBASE-SR10	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.2~~ A1-OM3	100	1 500 for OFL	2 000	100GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	70	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.3~~ A1-OM4 or ~~A1a.4~~ A1-OM5	10	3 500 for OFL	4 700	10BASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	400	500 for OFL	n.s.	n.s.	n.s.	n.s.

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
~~A1a.3~~ A1-OM4 or ~~A1a.4~~ A1-OM5	25	3 500 for OFL	4 700	25GBASE-SR	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.3~~ A1-OM4 or ~~A1a.4~~ A1-OM5	40	3 500 for OFL	4 700	40GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	150 [b]	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.3~~ A1-OM4 or ~~A1a.4~~ A1-OM5	100	3 500 for OFL	4 700	100GBASE-SR10	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	150 [b]	500 for OFL	n.s.	n.s.	n.s.	n.s.
~~A1a.3~~ A1-OM4 or ~~A1a.4~~ A1-OM5	100	3 500 for OFL	4 700	100GBASE-SR4	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.

Key

n.s. = not specified

[a] PMD = the IEEE 802.3 nomenclature for a device, such as a transceiver, that connects to the transmission medium.

[b] This is an engineered link with maximum 1,0 dB connection and splice loss.

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IEC 60793-2-10

Edition 7.0 2019-05

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Optical fibres –
Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

Fibres optiques –
Partie 2-10: Spécifications de produits – Spécification intermédiaire pour les fibres multimodales de catégorie A1

IEC 60793-2-10:2019-05(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

OPTICAL FIBRES –

Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

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.
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International Standard IEC 60793-2-10 has been prepared by subcommittee 86A: Fibres and cables, of IEC technical committee 86: Fibre optics.

This seventh edition cancels and replaces the sixth edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant change with respect to the previous edition: revision of the naming convention for A1 multimode fibres, which better matches with those found in ISO/IEC standards. These changes are outlined in the scope of this document along with a cross reference table for the new names.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
86A/1932/FDIS	86A/1939/RVD

Full information on the voting for the approval of this International Standard 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 60793 series, published under the general title *Optical fibres*, 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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication 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.

OPTICAL FIBRES –

Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres

1 Scope

This part of IEC 60793 is applicable to optical fibre sub-categories A1-OM1, A1-OM2, A1-OM3, A1-OM4, A1-OM5, and A1d. These fibres are used or can be incorporated in information transmission equipment and optical fibre cables.

Sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 apply to 50/125 μm graded index fibre in four bandwidth grades. Each of these bandwidth grades is defined for two levels of macrobend loss performance that are distinguished by "a" or "b" suffix. Those sub-categories with suffix "a" are specified to meet traditional macrobend loss performance levels. Those sub-categories with suffix "b" are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels.

Sub-category A1-OM5 is specified to support single wavelength or multi-wavelength transmission systems in the vicinity of 850 nm to 950 nm. Although not normatively specified, bandwidth information covering this wavelength range is also included for A1-OM3 and A1-OM4.

Sub-category A1-OM1 applies to 62,5/125 μm graded index fibre and sub-category A1d applies to 100/140 μm graded index fibre.

Other applications include, but are not restricted to, the following: short reach, high bit-rate systems in telephony, distribution and local networks carrying data, voice and/or video services; on-premises intra-building and inter-building fibre installations including data centres, local area networks (LANs), storage area networks (SANs), private branch exchanges (PBXs), video, various multiplexing uses, outside telephone cable plant use, and miscellaneous related uses.

Three types of requirements apply to these fibres:

- general requirements, as defined in IEC 60793-2;
- specific requirements common to the category A1 multimode fibres covered in this document and which are given in Clause 5;
- particular requirements applicable to individual fibre sub-categories and models, or specific applications, which are defined in the normative specification Annexes A to D.

Table 1 shows the cross reference between the IEC A1 multimode optical fibre designations used in this document compared to those used in IEC 60793-2-10:2017. The table also refers to the normative annexes A, B and C for the A1 sub-category multimode fibres in this document that contains the detailed specification.

Table 1 – Cross reference IEC A1 multimode fibre designations to IEC 60793-2-10:2017

Annex	Sub-category	Sub-category/Model	Core diameter (nominal)	ISO/IEC 11801-1:2017
	This document designations	IEC 60793-2-10:2017 designations		Usage of cabled OMx fibres
A	A1-OM2	A1a.1	50 µm [a]	OM2 [b]
	A1-OM3	A1a.2	50 µm	OM3
	A1-OM4	A1a.3	50 µm	OM4
	A1-OM5	A1a.4	50 µm	OM5
B	A1-OM1	A1b	62,5 µm [c]	OM1 [d]
C	A1d	A1d	100 µm	–

[a] Historically, ISO/IEC 11801:2002 also defined OM2 cables made with 62,5/125 µm fibres having a minimum overfilled launch bandwidth of 500 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 62,5/125 µm fibre is not part of this document.

[b] OM2 cables are not supported for new installations within ISO/IEC 11801-1:2017.

[c] Historically, ISO/IEC 11801:2002 also defined OM1 cables made with 50/125 µm fibres having a minimum overfilled launch bandwidth of 200 MHz·km at 850 nm and 500 MHz·km at 1 300 nm. This specific bandwidth combination of 50/125 µm fibre is not part of this document.

[d] OM1 cables are not supported for new installations within ISO/IEC 11801-1:2017.

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 60793-1-20, *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*

IEC 60793-1-21, *Optical fibres – Part 1-21: Measurement methods and test procedures – Coating geometry*

IEC 60793-1-22, *Optical fibres – Part 1-22: Measurement methods and test procedures – Length measurement*

IEC 60793-1-30, *Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test*

IEC 60793-1-31, *Optical fibres – Part 1-31: Measurement methods and test procedures – Tensile strength*

IEC 60793-1-32, *Optical fibres – Part 1-32: Measurement methods and test procedures – Coating strippability*

IEC 60793-1-33, *Optical fibres – Part 1-33: Measurement methods and test procedures – Stress corrosion susceptibility*

IEC 60793-1-40, *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*

IEC 60793-1-41, *Optical fibres – Part 1-41: Measurement methods and test procedures – Bandwidth*

IEC 60793-1-42, *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement*

IEC 60793-1-46, *Optical fibres – Part 1-46: Measurement methods and test procedures – Monitoring of changes in optical transmittance*

IEC 60793-1-47, *Optical fibres – Part 1-47: Measurement methods and test procedures – Macrobending loss*

IEC 60793-1-49, *Optical fibres – Part 1-49: Measurement methods and test procedures – Differential mode delay*

IEC 60793-1-50, *Optical fibres – Part 1-50: Measurement methods and test procedures – Damp heat (steady state) tests*

IEC 60793-1-51, *Optical fibres – Part 1-51: Measurement methods and test procedures –Dry heat (steady state) tests*

IEC 60793-1-52, *Optical fibres – Part 1-52: Measurement methods and test procedures – Change of temperature tests*

IEC 60793-1-53, *Optical fibres – Part 1-53: Measurement methods and test procedures – Water immersion tests*

IEC 60793-2, *Optical fibres – Part 2: Product specifications – General*

IEC 61280-4-1:2009, *Fibre-optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement*

3 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

4 Abbreviated terms

CPR	coupled power ratio
DMD	differential mode delay
EF	encircled flux
EMB	effective modal bandwidth
EMB_c	calculated effective modal bandwidth
LAN	local area network
MMF	multimode fibre
NA	numerical aperture
OFL	overfilled launch
OMB_c	overfilled launch modal bandwidth calculated from differential mode delay (also known as OFL_c)
PBX	private branch exchange
PMD	physical medium dependent
ROFL	radial overfilled launch
SAN	storage area network

5 Specifications

5.1 General

The fibre consists of a glass core with a graded index profile and a glass cladding in accordance with IEC 60793-2.

The term "glass" usually refers to material consisting of non-metallic oxides.

5.2 Dimensional requirements

Dimensional attributes and measurement methods are given in Table 2.

Requirements common to all fibres in category A1 are indicated in Table 3.

Table 4 lists additional attributes that shall be specified by each sub-category specification.

Table 2 – Dimensional attributes and measurement methods

Attributes	Measurement methods
Cladding diameter	IEC 60793-1-20
Core diameter [a, b]	IEC 60793-1-20
Cladding non-circularity	IEC 60793-1-20
Core non-circularity	IEC 60793-1-20
Core-cladding concentricity error	IEC 60793-1-20
Primary coating diameter	IEC 60793-1-21
Primary coating non-circularity	IEC 60793-1-21
Primary coating-cladding concentricity error	IEC 60793-1-21
Fibre length	IEC 60793-1-22

[a] Core diameter is specified at 850 nm ± 10 nm with a test specimen length of 2,0 m ± 0,2 m and a threshold value, k_{CORE}, of 0,025 for A1 fibres except A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

[b] Core diameter is specified at 850 nm ± 10 nm with a test specimen length of 100 m ± 5 % and a threshold value, k_{CORE}, of 0,025 for A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

Table 3 – Dimensional requirements common to category A1 fibres

Attributes	Unit	Limits
Core non-circularity	%	≤ 6
Primary coating diameter – uncoloured [a]	µm	245 ± 10
Primary coating diameter – coloured [a]	µm	250 ± 15
Primary coating-cladding concentricity error	µm	≤ 12,5
Fibre length	km	[b]

[a] The limits on primary coating diameter are most commonly used in telecommunications cables. There are other applications, which use other primary coating diameters, several of which are listed below.

Alternative nominal primary coating diameters and tolerance (µm):

400 ± 40

500 ± 50

700 ± 100

900 ± 100

[b] Length requirements vary and should be agreed between supplier and customer.

Table 4 – Additional dimensional attributes required in sub-category specifications

Attributes
Cladding diameter
Cladding non-circularity
Core diameter
Core-cladding concentricity error

5.3 Mechanical requirements

Mechanical attributes and measurement methods are given in Table 5.

Requirements common to all fibres in category A1 are in Table 6.

Table 5 – Mechanical attributes and measurement methods

Attributes	Test methods
Proof test	IEC 60793-1-30
Tensile strength	IEC 60793-1-31
Primary coating strippability	IEC 60793-1-32
Stress corrosion susceptibility	IEC 60793-1-33

Table 6 – Mechanical requirements common to category A1 fibres

Attributes	Unit	Limits
Proof stress level	GPa	≥ 0,69 [a]
Average strip force[b]	N	$1,0 \leq F_{avg} \leq 5,0$
Peak strip force[b]	N	$1,0 \leq F_{peak} \leq 8,9$
Tensile strength (median) for 0,5 m specimen length	GPa	≥ 3,8
Stress corrosion susceptibility constant, n_d	-	≥ 18

[a] The proof test value of 0,69 GPa equals about 1 % strain or about 8,8 N force, for A1-OM1 to A1-OM5 fibres. For the relation between these different units, see IEC TR 62048:2014, 8.4.

[b] Either average strip force or peak strip force, which are defined in the test procedure, may be specified by agreement between supplier and customer.

5.4 Transmission requirements

Transmission attributes and measurement methods are given in Table 7.

Table 8 lists additional attributes that shall be specified by each sub-category specification.

Table 7 – Transmission attributes and measurement methods

Attributes	Measurement methods
Attenuation coefficient	IEC 60793-1-40
Modal bandwidth [a,b]	IEC 60793-1-41
Numerical aperture [c,d]	IEC 60793-1-43
Chromatic dispersion	IEC 60793-1-42
Change of optical transmission	IEC 60793-1-46
Macrobending loss	IEC 60793-1-47
Differential mode delay [e]	IEC 60793-1-49

[a] For modal bandwidth, either overfilled launch (OFL) or overfilled launch modal bandwidth calculated from differential mode delay (OMB_c) can be used. OMB_c is the reference test method for A1-OM2, A1-OM3 and A1-OM4 fibres at 850 nm and is the required method for A1-OM5 fibres at 850 nm and 953 nm.

[b] 850 nm modal bandwidth is specified with a test specimen length of 1 000 m ± 5 % for A1-OM3 to A1-OM5 fibres. For A1-OM3 fibres, the 850 nm modal bandwidth is measured at 850 nm ± 10 nm. For A1-OM4 and A1-OM5 fibres, the 850 nm modal bandwidth is measured at 850 nm ± 2 nm. For A1-OM5 fibre, the modal bandwidth is also measured at 953 nm ± 6 nm.

[c] Numerical aperture is specified at 850 nm ± 10 nm with a test specimen length of 2 m ± 0,2 m and a threshold value, k_{NA}, of 0,05 for A1 fibres except A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b fibres.

[d] Numerical aperture is specified at 850 nm ± 10 nm with a test specimen length of 100 m ± 5 % and a threshold value, k_{NA}, of 0,05 for A1-OM2b, A1-OM3b, A1-OM4b and A1-OM5b fibres.

[e] Differential mode delay is specified with a test specimen length of 1 000 m ± 5 % for A1-OM3, A1-OM4 and A1-OM5 fibres. For A1-OM3 fibres, the DMD is measured at 850 nm ± 10 nm. For A1-OM4 and A1-OM5 fibres, the DMD is measured at 850 nm ± 2 nm. For A1-OM5 fibre, the DMD is also measured at 953 nm ± 6 nm.

Specification compliance of chromatic dispersion can be assured by compliance to the numerical aperture (NA) specification for A1 fibre.

Table 8 – Additional transmission attributes required in sub-category specifications

Attributes
Attenuation coefficient
Modal bandwidth
Chromatic dispersion
Numerical aperture
Macrobending loss

For attenuation coefficient and modal bandwidth, the sub-category specifications may contain ranges of specifiable values instead of fixed limits. In this case, the actual values of the maximum attenuation coefficient and minimum modal bandwidth, at both 850 nm and 1 300 nm (or just at one of these wavelengths) shall be agreed between supplier and customer. For commercial purposes, the modal bandwidth is linearly normalized to 1 km.

For guidance purposes, Annex H shows a number of standardised applications supported by A1 fibres and Annex I shows transmission capabilities for these fibres.

The indicated maximum attenuation coefficients apply to uncabled optical fibres; for the maximum cabled attenuation coefficients, reference is made to IEC 60794-1-1, which can be used in conjunction with this document. Tighter specifications for the fibre may be requested to account for added attenuation in the cabling process.

Remarks on the specification of modal bandwidth:

Care should be taken in writing dual wavelength bandwidth specifications. It is understood that for category A1 fibres, the bandwidth at 850 nm may be related to the bandwidth at 1 300 nm in a way shown in Figure 1, depending on the refractive index parameter, g (see IEC 60793-2). See [1][1], page 50, and [2], page 255, for similar figures. The shaded region under the curve of Figure 1 can be defined as the dual window area. In this area, regions X, Y, and Z are examples of where a fibre manufacturer may choose to optimise the process. That is, centre the production bandwidth peak at 850 nm, 1 300 nm, or between these two wavelengths.

Due to this optimisation of the manufacturing process, there will be combinations of bandwidth that are not possible (i.e., outside the shaded region).

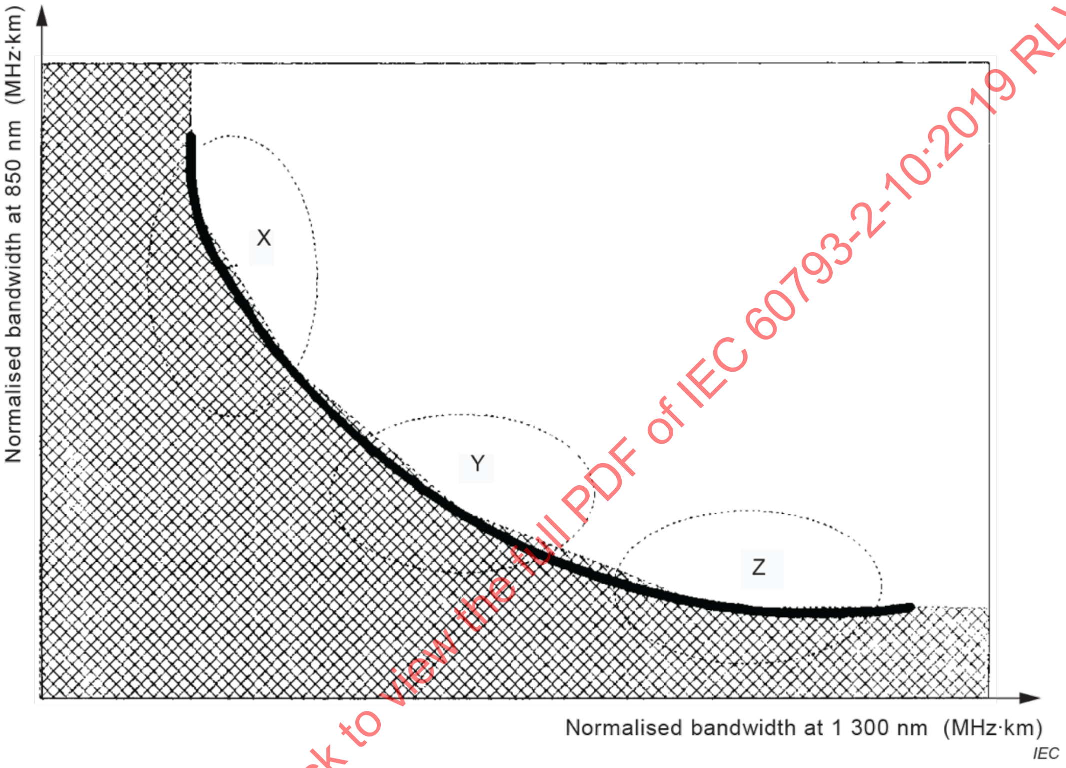

Figure 1 – Relation between bandwidths at 850 nm and 1 300 nm

5.5 Environmental requirements

5.5.1 General

Environmental exposure tests and measurement methods are documented in two forms:

- relevant environmental attributes and test procedures are given in Table 9;
- measurements of a particular mechanical or transmission attribute that may change on the application of the environment are listed in Table 10.

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

Table 9 – Environmental exposure tests

Environmental exposure	Test
Damp heat	IEC 60793-1-50
Dry heat	IEC 60793-1-51
Change of temperature	IEC 60793-1-52
Water immersion	IEC 60793-1-53

Table 10 – Attributes measured for environmental tests

Attribute	Measurement method
Change in optical transmission	IEC 60793-1-46
Attenuation	IEC 60793-1-40
Strip force	IEC 60793-1-32
Tensile strength	IEC 60793-1-31
Stress corrosion susceptibility	IEC 60793-1-33

These tests are normally conducted periodically as type-tests for a fibre and coating design. Unless otherwise indicated, the recovery period allowed between the completion of the environmental exposure and performing the attribute measurements shall be as stated in the particular environmental test method.

5.5.2 Mechanical environmental requirements (common to all fibres in category A1)

5.5.2.1 General

These tests are, in practice, the most severe requirements amongst the environments defined in Table 9.

Tables 11, 12, and 13 give the prescriptions for strip force, tensile strength and stress corrosion susceptibility respectively.

5.5.2.2 Strip force

The following attributes shall be verified following removal of the fibre from the particular environment.

Table 11 – Strip force for environmental tests

Environment	Average strip force N	Peak strip force N
Damp heat	$1,0 \le F_{avg} \le 5,0$	$1,0 \le F_{peak} \le 8,9$
Water immersion	$1,0 \le F_{avg} \le 5,0$	$1,0 \le F_{peak} \le 8,9$

5.5.2.3 Tensile strength

The following attribute shall be verified following removal of the fibre from the environment.

Table 12 – Tensile strength for environmental tests

Environment	Median tensile strength specimen length: 0,5 m GPa	15th percentile tensile strength specimen length: 0,5 m GPa
Damp heat	≥ 3,03	≥ 2,76
NOTE These requirements do not apply to hermetically coated fibre.		

5.5.2.4 Stress corrosion susceptibility

The following attribute shall be verified following removal of the fibre from the environment.

Table 13 – Stress corrosion susceptibility for environmental tests

Environment	Stress corrosion susceptibility constant, n_d
Damp heat	≥ 18
NOTE This requirement does not apply to hermetically coated fibre.	

5.5.3 Transmission environmental requirements

Change in attenuation from the initial value shall be less than the values in Table 14. Attenuation shall be measured periodically during the entire exposure to each environment and after removal.

Table 14 – Change in attenuation for environmental tests

Environment	Wavelength nm	Attenuation increase dB/km
Damp heat	850	≤ 0,20
	1 300	≤ 0,20
Dry heat	850	≤ 0,20
	1 300	≤ 0,20
Change of temperature	850	≤ 0,20
	1 300	≤ 0,20
Water immersion	850	≤ 0,20
	1 300	≤ 0,20

Annex A
(normative)

Specifications for sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 multimode fibres

A.1 General

Annex A contains particular requirements applicable to sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres. Common requirements, repeated here for ease of reference from the main body of this document, are noted by a clause entry in the "Reference" column. The "Reference" column also refers to other annexes containing relevant information on the attribute. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

Sub-categories A1-OM2, A1-OM3, A1-OM4 and A1-OM5 are 50/125 µm graded index multimode fibres in four bandwidth grades. All are specified using overfilled bandwidth metrics, while sub-categories A1-OM3, A1-OM4 and A1-OM5 also apply differential mode delay measurements to deliver laser-optimised performance near 850 nm. Sub-category A1-OM5 also specifies both overfilled and differential mode delay bandwidth metrics at 953 nm to deliver laser-optimized performance over a wavelength range in the vicinity of 850 nm to 950 nm. A1-OM3 complies with A1-OM2 specifications. A1-OM4 complies with A1-OM3 specifications. A1-OM5 complies with A1-OM4 specifications.

Sub-category A1-OM2, A1-OM3, A1-OM4 and A1-OM5 are also specified for two levels of macrobend loss performance that are distinguished by "a" or "b" suffix. Those with suffix "a" (i.e. models A1-OM2a, A1-OM3a, A1-OM4a and A1-OM5a) are specified to meet traditional macrobend loss performance levels. Those with suffix "b" (i.e. models A1-OM2b, A1-OM3b, A1-OM4b and A1-OM5b) are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels, and thereby also comply with traditional macrobend loss performance.

The nomenclature for the A1-OM2, A1-OM3, A1-OM4 and A1-OM5 sub-categories establishes a coding hierarchy that permits designation of fibres with increasing specificity. For example, purchase orders for A1-OM3 may be filled by A1-OM3a or A1-OM3b. As a result, where specifications and descriptions apply to all models at lower hierarchical levels, only the common portion of the name is stated.

The dimensional, mechanical and environmental requirements are common to all and specified in Tables A.1 and A.2. The common and distinguishing transmission requirements are specified in Table A.3.

A.2 Dimensional requirements

Table A.1 contains dimensional requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.1 – Dimensional requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	125 ± 1	
Cladding non-circularity	%	≤ 1	
Core diameter SS	µm	50 ± 2,5	
Core-cladding concentricity error	µm	≤ 2	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

A.3 Mechanical requirements

Table A.2 contains the mechanical requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.2 – Mechanical requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Peak strip force SS	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
SS See notes in the main body of this document..			

A.4 Transmission requirements

Table A.3 contains transmission requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres.

Table A.3 – Transmission requirements specific to A1-OM2, A1-OM3, A1-OM4 and A1-OM5 fibres

Attributes			Unit	Limits				Reference
Fibre sub-category				A1-OM2	A1-OM3	A1-OM4	A1-OM5	
Targeted operational wavelength(s) [a]			nm	850			850 to 950	Annex E
Maximum attenuation coefficient at 850 nm			dB/km	2,5				
Maximum attenuation coefficient at 953 nm			dB/km	Not specified			1,8	
Maximum attenuation coefficient at 1 300 nm			dB/km	0,8				
Minimum modal bandwidth-length product for overfilled launch at 850 nm [SS]			MHz·km	500	1 500	3 500	3 500	Clause D.6
Minimum modal bandwidth-length product for overfilled launch at 953 nm [SS]			MHz·km	Not specified			1 850	Clause D.6
Minimum modal bandwidth-length product for overfilled launch at 1 300 nm			MHz·km	500				
Minimum effective modal bandwidth-length product at 850 nm [SS]			MHz·km	Not specified	2 000 Meet Clause D.1 or Clause D.2	4 700 Meet Clause D.3 or Clause D.4	4 700 Meet Clause D.5	Annexes D, E, F, G
Minimum effective modal bandwidth-length product at 953 nm [SS]			MHz·km	Not specified			2 470 Meet Clause D.5	Annexes D, E, F, G
Numerical aperture [SS]			Dimen-sionless	0,200 ± 0,015				
Fibre model				A1-OM2a	A1-OM3a	A1-OM4a	A1-OM5a	
Maximum macro-bending loss [b]	Bending radius	Number of turns	dB	Max at 850 nm / 1 300 nm				
	37,5 mm	100		0,5 / 0,5				
	15 mm	2		1,0 / 1,0				
Fibre model				A1-OM2b	A1-OM3b	A1-OM4b	A1-OM5b	
Maximum macro-bending loss [b]	Bending radius	Number of turns	dB	Max at 850 nm / 1 300 nm				
	37,5 mm	100		0,5 / 0,5				
	15 mm	2		0,1 / 0,3				
	7,5 mm	2		0,2 / 0,5				
Zero dispersion wavelength, λ_0			nm	$1\ 295 \leq \lambda_0 \leq 1\ 340$ [c]			$1\ 297 \leq \lambda_0 \leq 1\ 328$ [d]	
Zero dispersion slope, S_0			ps/(nm^2·km)	$S_0 \leq 0{,}105$ from $1\ 295\ \text{nm} \leq \lambda_0 \leq 1\ 310$ nm, and $\leq 0{,}000\ 375\ (1\ 590 - \lambda_0)$ from $1\ 310\ \text{nm} \leq \lambda_0 \leq 1\ 340$ nm [c]			$S_0 \leq 4\ (-103)\ /\ (840\ (1 - (\lambda_0/840)^4))$ [d]	

[a] Targeted operational wavelength(s) is informative.

[b] The launch condition for the macrobending loss measurement shall fulfil that described in IEC 61280-4-1.

[c] The worst case chromatic dispersion coefficient at 850 nm (e.g. S_0 = 0,093 75 ps/(nm^2·km) at λ_0 = 1 340 nm or S_0 = 0,101 25 ps/(nm^2·km) at λ_0 = 1 320 nm) is –104 ps/(nm·km).

[d] The coordinate that generates the worst-case dispersion for operating wavelengths from 840 nm to 1 000 nm is λ_0 = 1 328 nm, S_0 = 0,093 477 ps/(nm^2·km) The worst case chromatic dispersion coefficient at 850 nm is –98,5 ps/(nm·km)

[SS] See notes in the main body of this document.

A.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex B
(normative)

Specifications for sub-category A1-OM1 multimode fibres

B.1 General

Annex B contains particular requirements applicable to A1-OM1 fibres. Common requirements, repeated here for ease of reference from the main body of this document, are noted by a clause entry in the "Reference" column. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

Sub-category A1-OM1 fibre is a 62,5/125 µm graded index fibre.

B.2 Dimensional requirements

Table B.1 contains dimensional requirements specific to A1-OM1 fibres.

Table B.1 – Dimensional requirements specific to A1-OM1 fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	125 ± 2	
Cladding non-circularity	%	≤ 2	
Core diameter SS	µm	62,5 ± 3	
Core-cladding concentricity error	µm	≤ 3	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length SS	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

B.3 Mechanical requirements

Table B.2 contains the mechanical requirements specific to A1-OM1 fibres.

Table B.2 – Mechanical requirements specific to A1-OM1 fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Peak strip force SS	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
SS See notes in the main body of this document.			

B.4 Transmission requirements

Table B.3 contains transmission requirements specific to A1-OM1 fibres.

Table B.3 – Transmission requirements specific to A1-OM1 fibres

Attributes	Unit	Limits	Reference
Maximum attenuation coefficient at 850 nm	dB/km	3,0	
Maximum attenuation coefficient at 1 300 nm	dB/km	1,0	
Minimum modal bandwidth-length product at 850 nm	MHz·km	200	
Minimum modal bandwidth-length product at 1 300 nm	MHz·km	500	
Numerical aperture [SS]	Dimensionless	0,275 ± 0,015	
Maximum macrobending loss 100 turns on bending radius of 37,5 mm at wavelengths 850 nm and 1 300 nm [a]	dB	0,5	
Zero dispersion wavelength, λ_0	nm	1 320 ≤ λ_0 ≤ 1 365 [b]	
Zero dispersion slope S_0 – from 1 320 nm ≤ λ_0 ≤ 1 348 nm – from 1 348 nm ≤ λ_0 ≤ 1 365 nm	ps/(nm²·km)	 ≤ 0,11 [b] ≤ 0,001 (1 458 – λ_0) [b]	

[a] The launch condition for the macrobending loss measurement shall fulfil that described in IEC 61280-4-1.

[b] The worst case chromatic dispersion coefficient at 850 nm (S_0 = 0,11 ps/(nm²·km) at λ_0 = 1 348 nm) is –125 ps/(nm·km).

[SS] See notes in the main body of this document.

B.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex C
(normative)

Specifications for sub-category A1d multimode fibres

C.1 General

Annex C contains particular requirements for A1d fibres. Common requirements, repeated here for ease of reference from this document, are noted by an entry in the "Reference" column. Relevant notes from the main body of this document are not repeated but indicated with a superscript "SS".

Sub-category A1d fibre is a 100/140 µm graded index fibre.

C.2 Dimensional requirements

Table C.1 contains dimensional requirements specific to A1d fibres.

Table C.1 – Dimensional requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	140 ± 4	
Cladding non-circularity	%	≤ 4	
Core diameter SS	µm	100 ± 5	
Core-cladding concentricity error	µm	≤ 6	
Core non-circularity	%	≤ 6	5.2
Primary coating diameter – uncoloured SS	µm	245 ± 10	5.2
Primary coating diameter – coloured SS	µm	250 ± 15	5.2
Primary coating-cladding concentricity error	µm	≤ 12,5	5.2
Length SS	km	(see 5.2)	5.2
SS See notes in the main body of this document.			

C.3 Mechanical requirements

Table C.2 contains the mechanical requirements specific to A1d fibres.

Table C.2 – Mechanical requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Proof stress level SS	GPa	≥ 0,69	5.3
Average strip force SS	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Peak strip force SS	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
SS See notes in the main body of this document.			

C.4 Transmission requirements

Table C.3 contains transmission requirements specific to A1d fibres.

Table C.3 – Transmission requirements specific to A1d fibres

Attributes	Unit	Limits	Reference
Maximum attenuation coefficient at 850 nm [a]	dB/km	3,5 to 7,0	
Maximum attenuation coefficient at 1 300 nm [a]	dB/km	1,5 to 4,5	
Minimum modal bandwidth-length product at 850 nm [a]	MHz·km	10 to 200	
Minimum modal bandwidth-length product at 1 300 nm [a]	MHz·km	100 to 300	
Numerical aperture [SS]	Dimensionless	0,26 ± 0,03 or 0,29 ± 0,03	
Maximum macrobending loss	dB	For further study	
Zero dispersion wavelength, λ_0	nm	1 330 ≤ λ_0 ≤ 1 385 [b]	
Zero dispersion slope S_0 – from 1 330 nm ≤ λ_0 ≤ 1 365 nm – from 1 365 nm ≤ λ_0 ≤ 1 385 nm	ps/(nm²·km)	 ≤ 0,105 [b] ≤ 0,000 5 (1 575 – λ_0) [b]	

[a] The limit column forms a range of values that may be specified.

[b] The worst case chromatic dispersion coefficient at 850 nm (S_0 = 0,105 ps/(nm²·km) at λ_0 = 1 365 nm) is –126 ps/(nm·km).

[SS] See notes in the main body of this document.

C.5 Environmental requirements

The requirements of 5.5 shall be met.

Annex D
(normative)

Fibre differential mode delay (DMD), calculated effective modal bandwidth (EMB_c) and calculated overfilled modal bandwidth (OMB_c) requirements

D.1 A1-OM3 fibre DMD requirements

D.1.1 General

A1-OM3 fibres selected using the DMD mask method shall meet the requirements of D.1.2 and D.1.3. The radial limits, R_{INNER} and R_{OUTER}, were established for transmitters meeting the requirements of Clause E.4.

Refer to Annex E for information regarding effective modal bandwidth (EMB).

D.1.2 DMD templates

A1-OM3 fibres shall meet at least one of the six templates in Table D.1, each of which includes an inner and outer mask requirement, when measured according to IEC 60793-1-49.

Table D.1 – DMD templates for A1-OM3 fibres

Template number	Inner mask DMD (ps/m) for R_{INNER} = 5 µm to R_{OUTER} = 18 µm	Outer mask DMD (ps/m) for R_{INNER} = 0 µm to R_{OUTER} = 23 µm
1	≤ 0,23	≤ 0,70
2	≤ 0,24	≤ 0,60
3	≤ 0,25	≤ 0,50
4	≤ 0,26	≤ 0,40
5	≤ 0,27	≤ 0,35
6	≤ 0,33	≤ 0,33

The DMD requirements in Table D.1 are illustrated in Figure D.1. In this figure, the allowable DMD (as measured according to IEC 60793-1-49) is plotted versus the radial offset position of the single mode probe. There is a trade-off between the tightness of the inner mask and the outer mask to ensure a sufficient amount of the baud energy from a transmitter (meeting the launch specifications) arrives within the required time period (defined by the baud rate of the transmission system).

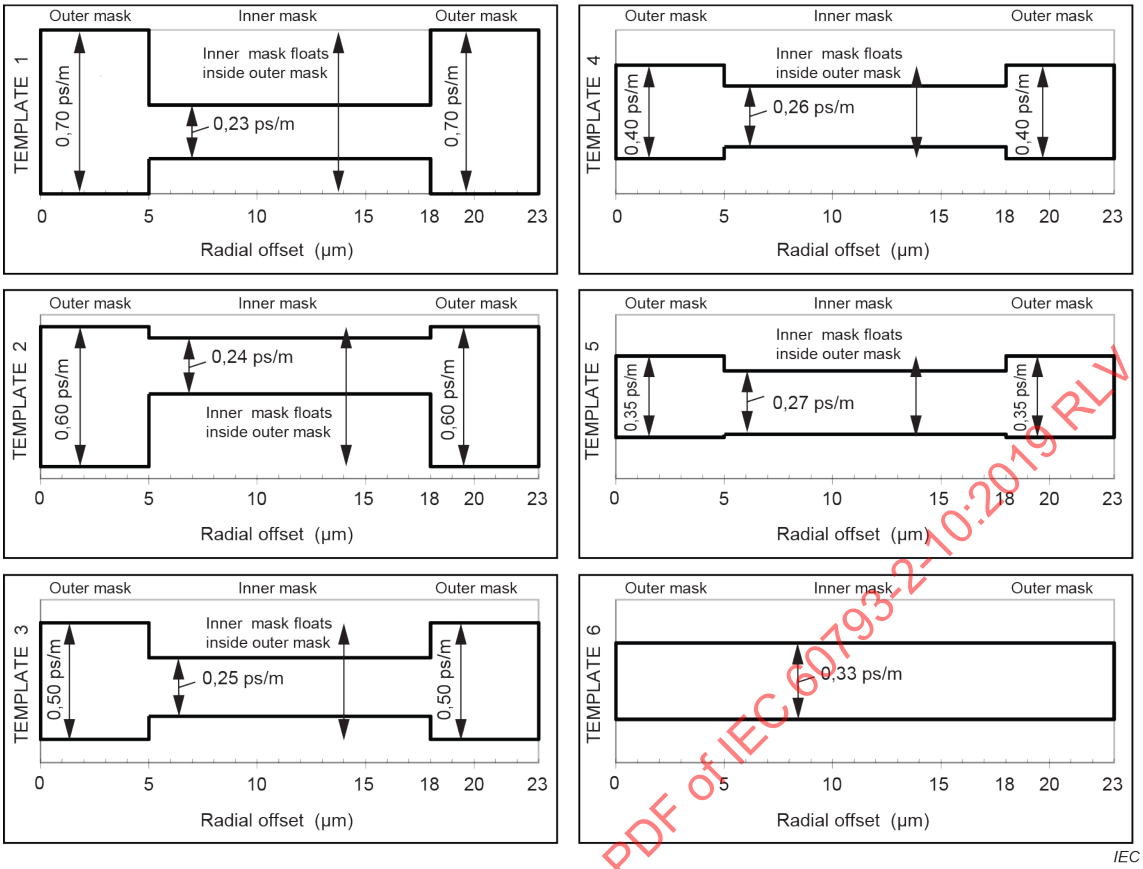

Figure D.1 – DMD template requirements

The "floating" characteristic of the inner mask is also illustrated in Figure D.1. In this figure, the inner mask (5 µm to 18 µm) may be positioned vertically (temporally) anywhere within the outer mask (0 µm to 23 µm). The DMD is more tightly constrained in the inner mask to allow for looser tolerances on the outer mask providing for improved ability to manufacture fibre conforming to this requirement. In the case of the 0,33 ps/m mask, the requirement is the same over the whole range from 0 µm to 23 µm creating a "flat" mask.

IEC 60793-1-49 can be used to ensure a minimum effective modal bandwidth-length product, when using sources meeting appropriate restrictions. When the launch condition requirements on the transmitters are coupled to the DMD requirements on the fibre, a balance can be achieved between fibre tolerance and transmitter tolerance. A careful study, using fibres contributed by several different fibre manufacturers and laser transmitters from several different source manufacturers, and including extensive and detailed simulations, shows that the above coupled specifications on fibre and sources will yield a minimum effective modal bandwidth-length product of 2 000 MHz·km [3] to [14].

The use of a template on the values of DMD achieves an effective trade-off between transmitter and fibre properties. The transmitter launch condition is bounded by encircled flux requirements at 4,5 µm and 19 µm as discussed in Clause E.4. The limitation on the transmitter encircled flux at the 4,5 µm radius assures that very little energy is carried by the lowest order modes of the fibre, allowing the relaxed tolerance on modal structure excited at small radii. The limitation on the transmitter encircled flux at the 19 µm radius assures that very little energy is carried by the highest order modes of the fibre, allowing the relaxed tolerance on modal structure excited at high radii.

D.1.3 DMD interval masks

The A1-OM3 fibre DMD shall not exceed 0,25 ps/m for any of the radial offset intervals given in Table D.2.

Table D.2 – DMD interval masks for A1-OM3 fibres

Interval number	R_{INNER} µm	R_{OUTER} µm
1	7	13
2	9	15
3	11	17
4	13	19

These interval masks screen out fibres having DMD that change too rapidly over short radial ranges. Fibres passing this screen have lower inter-symbol interference than those that do not.

D.2 A1-OM3 fibre EMB_c requirements

D.2.1 General

A1-OM3 fibres selected using the EMB_c method shall meet the requirements of D.2.2.

D.2.2 Calculated effective bandwidth

The DMD optical pulse shapes can be weighted by a set of launch distributions to determine a corresponding set of EMB_c values. The minimum EMB_c ($minEMB_c$) within this set shall meet the requirement of Equation (D.1):

$$minEMB_c \geq 1\,770 \text{ MHz·km} \qquad (D.1)$$

where

$minEMB_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

NOTE 1 Minimum EMB_c is a fibre parameter, and it is possible that its value is not optimal for use in system models. Refer to Annex E for information regarding the corresponding system parameter called the "effective modal bandwidth" (EMB) and its relationship to EMB_c.

NOTE 2 Refer to Annex F for additional explanation of bandwidth nomenclature.

Weightings within Table D.3 are provided for DMD measured at 1 µm radial intervals starting from the centre of the core (r = 0) for ten simulated lasers with encircled flux (EF) metrics that correspond to those of ten actual lasers. The DMD weightings in Table D.3 are specific to sources meeting the specifications of Clause E.4.

Table D.3 – DMD weightings

Radial position	Laser ID				
r (µm)	1	2	3	4	5
0	0	0	0	0	0
1	0,033 023	0,023 504	0	0	0
2	0,262 463	0,188 044	0	0	0
3	0,884 923	0,634 634	0	0	0
4	2,009 102	1,447 235	0,007 414	0,005 637	0,003 034
5	3,231 216	2,376 616	0,072 928	0,055 488	0,029 856
6	3,961 956	3,052 908	0,262 906	0,200 05	0,107 634
7	3,694 686	3,150 634	0,637 117	0,483 667	0,258 329
8	2,644 369	2,732 324	1,197 628	0,896 95	0,458 494
9	1,397 552	2,060 241	1,916 841	1,402 833	0,661 247
10	0,511 827	1,388 339	2,755 231	1,957 805	0,826 035
11	0,110 549	0,834 722	3,514 797	2,433 247	1,000 204
12	0,004 097	0,419 715	3,883 317	2,639 299	1,294 439
13	0,000 048	0,160 282	3,561 955	2,397 238	1,813 982
14	0,001 111	0,047 143	2,617 093	1,816 953	2,506 95
15	0,005 094	0,044 691	1,480 325	1,296 977	3,164 213
16	0,013 918	0,116 152	0,593 724	1,240 553	3,572 113
17	0,026 32	0,219 802	0,153 006	1,700 02	3,618 037
18	0,036 799	0,307 088	0,012 051	2,240 664	3,329 662
19	0,039 465	0,329 314	0	2,394 077	2,745 395
20	0,032 152	0,268 541	0	1,952 429	1,953 241
21	0,019 992	0,166 97	0	1,213 833	1,137 762
22	0,008 832	0,073 514	0	0,534 474	0,494 404
23	0,002 612	0,021 793	0	0,158 314	0,146 517
24	0,000 282	0,002 679	0	0,019 738	0,018 328
25	0	0	0	0	0

Radial position	Laser ID				
r (µm)	6	7	8	9	10
0	0	0	0	0	0
1	0,015 199	0,016 253	0,022 057	0,010 43	0,015 681
2	0,120 91	0,129 011	0,176 39	0,083 496	0,124 978
3	0,407 702	0,434 844	0,595 248	0,281 802	0,421 548
4	0,925 664	0,987 184	1,351 845	0,650 28	0,957 203
5	1,488 762	1,587 6	2,174 399	1,130 599	1,539 535
6	1,825 448	1,94 661 4	2,666 278	1,627 046	1,887 747
7	1,702 306	1,815 285	2,486 564	2,044 326	1,762 955
8	1,218 378	1,299 241	1,780 897	2,291 72	1,292 184
9	0,643 911	0,686 635	0,945 412	2,280 813	0,790 844
10	0,238 557	0,255 85	0,360 494	1,937 545	0,559 38
11	0,098 956	0,131 429	0,163 923	1,383 006	0,673 655
12	0,204 274	0,327 091	0,318 712	0,878 798	1,047 689
13	0,529 982	0,848 323	0,778 983	0,679 756	1,589 037
14	1,024 948	1,567 513	1,383 174	0,812 36	2,138 626
15	1,611 695	2,224 027	1,853 992	1,074 702	2,470 827
16	2,210 689	2,555 06	1,914 123	1,257 323	2,361 764
17	2,707 415	2,464 566	1,511 827	1,255 967	1,798 213
18	2,938 8	2,087 879	0,908 33	1,112 456	1,059 264
19	2,739 32	1,577 111	0,386 991	0,879 309	0,444 481
20	2,090 874	1,056 343	0,111 76	0,608 183	0,123 304
21	1,261 564	0,595 102	0,014 829	0,348 921	0,012 552
22	0,552 14	0,256 718	0,001 818	0,151 12	0
23	0,163 627	0,076 096	0,000 54	0,044 757	0
24	0,020 443	0,009 446	0	0,005 639	0
25	0	0	0	0	0

D.3 A1-OM4 DMD requirements

D.3.1 General

A1-OM4 fibres selected using the DMD mask method shall meet the requirements of D.3.2 and D.3.3. See Clause D.1 for supporting information. The radial limits, R_{INNER} and R_{OUTER}, were established for transmitters meeting the requirements of Clause E.4.

Refer to Annex E for information regarding effective modal bandwidth (EMB).

D.3.2 DMD templates

A1-OM4 fibres shall meet at least one of the three templates in Table D.4, each of which includes an inner and outer mask requirement, when measured according to IEC 60793-1-49.

Table D.4 – DMD templates for A1-OM4 fibres

Template number	Inner mask DMD (ps/m) for R_{INNER} = 5 µm to R_{OUTER} = 18 µm	Outer mask DMD (ps/m) for R_{INNER} = 0 µm to R_{OUTER} = 23 µm
1	≤ 0,10	≤ 0,30
2	≤ 0,11	≤ 0,17
3	≤ 0,14	≤ 0,14

D.3.3 DMD interval masks

The A1-OM4 fibre DMD shall not exceed 0,11 ps/m for any of the radial offset intervals given in Table D.5 when measured according to IEC 60793-1-49.

Table D.5 – DMD interval masks for A1-OM4 fibres

Interval number	R_{INNER} µm	R_{OUTER} µm
1	7	13
2	9	15
3	11	17
4	13	19

D.4 A1-OM4 fibre EMB_c requirements

D.4.1 General

A1-OM4 fibres selected using the EMB_c method shall meet the requirements of D.4.2. See the introductory text for Table D.3 in D.2.2 for supporting information.

D.4.2 Calculated effective bandwidth

The DMD optical pulse shapes can be weighted by a set of launch distributions to determine a corresponding set of EMB_c values. The minimum EMB_c ($minEMB_c$) within this set shall meet the requirement of Equation (D.2):

$$minEMB_c \geq 4\ 160\ \text{MHz·km} \qquad \text{(D.2)}$$

where

$minEMB_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

D.5 A1-OM5 fibre modal bandwidth requirements

D.5.1 General

A1-OM5 fibres shall meet the requirements of D.5.2 and D.6. See the introductory text for Table D.3 in D.2.2 for supporting information.

D.5.2 Calculated effective modal bandwidth

The DMD optical pulse shapes shall be weighted by a set of launch distributions to determine a corresponding set of EMB_c values. The minimum EMB_c ($minEMB_c$) within this set shall meet the requirement of Equations (D.3) and (D.4):

$$minEMB_c \geq 4\ 160 \text{ MHz·km at 850 nm} \tag{D.3}$$

$$minEMB_c \geq 2\ 190 \text{ MHz·km at 953 nm} \tag{D.4}$$

where

$minEMB_c$ is determined from the complex transfer function as described in IEC 60793-1-49 using the weights defined in Table D.3.

D.6 A1-OM2, A1-OM3, A1-OM4 and A1-OM5 calculated overfilled modal bandwidth

The DMD optical pulse shapes shall be weighted for A1-OM2, A1-OM3 and A1-OM4 fibres by the launch distribution of Table D.6 to determine a corresponding OMB_c value at 850 nm. For A1-OM5 fibres, the launch distribution of Table D.6 shall be used to determine a corresponding value at 850 nm and 953 nm. The weights of Table D.6 are the same as those in IEC 60793-1-41 for method C.

Table D.6 – DMD weighting for OMB_c

Radial position, *r* µm	**OFL weighting**
0	0
1	0,000 73
2	0,001 57
3	0,002 53
4	0,003 62
5	0,004 87
6	0,006 31
7	0,007 95
8	0,009 83
9	0,011 98
10	0,014 43
11	0,017 25
12	0,020 46
13	0,024 14
14	0,028 36
15	0,033 17
16	0,038 69
17	0,045 00
18	0,052 21
19	0,060 47
20	0,069 92
21	0,080 73
22	0,093 10
23	0,107 25
24	0,123 45
25	0,141 97

Annex E
(informative)

System, modal bandwidth, and transmitter considerations

E.1 Background

When a multimode fibre is used with laser transmitters, the bandwidth of the combination may vary widely, depending on the details of the modal structure of the lasers, the modal delay structure of the fibre, and the coupling between the laser and the fibre modes. More precisely, modal bandwidth is the –3 dB bandwidth of the impulse response produced from the modal delays of a particular fibre weighted by the mode power distribution excited by a particular laser. To generate a robust bandwidth estimate when the impulse response is non-Gaussian, the 3 dB bandwidth is replaced by an extrapolation of the 1,5 dB bandwidth.

Knowledge of the modal structure of a fibre, as determined by IEC 60793-1-49, allows a lower limit to be placed on the range of bandwidths which will be experienced when using a given fibre with various laser transmitters. The minEMB$_c$ technique reviewed in Clause E.3 screens the fibre with 10 simulated lasers that explore the observed mode power distribution; the set of 10 simulated lasers is believed to be conservative compared to commercially available lasers but narrower than the set of theoretical lasers in the original TIA model shown in Figure E.2 [13]. The chosen lasers exhibit a variety of coupled mode power distribution characteristics: some with power more concentrated in lower order modes, some with power more concentrated in higher order modes, and some with both low order and high order mode power concentrations.

By using lasers which couple primarily into modes with well bounded delays, minimum modal bandwidth can be ensured. IEC 61280-1-4 can be used to measure the launch condition of laser transmitters into multimode fibre [15]. Appropriately selected launch condition specifications can restrict the modes of the fibre used by the transmitters primarily to those with appropriately limited differential mode delays.

A minimum modal bandwidth-length product can be ensured by combining a transmitter meeting the specifications in Clause E.4 below with a 50 µm fibre meeting the specifications in Annex D.

E.2 System considerations

E.2.1 A1-OM3 and A1-OM4 fibres

Refer to Clause E.3.

E.2.2 A1-OM5 fibre

Fibre specifications for high data systems have been developed using link models [16]. The 10 Gb/s and 25 Gb/s models build on the 1 Gb/s link model [16] which includes both a requirement that the power penalty or margin be positive and that the inter-symbol interference (ISI) be less than 3,6 dB.

The A1-OM5 fibre specifications were developed using the Excel link models for IEEE 100GBASE-SR4 (Example MMF Link Model.xls [17]) and Fibre Channel 32GFC (T11-12-376v0.xlsx [18]). The link models were used to determine the bandwidth requirements over the wavelength range from 840 nm to 953 nm. The wavelengths were varied within this range in the models. In the link models, the dispersion parameters U_0 (zero dispersion wavelength) and S_0 (zero dispersion slope) were adjusted to new values of 1 328 nm and 0,093 477 ps/(nm^2·km) based on round-robin results, and the cabled fibre attenuation was decreased from 3,5 dB/km to 3,0 dB/km. Both link models are margin-limited over the 840 nm to 953 nm wavelength range (unlike the IEEE P802.3ae 10GBASE-S model [19] used for OM3, which is inter-symbol interference limited to less than or equal to 3,6 dB), and the EMB in the link model was adjusted to achieve a margin of 0,000 dB. For setting the EMB specification, it was agreed to use the 32GFC link model with zero margin because the EMB requirements are higher than for the 100GBASE-SR4 model (that is, bandwidth requirements were chosen that met requirements of both system link models). The normative EMB specifications are 4 700 MHz·km at 850 nm and 2 470 MHz·km at 953 nm. These are marked with circles in Figure E.1. With these requirements fulfilled, the expected worst-case EMB lies on or above the system requirements, as explained in Clause E.3.

E.3 Effective modal bandwidth (EMB)

During the development of fibre sub-category A1-OM3, a detailed time-domain Monte-Carlo simulation was used to assess the performance-screening ability of various DMD mask and DMD weighting proposals for transmitters meeting the specifications of Clause E.4 [3] to [14]. The proposals were judged based on their ability to pass fibres that did not cause inter-symbol interference (ISI) to exceed a specific value more often than a 0,5 % rate [13]. The specific ISI value was established via the IEEE 802.3ae link budget spreadsheet [19] for a channel that included the effects of transmitter rise time, receiver bandwidth, and a fibre with 2 000 MHz·km modal bandwidth. Thus, through the use of the Monte-Carlo simulation, fibres meeting the requirements of sub-category A1-OM3 provide a minimum EMB of 2 000 MHz·km.

The minimum EMB value is aligned with the assumptions of the IEEE 802.3ae link budget spreadsheet. Of particular relevance is the fact that, in the spreadsheet, the ISI impairment is modelled under Gaussian waveform assumptions for the transmitter and fibre outputs. According to the results of the Monte-Carlo simulation for fibres passing the requirements, the spreadsheet relationship between ISI and minimum fibre modal bandwidth is pessimistic. Therefore, the calculation of EMB from weighted DMD included a factor of 1,13 to align the fibre requirements developed with the time-domain Monte-Carlo simulation with the spreadsheet model as shown in Equation (E.1).

$$\mathrm{EMB} = 1{,}13 \times \mathrm{minEMB_c} \qquad \text{(E.1)}$$

The EMB derived by Equation (E.1) also applies to the Fibre Channel link models. If other models are used, then a different EMB may be appropriate.

Fibres passing the requirements of Clauses D.3 and D.4 (i.e. A1-OM4 fibres) provide a minimum modal bandwidth at 850 nm that is 2,35 times higher than the minimum modal bandwidth of those passing the requirements of Clauses D.1 and D.2 (i.e. A1-OM3 fibres). As such, their minimum EMB is also 2,35 times higher under the same link budget spreadsheet assumptions as stated by Equation (E.2).

$$\mathrm{EMB} \geq 2{,}35 \times 2\,000\ \mathrm{MHz{\cdot}km} \geq 4\,700\ \mathrm{MHz{\cdot}km} \qquad \text{(E.2)}$$

System performance studies with actual fibres and laser sources support this relationship [20] to [22]. Applications have emerged which will utilize multiple wavelengths in the vicinity of 850 nm to 950 nm. To support these applications, guidance which characterizes the minimum EMB for A1-OM3, A1-OM4, and A1-OM5 is provided in the form of Equations (E.3) through (E.9) and Figures E.1 through E.3. These equations should not be extrapolated without due consideration.

The population of A1-OM3 subcategory fibres generally exhibit estimated minimum EMB meeting Equations (E.3) and (E.4) which are depicted as two curves from (a) 840 nm to 850 nm and (b) 850 nm to 953 nm as depicted in Figure E.1. The unit of EMB in the two equations is MHz·km.

For 840 nm ≤ λ_c ≤ 850 nm:

$$\text{EMB} \geq 1\,826 + (2\,000 - 1\,826) \times (\lambda_c - 840) / (850 - 840) \quad \text{(E.3)}$$

For 850 nm ≤ λ_c ≤953 nm:

$$\text{EMB} \geq 2\,000 \times (1{,}001\,0 - 0{,}980\,9x + 0{,}807\,3x^2 - 0{,}430\,4x^3 + 0{,}119\,4x^4) \quad \text{(E.4)}$$

where

x = (λ_c – 850) / (953 – 850)

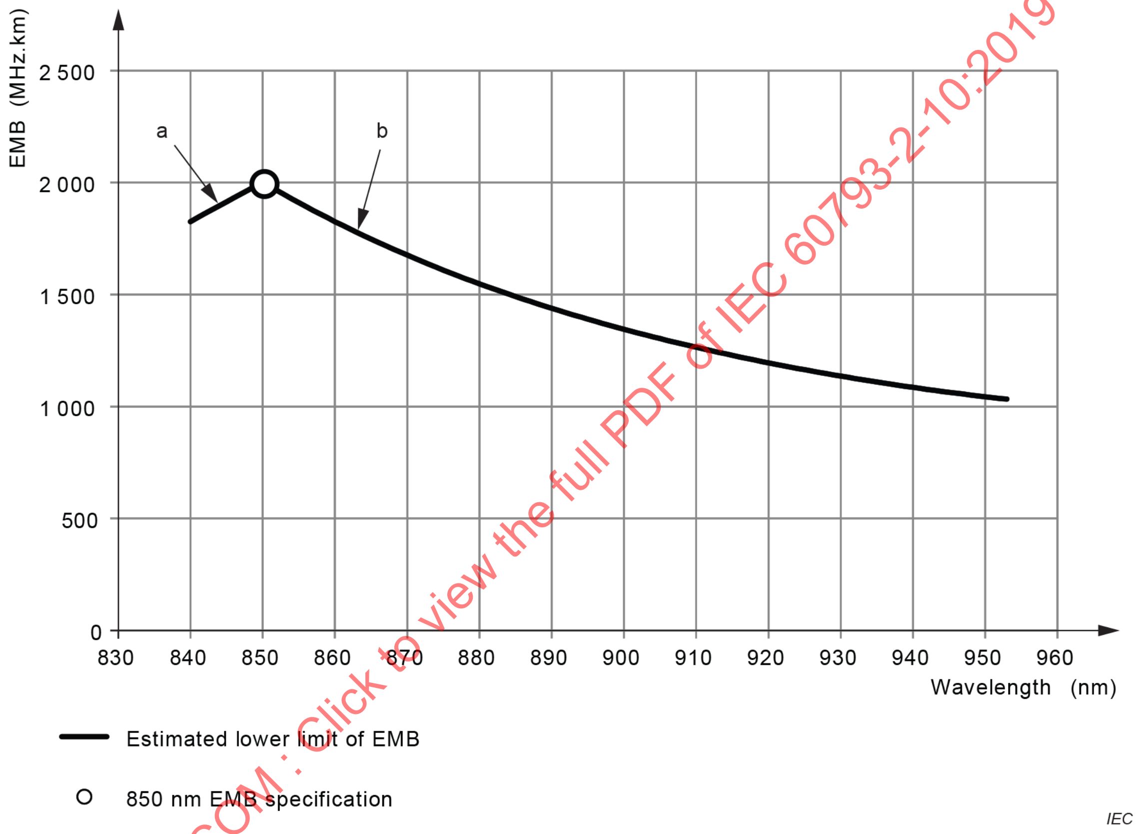

Figure E.1 – Estimated minimum wide band EMB versus wavelength for A1-OM3

The population of A1-OM4 subcategory fibres generally exhibit estimated minimum EMB meeting Equations (E.5) and (E.6) which are depicted as two curves from (a) 840 nm to 850 nm and (b) 850 nm to 953 nm in Figure E.2. The unit of EMB in the two equations is MHz·km.

For 840 nm ≤ λ_c ≤ 850 nm:

$$\text{EMB} \geq 3\,840 + (4\,700 - 3\,840) \times (\lambda_c - 840) / (850 - 840) \quad \text{(E.5)}$$

For 850 nm ≤ λ_c ≤ 953 nm:

$$\text{EMB} \geq 4\,700 \times (1{,}000\,2 - 2{,}154\,9x + 3{,}270\,0x^2 - 2{,}732\,8x^3 + 0{,}928\,0x^4) \quad \text{(E.6)}$$

where

$x = (\lambda_c - 850) / (953 - 850)$

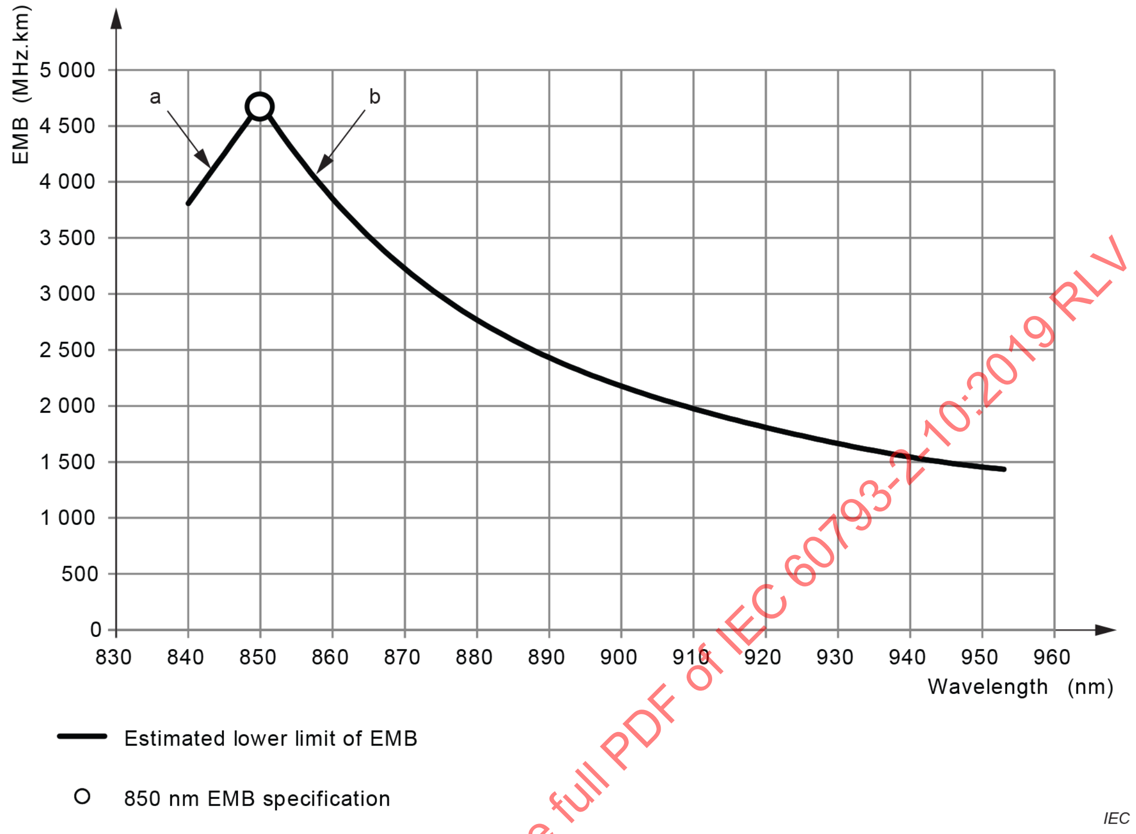

Figure E.2 – Estimated minimum wide band EMB versus wavelength for A1-OM4

Fibres passing the requirements of Clause D.5 (i.e. A1-OM5 fibres) generally exhibit estimated EMB meeting Equations (E.7), (E.8) and (E.9), which are depicted as three straight-line segments from (a) 840 nm to 850 nm, (b) 850 nm to 930 nm, and (c) 930 nm to 953 nm in Figure E.3. The unit of EMB in all three equations is MHz·km.

For 840 nm $\leq \lambda_c \leq$ 850 nm:

$$EMB \geq 3\,840 + (4\,700 - 3\,840) \times (\lambda_c - 840) / (850 - 840) \quad (E.7)$$

For 850 nm $\leq \lambda_c \leq$ 930 nm:

$$EMB \geq 4\,700 + (2\,565 - 4\,700) \times (\lambda_c - 850) / (930 - 850) \quad (E.8)$$

For 930 nm $\leq \lambda_c \leq$ 953 nm:

$$EMB \geq 2\,565 + (2\,470 - 2\,565) \times (\lambda_c - 930) / (953 - 930) \quad (E.9)$$

Equations (E.7), (E.8), and (E.9) describe three straight line segments between the minimum EMB indicated by the 32GFC link model at 840 nm and the two minimum EMBs at the nominal measurement wavelengths of 850 nm and 953 nm. Equations (E.7), (E.8) and (E.9) are plotted in Figure E.3 along with values of EMB that close the 32GFC link model. The straight line segments from 840 nm to 953 nm were carefully established as providing a minimum EMB guidance over the wavelength range while not intentionally introducing special fibre design dependence.

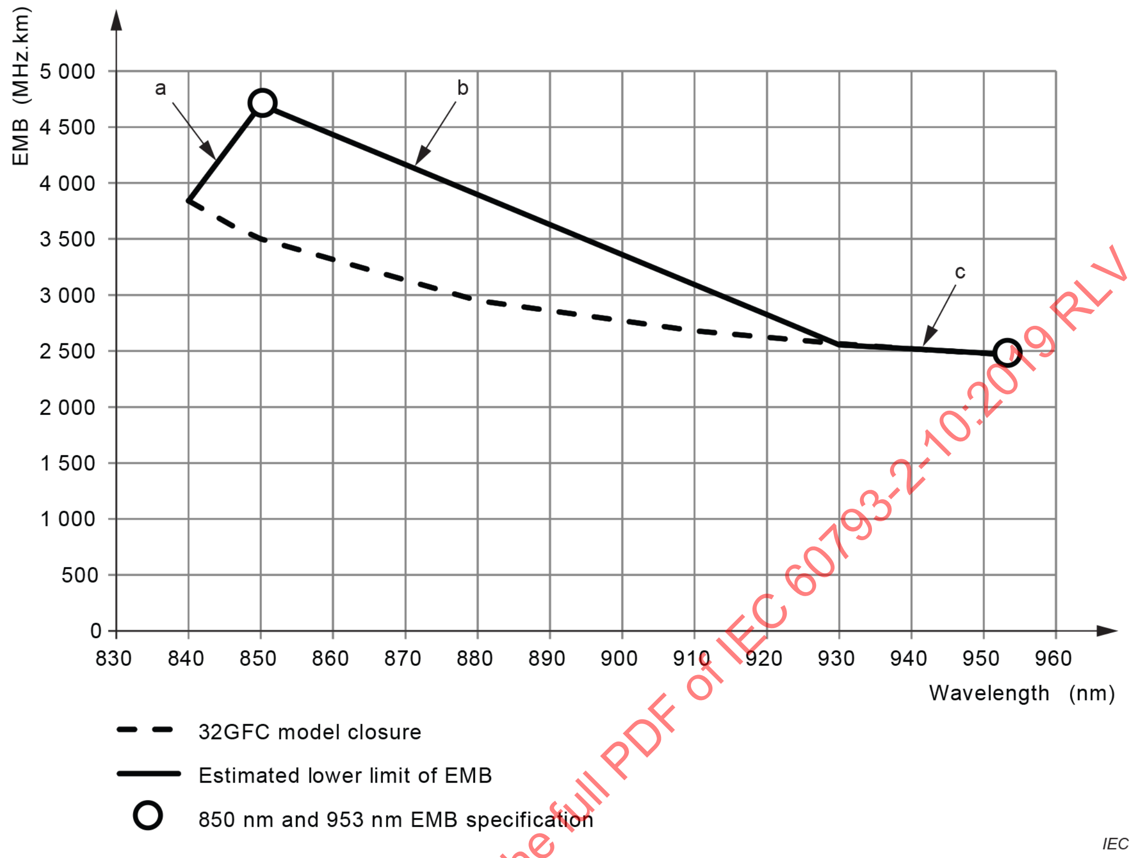

Figure E.3 – Estimated minimum wide band EMB versus wavelength for A1-OM5

E.4 Transmitter encircled flux (EF) and centre wavelength requirements

E.4.1 Encircled flux

The DMD radial limits of the inner, outer and interval masks specified in Clauses D.1 and D.3, and the DMD weightings specified in Clauses D.2, D.4 and D.5, were established in conjunction with the particular bounded range of laser launch conditions specified in Equations (E.10) and (E.11). The minimum modal bandwidth for launch conditions outside of this range has not been determined, but will be lower than for launch conditions within this range.

The transmitter launch condition power distribution should meet the requirements of Equations (E.10) and (E.11) when measured according to IEC 61280-1-4 [15] with the transmitter coupled into a 50-µm fibre meeting the specifications of this document.

$$\text{EF at radius } 4{,}5\ \mu\text{m} \leq 30\ \% \qquad \text{(E.10)}$$

$$\text{EF at radius } 19\ \mu\text{m} \geq 86\ \% \qquad \text{(E.11)}$$

The approximate positions of the DMD weightings specified in Table D.3 are depicted in the Figure E.4 below, relative to the boundaries given in Equations (E.10) and (E.11) [2].

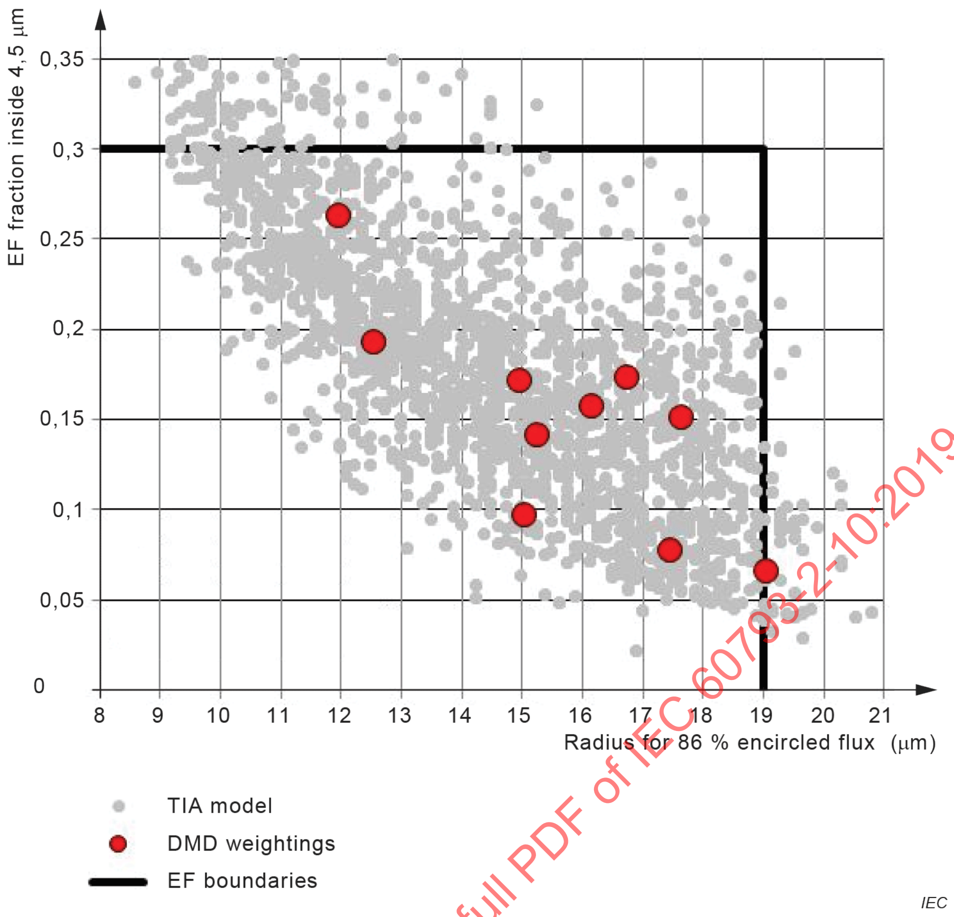

Figure E.4 – Approximate position of DMD weightings relative to the EF boundaries of Equations (E.10) and (E.11)

Several published application standards meet the requirements of E.4.1 and E.4.2 [23] to [26].

E.4.2 Centre wavelength for A1-OM3 and A1-OM4 fibres

Because the fibre's modal delays change with wavelength, the transmitter centre wavelength should be kept close to the nominal DMD measurement wavelength of 850 nm to achieve the highest modal bandwidth performance over the population of passing fibres. It may be appropriate to de-rate the modal bandwidth when the transmitter is not operating at 850 nm [8]. See [27] for an illustration of bandwidth roll-off for fibres with bandwidth similar to fibre model A1-OM4.

The laser transmitter centre wavelength (λ_c) should meet the requirements of Equation (E.12) when tested according to IEC 61280-1-3 [28].

$$840 \text{ nm} \leq \lambda_c \leq 860 \text{ nm} \quad \text{(E.12)}$$

E.4.3 Centre wavelength for A1-OM5 fibre

Because the fibre's modal delays change with wavelength, the highest modal bandwidth performance is attained when the laser transmitter centre wavelength is between the DMD measurement wavelengths. When the laser transmitter's centre wavelength is outside this range, the modal bandwidth may degrade. See Equation (E.7), (E.8) and (E.9) for advice on bandwidth values between the DMD measurement wavelengths.

The laser transmitter centre wavelength (λ_c) should meet the requirements of Equation (E.13) when tested according to IEC 61280-1-3 [28].

$$840\ \text{nm} \le \lambda_c \le 953\ \text{nm} \qquad \text{(E.13)}$$

Annex F
(informative)

Bandwidth nomenclature explanation

Table F.1 provides explanations of bandwidth parameters that have similar names and abbreviations.

Table F.1 – Bandwidth nomenclature explanation

Parameter name and abbreviation	Parameter description
Calculated effective modal bandwidth (EMB_c)	The calculated modal bandwidth resulting from a particular weighting of a particular DMD.
Minimum calculated effective modal bandwidth (minimum EMB_c or $minEMB_c$)	The minimum calculated modal bandwidth resulting from a particular set of weightings of a particular DMD.
Effective modal bandwidth (EMB)	The modal bandwidth that results from multiplying the minimum calculated effective modal bandwidth by 1,13 to arrive at a value aligned with the assumptions of the IEEE 802.3ae link model for transmitters compliant to Clause E.2.
Calculated overfilled modal bandwidth (OMB_c)	The calculated modal bandwidth resulting from weighting a particular DMD to simulate an overfilled launch condition.

Annex G
(informative)

Preliminary indications for items needing further study

G.1 Effective modal bandwidth (EMB) at 1 300 nm

Chromatic dispersion properties allow DMD measured at one wavelength to be transformed to DMD at another wavelength. Thus, 850 nm DMD may be used to predict minimum effective modal bandwidth-length product at 1 300 nm. Preliminary engineering analysis indicates that fibres meeting the requirements of Annex D for ≥ 2 000 MHz·km EMB at 850 nm will also provide ≥ 500 MHz·km EMB at 1 300 nm.

Some 1 300 nm laser-based transmitters are defined to operate into both multimode fibre and single mode fibre. In order to provide better assurance that multimode fibres, with bandwidth performance specified only on the basis of overfilled launch conditions, deliver at least their minimum overfilled bandwidth-length product for 1 300 nm transmitters designed to launch into single mode fibre (e.g. 1000BASE-LX), IEEE Std 802.3™ specifies the use of offset-launch mode-conditioning patch cords when connecting such transmitters to this type of multimode fibre.

The offset-launch is implemented by joining a single mode fibre to a multimode fibre within the patch cord using a specified range of single mode-to-multimode radial offset. By launching significantly off-centre from the single mode fibre into the multimode fibre, many modes are excited that produce a mode power distribution closer to that of an overfilled launch than that of the native launch, which typically strongly excites only low-order modes.

Because overfilled-launch bandwidth measurements are heavily dominated by high-order mode behaviour, they are insensitive to the behaviour of low-order modes. Therefore, by avoiding strong excitation of the low-order modes, the offset-launch patch cord eliminates dependence on the behaviour of these poorly-characterized modes, and improves the correlation between minimum system bandwidth and the overfilled launch bandwidth-length measurement.

However, because the DMD test procedure does measure low-order mode behaviour, it is capable of bounding the lower limit of bandwidth-distance product for the native launches of these 1 300 nm transmitters. Fibres meeting A1-OM3 and A1-OM4 specifications are optimised for peak bandwidth at 850 nm, and have specifically limited low-order mode DMD.

Operating at wavelengths different from the peak wavelength introduces a systematic increase in DMD. The largest increase in DMD occurs for the highest order modes. Thus the overfilled bandwidth, which is dominated by high-order mode DMD, is a conservative indicator of lowest effective modal bandwidth for native 1 300 nm launches that concentrate power in the low order modes. Therefore, A1-OM3 and A1-OM4 fibres are expected to provide EMB at least as high as their 500 MHz·km minimum overfilled bandwidth-length product at 1 300 nm without the use of mode conditioning patch cords.

G.2 Scaling of EMB with DMD

Different effective modal bandwidth-length products can be derived from the templates and interval masks defined in Clauses D.1 and D.3 simply by scaling EMB in inverse proportion to DMD temporal width, provided the following three conditions are met:

1) the fibre is used with transmitters meeting the specifications in E.4.1;
2) the radial offset limits of the templates are not changed; and
3) the overfilled modal bandwidth-length product requirements are scaled in direct proportion to the EMB.

This scaling ability is substantiated by the following relationships. From the waveguide theory, the mode power distribution of the transmitter relates directly to the radial extents of the inner and outer DMD masks. The operating wavelength range constrains operation in close proximity to the nominal DMD measurement wavelength to minimise modal bandwidth changes due to wavelength. With the mode power distribution and the radial extent of the DMD masks fixed, and the operating wavelength range unchanged, scaling is supported by the inverse proportionality between RMS pulse width and bandwidth [29] [30]. In this case, the RMS pulse width equates to the DMD temporal width. Scaling the overfilled bandwidth in direct proportion to the desired EMB maintains the established proportionality between the DMD and overfilled bandwidth.

For example, an effective modal bandwidth-length product at 850 nm of ≥ 1 000 MHz·km (one-half of 2 000 MHz·km) can be provided with fibre meeting any of the six DMD templates given in Clause D.1, with each template having double the DMD temporal width in both the inner and outer masks, and an overfilled bandwidth-length product of ≥ 750 MHz·km.

Annex H
(informative)

Applications and cabling categories supported by A1 fibres

Table H.1 shows various internationally standardised applications, as well as other recommended applications, which are supported by A1 fibres. It is not an exhaustive list, and many other applications not specifically listed may also be supported.

Table H.1 – Some standardised applications supported by A1-OM2, A1-OM3, A1-OM4, A1-OM5 fibres and in some cases A1-OM1 fibres

Application	Source	Name
1GFC	ISO/IEC 14165-115	1-Gigabit Fibre Channel
2GFC	ISO/IEC 14165-115	2-Gigabit Fibre Channel
4GFC	ANSI/INCITS 479	4-Gigabit Fibre Channel
8GFC	ANSI/INCITS 479	8-Gigabit Fibre Channel
10GFC	ISO/IEC 14165-116	10-Gigabit Fibre Channel
16GFC	ANSI/INCITS 479	16-Gigabit Fibre Channel
32GFC	ANSI/INCITS 512	32-Gigabit Fibre Channel
1000BASE-SX	ISO/IEC/IEEE 8802-3	Gigabit Ethernet
1000BASE-LX	ISO/IEC/IEEE 8802-3	Gigabit Ethernet
10GBASE-S	ISO/IEC/IEEE 8802-3	10-Gigabit Ethernet
25GBASE-SR	ISO/IEC/IEEE 8802-3	25-Gigabit Ethernet
40GBASE-SR4	ISO/IEC/IEEE 8802-3	40-Gigabit Ethernet
100GBASE-SR10	ISO/IEC/IEEE 8802-3	100-Gigabit Ethernet
100GBASE-SR4	ISO/IEC/IEEE 8802-3	100-Gigabit Ethernet

Annex I
(informative)

1-Gigabit, 10-Gigabit, 25-Gigabit, 40-Gigabit and 100-Gigabit Ethernet applications

Annex I is intended to outline a summary of category A1-OM2, A1-OM3, A1-OM4, A1-OM5 and A1-OM1 fibre requirements and related transmission capabilities for the 1-Gigabit, 10-Gigabit, 25-Gigabit, 40-Gigabit, and 100-Gigabit Ethernet application standards developed within IEEE 802.3. All the Ethernet applications at 1 Gb/s or higher are considered as "laser launch" applications.

Table I.1 shows a summary of 1 Gb/s, 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities. The rows of Table I.1 are grouped by fibre sub-category and model and listed by increasing data rate. For each line item, there is an indication of the application link length and the requirements on transmitter launch characteristics. The requirements of the transmitter launch characteristics are of three types.

- Offset-launch mode-conditioning patch cord for 1 300 nm operations, defined in IEEE 802.3.
- Coupled power ratio (CPR) > 9 dB and avoidance of radial overfilled launch (ROFL) for 1 Gb/s 850 nm operations on fibres characterised solely by overfilled launch (OFL) bandwidth. CPR is defined in IEC 61280-4-1:2009; ROFL is defined in IEEE 802.3.
- Encircled Flux (EF) requirements for 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s 850 nm operation on fibre models A1-OM3, A1-OM4 and A1-OM5 with effective modal bandwidth ensured by DMD measurement. The EF requirements are: EF at 4,5 μm radius ≤ 30 % and EF at 19,0 μm radius ≥ 86 %. For EF measurements, see IEC 61280-1-4.

Table I.1 – Summary of 1 Gb/s, 10 Gb/s, 25 Gb/s, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
A1-OM1	1	160 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	220	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
A1-OM1	1	200 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	275	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
A1-OM1	10	160 for OFL	n.s.	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	26	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
A1-OM1	10	200 for OFL	n.s.	10GBASE-S	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	33	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
A1-OM1	10	160 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
A1-OM1	10	200 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220
A1-OM2	1	400 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	500	400 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
A1-OM2	1	500 for OFL	n.s.	1000BASE-SX	CPR > 9 dB, avoid ROFL	550	500 for OFL	n.s.	1000BASE-LX	Offset-launch patch cord	550
A1-OM2	10	400 for OFL	n.s.	10GBASE-S	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	66	400 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	240
A1-OM2	10	500 for OFL	n.s.	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	82	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
A1-OM2	10	400 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	100
A1-OM2	10	500 for OFL	n.s.	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	Offset-launch patch cord or EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220
A1-OM3	10	1 500 for OFL	2 000	10GBASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	300	500 for OFL	n.s.	10GBASE-LX4	Offset-launch patch cord	300
A1-OM3	10	1 500 for OFL	2 000	n.s.	n.s.	n.s.	500 for OFL	n.s.	10GBASE-LRM	EF at 5 µm radius ≥ 30 %, EF at 11 µm radius ≥ 81 %	220

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
A1-OM3	25	1 500 for OFL	2 000	25GBASE-SR	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	70	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM3	40	1 500 for OFL	2 000	40GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM3	100	1 500 for OFL	2 000	100GBASE-SR10	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM3	100	1 500 for OFL	2 000	100GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	70	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM4 or A1-OM5	10	3 500 for OFL	4 700	10BASE-S	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	400	500 for OFL	n.s.	n.s.	n.s.	n.s.

Fibre sub-category or model	Bit rate Gb/s	Nominal wavelength									
		850 nm					1 300 nm				
		Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m	Minimum modal bandwidth for indicated measurement launch condition MHz·km	Minimum effective modal bandwidth for transmitters meeting launch requirement MHz·km	IEEE 802.3 PMD [a]	Transmitter launch requirement	Link length m
A1-OM4 or A1-OM5	25	3 500 for OFL	4 700	25GBASE-SR	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM4 or A1-OM5	40	3 500 for OFL	4 700	40GBASE-SR4	EF at 4,5 µm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	150 [b]	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM4 or A1-OM5	100	3 500 for OFL	4 700	100GBASE-SR10	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	150 [b]	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1-OM4 or A1-OM5	100	3 500 for OFL	4 700	100GBASE-SR4	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 µm radius ≥ 86 %	100	500 for OFL	n.s.	n.s.	n.s.	n.s.

Key

n.s. = not specified

[a] PMD = the IEEE 802.3 nomenclature for a device, such as a transceiver, that connects to the transmission medium.

[b] This is an engineered link with maximum 1,0 dB connection and splice loss.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

FIBRES OPTIQUES –

Partie 2-10: Spécifications de produits – Spécification intermédiaire pour les fibres multimodales de catégorie A1

AVANT-PROPOS

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La Norme internationale IEC 60793-2-10 a été établie par le sous-comité 86A: Fibres et câbles, du comité d'études 86 de l'IEC: Fibres optiques.

Cette septième édition annule et remplace la sixième édition parue en 2017. Cette édition constitue une révision technique.

La présente édition inclut les modifications majeures suivantes par rapport à l'édition précédente: révision de la convention de dénomination pour les fibres multimodales A1, correspondant mieux aux noms compris dans les normes ISO/IEC. Ces modifications sont indiquées dans le domaine d'application du présent document avec une table de correspondance pour les nouveaux noms.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
86A/1932/FDIS	86A/1939/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60793, publiées sous le titre général *Fibres optiques,* peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. A cette date, le document sera

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FIBRES OPTIQUES –

**Partie 2-10: Spécifications de produits –
Spécification intermédiaire pour les fibres multimodales de catégorie A1**

1 Domaine d'application

La présente partie de l'IEC 60793 est applicable aux fibres optiques des sous-catégories A1-OM1, A1-OM2, A1-OM3, A1-OM4, A1-OM5 et A1d. Ces fibres sont utilisées ou peuvent être intégrées dans des équipements destinés à la transmission de l'information et dans des câbles à fibres optiques.

Les sous-catégories A1-OM2, A1-OM3, A1-OM4 et A1-OM5 s'appliquent à la fibre à gradient d'indice de 50/125 μm dans quatre classes de largeur de bande. Chaque classe de largeur de bande est définie pour deux niveaux de performances en matière de pertes par macrocourbures, qui se distinguent par le suffixe "a" ou "b". Les sous-catégories qui comportent le suffixe "a" sont spécifiées de façon à satisfaire aux niveaux de performances classiques en matière de pertes par macrocourbures. Les sous-catégories qui comportent le suffixe "b" sont spécifiées de façon à satisfaire aux niveaux de performances avancées en matière de pertes par macrocourbures (c'est-à-dire des niveaux de pertes plus faibles).

La sous-catégorie A1-OM5 est spécifiée pour prendre en charge des systèmes de transmission à une seule ou plusieurs longueurs d'onde au voisinage de 850 nm à 950 nm. Bien qu'elles ne soient pas spécifiées sur le plan normatif, les informations de largeur de bande couvrant cette plage de longueurs d'onde sont également incluses pour A1-OM3 et A1-OM4.

La sous-catégorie A1-OM1 s'applique aux fibres à gradient d'indice de 62,5/125 μm et la sous-catégorie A1d à celles de gradient d'indice de 100/140 μm.

D'autres applications comprennent, mais sans s'y limiter, ce qui suit: les systèmes téléphoniques de courtes distances à haut débit, les réseaux de distribution et les réseaux locaux qui transportent des données, la voix et/ou des services vidéo; et les connexions par fibres intra ou inter bâtiment dans les locaux utilisateurs, englobant les centres de traitement de données, les réseaux locaux (LAN), les réseaux dédiés sauvegarde (SAN), les centraux téléphoniques privés (PABX), la vidéo, les différentes utilisations de multiplexage, l'utilisation d'une installation de câble du réseau téléphonique externe et les différentes utilisations associées.

Trois types d'exigences s'appliquent à ces fibres:

- les exigences générales, qui sont définies dans l'IEC 60793-2;
- des exigences spécifiques communes aux fibres multimodales de catégorie A1, couvertes par le présent document et qui sont données à l'Article 5;
- des exigences particulières applicables à des sous-catégories et des modèles particuliers de fibres ou à des applications spécifiques, qui sont définies dans les Annexes de spécifications normatives A à D.

Le Tableau 1 montre la correspondance entre les désignations de fibres optiques multimodales IEC A1 utilisées dans le présent document et celles utilisées dans l'IEC 60793-2-10:2017. Le tableau se réfère également aux Annexes normatives A, B et C pour les fibres multimodales de la sous-catégorie A1 dans le présent document contenant la spécification particulière.

Tableau 1 – Correspondance entre les désignations de fibres optiques multimodales IEC A1 et l'IEC 60793-2-10:2017

Annexe	Sous-catégorie	Sous-catégorie/ Modèle	Diamètre du noyau (nominal)	ISO/IEC 11801-1:2017
	Désignations du présent document	Désignations de l'IEC 60793-2-10:2017		Utilisation de fibres OMx câblées
A	A1-OM2	A1a.1	50 µm [a]	OM2 [b]
	A1-OM3	A1a.2	50 µm	OM3
	A1-OM4	A1a.3	50 µm	OM4
	A1-OM5	A1a.4	50 µm	OM5
B	A1-OM1	A1b	62,5 µm [c]	OM1 [d]
C	A1d	A1d	100 µm	–

[a] Historiquement, l'ISO/IEC 11801:2002 définissait également des câbles OM2 faits de fibres de 62,5/125 µm ayant une largeur de bande à injection saturée minimale de 500 MHz·km à 850 nm et 500 MHz·km à 1 300 nm. Cette combinaison de largeur de bande spécifique de fibres de 62,5/125 µm ne fait pas partie du présent document.

[b] Les câbles OM2 ne sont pas pris en charge dans les nouvelles installations dans l'ISO/IEC 11801-1:2017.

[c] Historiquement, l'ISO/IEC 11801:2002 définissait également des câbles OM1 faits de fibres de 50/125 µm ayant une largeur de bande à injection saturée minimale de 200 MHz·km à 850 nm et 500 MHz·km à 1 300 nm. Cette combinaison de largeur de bande spécifique de fibres de 50/125 µm ne fait pas partie du présent document.

[d] Les câbles OM1 ne sont pas pris en charge dans les nouvelles installations dans l'ISO/IEC 11801-1:2017.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60793-1-20, *Fibres optiques – Partie 1-20: Méthodes de mesure et procédures d'essai – Géométrie de la fibre*

IEC 60793-1-21, *Fibres optiques – Partie 1-21: Méthodes de mesure et procédures d'essai – Géométrie du revêtement*

IEC 60793-1-22, *Fibres optiques – Partie 1-22: Méthodes de mesure et procédures d'essai – Mesure de la longueur*

IEC 60793-1-30, *Fibres optiques – Partie 1-30: Méthodes de mesure et procédures d'essai – Essais de sélection*

IEC 60793-1-31, *Fibres optiques – Partie 1-31: Méthodes de mesure et procédures d'essai – Résistance à la traction*

IEC 60793-1-32, *Fibres optiques – Partie 1-32: Mesures de mesure et procédures d'essai – Dénudabilité du revêtement*

IEC 60793-1-33, *Fibres optiques – Partie 1-33: Méthodes de mesure et procédures d'essai – Résistance à la corrosion sous contrainte*

IEC 60793-1-40, *Fibres optiques – Partie 1-40: Méthodes de mesure et procédures d'essai – Affaiblissement*

IEC 60793-1-41, *Fibres optiques – Partie 1-41: Méthodes de mesure et procédures d'essai – Largeur de bande*

IEC 60793-1-42, *Fibres optiques – Partie 1-42: Méthodes de mesure et procédures d'essai – Dispersion chromatique*

IEC 60793-1-43, *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture measurement* (disponible en anglais seulement)

IEC 60793-1-46, *Fibres optiques – Partie 1-46: Méthodes de mesure et procédures d'essai – Contrôle des variations du facteur de transmission optique*

IEC 60793-1-47, *Fibres optiques – Partie 1-47: Méthodes de mesure et procédures d'essai – Pertes par macrocourbures*

IEC 60793-1-49, *Fibres optiques – Partie 1-49: Méthodes de mesure et procédures d'essai – Retard différentiel de mode*

IEC 60793-1-50, *Fibres optiques – Partie 1-50: Méthodes de mesure et procédures d'essai – Essais de chaleur humide (état continu)*

IEC 60793-1-51, *Fibres optiques – Partie 1-51: Méthodes de mesure et procédures d'essai – Essais de chaleur sèche (état continu)*

IEC 60793-1-52, *Fibres optiques – Partie 1-52: Méthodes de mesure et procédures d'essai – Essais de variations de température*

IEC 60793-1-53, *Fibres optiques – Partie 1-53: Méthodes de mesure et procédures d'essai – Essais d'immersion dans l'eau*

IEC 60793-2, *Fibres optiques – Partie 2: Spécifications de produits – Généralités*

IEC 61280-4-1:2009, *Procédures d'essai des sous-systèmes de télécommunication à fibres optiques – Partie 4-1: Installation câblée – Mesure de l'affaiblissement en multimodal*

3 Termes et définitions

Aucun terme n'est défini dans le présent document.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

4 Termes abrégés

CPR	coupled power ratio (rapport de puissance couplé)
DMD	differential mode delay (retard de mode différentiel)
EF	encircled flux (flux inscrit)
EMB	effective modal bandwidth (largeur de bande modale effective)
EMB_c	calculated effective modal bandwidth (largeur de bande modale effective calculée)
LAN	local area network (réseau local)
MMF	multimode fibre (fibre multimodale)
NA	numerical aperture (ouverture numérique)
OFL	overfilled launch (injection saturée)
OMB_c	overfilled launch modal bandwidth calculated from differential mode delay (largeur de bande modale à injection saturée, calculée à partir du retard de mode différentiel) – également appelée OFL_c)
PBX	private branch exchange (central téléphonique privé)
PMD	physical medium dependent (dépendant du support physique)
ROFL	radial overfilled launch (injection saturée radiale)
SAN	storage area network (réseau dédié sauvegarde)

5 Spécifications

5.1 Généralités

La fibre est constituée d'un cœur de verre avec un profil à gradient d'indice et d'une gaine de verre conformément à l'IEC 60793-2.

Le terme "verre" se réfère habituellement à des matériaux constitués d'oxydes non métalliques.

5.2 Exigences dimensionnelles

Les attributs dimensionnels et les méthodes de mesure applicables sont donnés dans le Tableau 2.

Les exigences communes à toutes les fibres de catégorie A1 sont données dans le Tableau 3.

Le Tableau 4 énumère les attributs supplémentaires qui doivent être indiqués par chaque spécification de sous-catégorie.

Tableau 2 – Attributs dimensionnels et méthodes de mesure

Attributs	Méthodes de mesure
Diamètre de la gaine	IEC 60793-1-20
Diamètre du cœur [a, b]	IEC 60793-1-20
Non-circularité de la gaine	IEC 60793-1-20
Non-circularité du cœur	IEC 60793-1-20
Erreur de concentricité entre le cœur et la gaine	IEC 60793-1-20
Diamètre du revêtement primaire	IEC 60793-1-21
Non-circularité du revêtement primaire	IEC 60793-1-21
Erreur de concentricité gaine-revêtement primaire	IEC 60793-1-21
Longueur de fibre	IEC 60793-1-22

[a] Le diamètre du cœur est spécifié à 850 nm ± 10 nm avec une longueur de spécimen d'essai de 2,0 m ± 0,2 m et une valeur de seuil, k_{CORE}, de 0,025 pour les fibres A1, à l'exception des fibres A1-OM2b, A1-OM3b, A1-OM4b et A1-OM5b.

[b] Le diamètre du cœur est spécifié à 850 nm ± 10 nm avec une longueur de spécimen d'essai de 100 m ± 5 % et une valeur de seuil, k_{CORE}, de 0,025 pour les fibres A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b.

Tableau 3 – Exigences dimensionnelles communes aux fibres de catégorie A1

Attributs	Unité	Limites
Non-circularité du cœur	%	≤ 6
Diamètre du revêtement primaire – incolore [a]	µm	245 ± 10
Diamètre du revêtement primaire – coloré [a]	µm	250 ± 15
Erreur de concentricité gaine-revêtement primaire	µm	≤ 12,5
Longueur de fibre	km	[b]

[a] Les limites sur le diamètre du revêtement primaire sont plus communément utilisées dans les câbles de télécommunications. Il existe d'autres applications qui utilisent d'autres diamètres de revêtement primaire; plusieurs d'entre eux sont donnés ci-dessous.

Autres diamètres nominaux et tolérances pour le revêtement primaire (µm):

400 ± 40

500 ± 50

700 ± 100

900 ± 100

[b] Les exigences de longueurs varient et il convient qu'elles fassent l'objet d'un accord entre fournisseur et client.

Tableau 4 – Attributs dimensionnels supplémentaires exigés dans les spécifications de sous-catégories

Attributs
Diamètre de la gaine
Non-circularité de la gaine
Diamètre du cœur
Erreur de concentricité entre le cœur et la gaine

5.3 Exigences mécaniques

Les attributs mécaniques et les méthodes de mesure applicables sont donnés dans le Tableau 5.

Les exigences communes à toutes les fibres de catégorie A1 sont données dans le Tableau 6.

Tableau 5 – Attributs mécaniques et méthodes de mesure

Attributs	Méthodes d'essais
Essai d'épreuve	IEC 60793-1-30
Résistance à la traction	IEC 60793-1-31
Dénudabilité du revêtement primaire	IEC 60793-1-32
Résistance à la corrosion sous contrainte	IEC 60793-1-33

Tableau 6 – Exigences mécaniques communes aux fibres de catégorie A1

Attributs	Unité	Limites
Niveau de contrainte d'épreuve	GPa	≥ 0,69 [a]
Force de dénudage moyenne[b]	N	$1,0 \leq F_{avg} \leq 5,0$
Force de dénudage de crête[b]	N	$1,0 \leq F_{peak} \leq 8,9$
Résistance à la traction (moyenne) pour une longueur de spécimen de 0,5 m	GPa	≥ 3,8
Constante de résistance à la corrosion sous contrainte, n_d	-	≥ 18

[a] La valeur d'essai d'épreuve de 0,69 GPa est égale à une déformation d'environ 1 % ou une force d'environ 8,8 N, pour les fibres A1-OM1 à A1-OM5. Pour la relation entre ces différentes unités, voir l'IEC TR 62048:2014, 8.4.

[b] Soit la force de dénudage moyenne, soit la force de dénudage de crête, qui sont toutes les deux définies dans la procédure d'essai, peut être spécifiée par accord entre fournisseur et client.

5.4 Exigences de transmission

Les attributs de transmission et les méthodes de mesure applicables sont donnés dans le Tableau 7.

Le Tableau 8 énumère les attributs supplémentaires qui doivent être indiqués par chaque spécification de sous-catégorie.

Tableau 7 – Attributs de transmission et méthodes de mesure

Attributs	Méthodes de mesure
Affaiblissement linéique	IEC 60793-1-40
Largeur de bande modale [a,b]	IEC 60793-1-41
Ouverture numérique [c,d]	IEC 60793-1-43
Dispersion chromatique	IEC 60793-1-42
Variations du facteur de transmission optique	IEC 60793-1-46
Pertes par macrocourbures	IEC 60793-1-47
Retard de mode différentiel [e]	IEC 60793-1-49

[a] Pour la largeur de bande modale, soit l'injection saturée (OFL), soit la largeur de bande modale à injection saturée calculée à partir du retard de mode différentiel (OMB_c) peut être utilisée. L'OMB_c est la méthode d'essai de référence pour les fibres A1-OM2, A1-OM3 et A1-OM4 à 850 nm et la méthode exigée pour les fibres A1-OM5 à 850 nm et 953 nm.

[b] La largeur de bande modale 850 nm est spécifiée avec une longueur de spécimen d'essai de 1 000 m ± 5 % pour les fibres A1-OM3 à A1-OM5. Pour les fibres A1-OM3, la largeur de bande modale 850 nm est mesurée à 850 nm ± 10 nm. Pour les fibres A1-OM4 et A1-OM5, la largeur de bande modale 850 nm est mesurée à 850 nm ± 2 nm. Pour les fibres A1-OM5, la largeur de bande modale est également mesurée à 953 nm ± 6 nm.

[c] L'ouverture numérique est spécifiée à 850 nm ± 10 nm avec une longueur de spécimen d'essai de 2 m ± 0,2 m et une valeur de seuil, k_{NA}, de 0,05 pour les fibres A1, à l'exception des fibres A1-OM2b, A1-OM3b, A1-OM4b, A1-OM5b.

[d] L'ouverture numérique est spécifiée à 850 nm ± 10 nm avec une longueur de spécimen d'essai de 100 m ± 5 % et une valeur de seuil, k_{NA}, de 0,05 pour les fibres A1-OM2b, A1-OM3b, A1-OM4b et A1-OM5b.

[e] Le retard de mode différentiel est spécifié avec une longueur de spécimen d'essai de 1 000 m ± 5 % pour les fibres A1-OM3, A1-OM4 et A1-OM5. Pour les fibres A1-OM3, le retard de mode différentiel est mesuré à 850 nm ± 10 nm. Pour les fibres A1-OM4 et A1-OM5, le retard de mode différentiel est mesuré à 850 nm ± 2 nm. Pour les fibres A1-OM5, le retard de mode différentiel est également mesuré à 953 nm ± 6 nm.

La conformité à la spécification relative à la dispersion chromatique peut être assurée par la conformité à la spécification relative à l'ouverture numérique pour les fibres A1.

Tableau 8 – Attributs de transmission supplémentaires exigés dans les spécifications de sous-catégories

Attributs
Affaiblissement linéique
Largeur de bande modale
Dispersion chromatique
Ouverture numérique
Pertes par macrocourbures

Pour l'affaiblissement linéique et la largeur de bande modale, les spécifications de sous-catégories peuvent contenir des plages de valeurs qui peuvent être choisies par spécification au lieu des limites fixées. Dans ce cas, les valeurs réelles de l'affaiblissement linéique maximal et de la largeur de bande modale minimale, à 850 nm et à 1 300 nm (ou à une seule de ces longueurs d'onde) doivent faire l'objet d'un accord entre fournisseur et client. Dans un but commercial, la largeur de bande modale est normalisée linéairement à 1 km.

À des fins de recommandations, l'Annexe H montre plusieurs applications normalisées prises en charge par les fibres A1, et l'Annexe I des capacités de transmissions pour ces mêmes fibres.

Les coefficients d'affaiblissement maximal indiqués s'appliquent aux fibres optiques non câblées; pour les coefficients d'affaiblissement maximal des fibres câblées, il est fait référence à l'IEC 60794-1-1, utilisable conjointement avec le présent document. Des spécifications plus strictes pour la fibre peuvent être exigées pour prendre en compte l'affaiblissement ajouté dans le processus de câblage.

Remarques sur la spécification de largeur de bande modale:

Il convient d'être rigoureux lors de la rédaction des spécifications de largeurs de bandes doubles. Il est entendu que pour les fibres de catégorie A1, la largeur de bande à 850 nm peut être liée à la largeur de bande à 1 300 nm de la façon représentée à la Figure 1, en fonction du paramètre d'indice de réfraction, g (voir l'IEC 60793-2). Des figures similaires sont données dans les publications [1][1], page 50, et [2], page 255. La région ombrée sous la courbe de la Figure 1 peut être définie comme la zone de fenêtre double. Dans cette zone, les régions X, Y et Z sont des exemples des endroits où un fabricant de fibres peut choisir d'optimiser le processus. C'est-à-dire, centrer la largeur de bande de production sur 850 nm, 1 300 nm, ou bien entre ces deux longueurs d'onde.

Du fait de l'optimisation du processus de fabrication, certaines combinaisons de largeurs de bandes sont impossibles (c'est-à-dire à l'extérieur de la région ombrée).

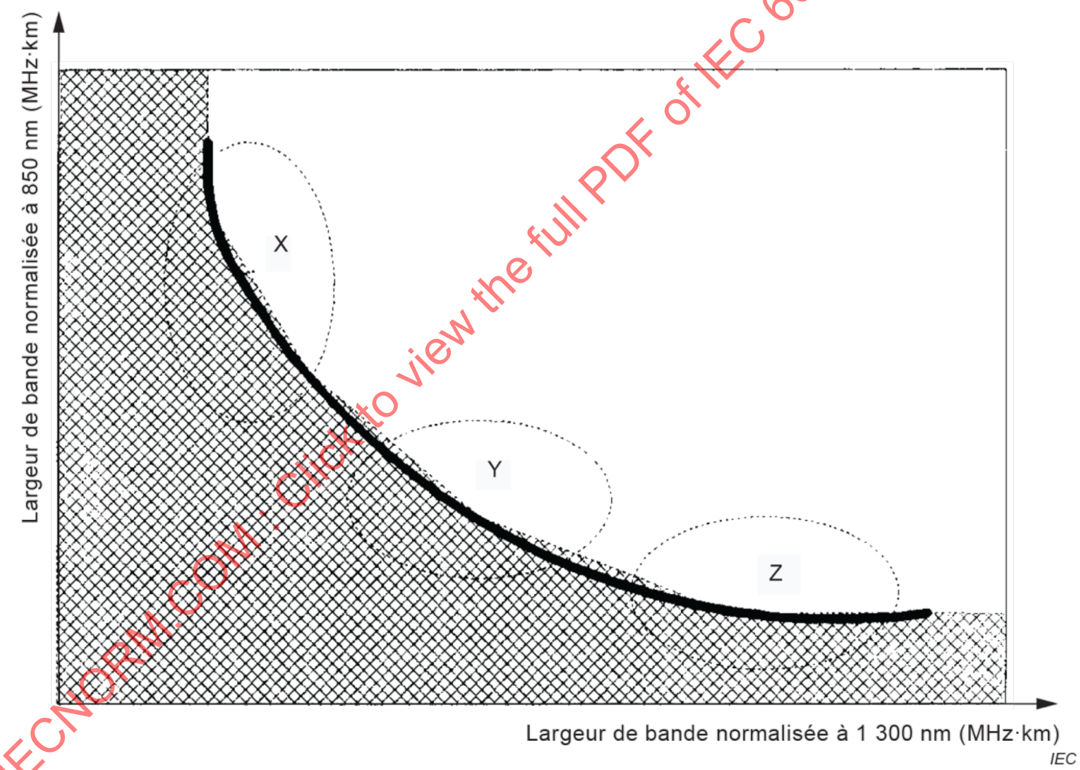

Figure 1 – Relation entre les largeurs de bande à 850 nm et à 1 300 nm

5.5 Exigences environnementales

5.5.1 Généralités

Les essais d'exposition à l'environnement et les méthodes de mesure correspondantes sont documentés sous deux formes:

[1] Les chiffres entre crochets se réfèrent à la Bibliographie.

- les attributs d'environnement et les procédures d'essai applicables sont donnés dans le Tableau 9;
- les mesures d'un attribut mécanique ou de transmission particulier qui peuvent varier lors de l'application de l'environnement sont données au Tableau 10.

Tableau 9 – Essais d'exposition à l'environnement

Exposition à l'environnement	Essai
Chaleur humide	IEC 60793-1-50
Chaleur sèche	IEC 60793-1-51
Variations de température	IEC 60793-1-52
Immersion dans l'eau	IEC 60793-1-53

Tableau 10 – Attributs mesurés pour les essais d'environnement

Attribut	Méthode de mesure
Variations du facteur de transmission optique	IEC 60793-1-46
Affaiblissement	IEC 60793-1-40
Force de dénudage	IEC 60793-1-32
Résistance à la traction	IEC 60793-1-31
Résistance à la corrosion sous contrainte	IEC 60793-1-33

Ces essais sont normalement effectués de manière périodique comme essais de type pour une conception de fibre et de revêtement donnée. Sauf indication contraire, la période de reprise autorisée entre la fin de l'exposition à l'environnement et la réalisation des mesures des attributs doit être celle spécifiée dans la méthode d'essai d'environnement spécifique.

5.5.2 Exigences liées à l'environnement mécanique (communes à toutes les fibres de catégorie A1)

5.5.2.1 Généralités

Ces essais correspondent, en pratique, aux exigences les plus sévères applicables aux essais d'exposition à l'environnement indiqués au Tableau 9.

Les Tableaux 11, 12 et 13 donnent, respectivement, la force de dénudage, la résistance à la traction et la résistance à la corrosion sous contrainte prescrites.

5.5.2.2 Force de dénudage

Les attributs suivants doivent être vérifiés dès que la fibre a été retirée de l'environnement.

Tableau 11 – Force de dénudage pour les essais d'environnement

Environnement	Force de dénudage moyenne N	Force de dénudage de crête N
Chaleur humide	$1,0 \leq F_{avg} \leq 5,0$	$1,0 \leq F_{peak} \leq 8,9$
Immersion dans l'eau	$1,0 \leq F_{avg} \leq 5,0$	$1,0 \leq F_{peak} \leq 8,9$

5.5.2.3 Résistance à la traction

Les attributs suivants doivent être vérifiés une fois la fibre retirée de l'environnement.

Tableau 12 – Résistance à la traction pour les essais d'environnement

Environnement	Longueur du spécimen pour la résistance à la traction médiane: 0,5 m GPa	Longueur de spécimen pour la résistance à la traction à 15 %: 0,5 m GPa
Chaleur humide	≥ 3,03	≥ 2,76
NOTE Ces exigences ne s'appliquent pas aux fibres sous revêtement hermétique.		

5.5.2.4 Résistance à la corrosion sous contrainte

Les attributs suivants doivent être vérifiés une fois la fibre retirée de l'environnement.

Tableau 13 – Résistance à la corrosion sous contrainte pour les essais d'environnement

Environnement	Constante de résistance à la corrosion sous contrainte, n_d
Chaleur humide	≥ 18
NOTE Cette exigence ne s'applique pas aux fibres sous revêtement hermétique.	

5.5.3 Exigences d'environnement pour la transmission

La variation d'affaiblissement par rapport à la valeur initiale doit être inférieure aux valeurs du Tableau 14. L'affaiblissement doit être mesuré de manière périodique au cours de toute la durée d'exposition, pour chaque environnement et après retrait de cet environnement.

Tableau 14 – Variation de l'affaiblissement pour les essais d'environnement

Environnement	Longueur d'onde nm	Augmentation de l'affaiblissement dB/km
Chaleur humide	850	≤ 0,20
	1 300	≤ 0,20
Chaleur sèche	850	≤ 0,20
	1 300	≤ 0,20
Variations de température	850	≤ 0,20
	1 300	≤ 0,20
Immersion dans l'eau	850	≤ 0,20
	1 300	≤ 0,20

Annexe A
(normative)

Spécifications pour les fibres multimodales de la sous-catégorie A1-OM2, A1-OM3, A1-OM4 et A1-OM5

A.1 Généralités

L'Annexe A contient les exigences particulières applicables aux fibres de sous-catégories A1-OM2, A1-OM3, A1-OM4 et A1-OM5. Les exigences communes, rappelées pour faciliter la référence par rapport au corps du présent document, sont notées par une entrée dans la colonne "Référence". La colonne "Référence" contient également d'autres annexes présentant des informations applicables à l'attribut. Les notes correspondantes du corps du présent document ne sont pas répétées, mais indiquées à l'aide d'un exposant "SS".

Les sous-catégories A1-OM2, A1-OM3, A1-OM4 et A1-OM5 sont des fibres multimodales à gradient d'indice de 50/125 µm dans quatre classes de largeur de bande. Tous les modèles sont spécifiés en utilisant des valeurs de largeur de bande saturée, et les sous-catégories A1-OM3, A1-OM4 et A1-OM5 s'appliquent également aux mesures du retard de mode différentiel pour offrir des performances optimisées pour des lasers proches de 850 nm. En outre, la sous-catégorie A1-OM5 spécifie à la fois les valeurs de largeur de bande saturée et du retard de mode différentiel à 953 nm pour offrir des performances optimisées pour les lasers sur une plage de longueurs d'onde au voisinage de 850 nm à 950 nm. Le modèle A1-OM3 est conforme aux spécifications du modèle A1-OM2. Le modèle A1-OM4 est conforme aux spécifications du modèle A1-OM3. Le modèle A1-OM5 est conforme aux spécifications du modèle A1-OM4.

Les sous-catégories A1-OM2, A1-OM3, A1-OM4 et A1-OM5 sont également spécifiées pour deux niveaux de performances en matière de pertes par macrocourbures, qui se distinguent par le suffixe "a" ou "b". Ceux qui comportent le suffixe "a" (c'est-à-dire les modèles A1-OM2a, A1-OM3a, A1-OM4a et A1-OM5a) sont spécifiés de façon à satisfaire aux niveaux de performances classiques en matière de pertes par macrocourbures. Ceux qui comportent le suffixe "b" (c'est-à-dire A1-OM2b, A1-OM3b, A1-OM4b et A1-OM5b) sont spécifiés de façon à satisfaire aux niveaux de performances avancées en matière de pertes par macrocourbures (c'est-à-dire des niveaux de perte plus faibles) et sont donc conformes aux performances classiques en matière de pertes par macrocourbures.

La nomenclature utilisée pour les sous-catégories A1-OM2, A1-OM3, A1-OM4 et A1-OM5 établit une hiérarchie de codage qui permet de désigner des fibres de spécificité croissante. Par exemple, des bons de commande de fibres A1-OM3 peuvent être rédigés en suivant la spécification A1-OM3a ou A1-OM3b. Par conséquent, lorsque les spécifications et les descriptions s'appliquent à tous les modèles à des niveaux hiérarchiques plus bas, seule la partie commune du nom est indiquée.

Les exigences dimensionnelles, mécaniques et environnementales sont communes à tous les types et sont spécifiées dans les Tableaux A.1 et A.2. Les exigences de transmission communes et particulières sont spécifiées dans le Tableau A.3.

A.2 Exigences dimensionnelles

Le Tableau A.1 contient les exigences dimensionnelles qui sont spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5.

Tableau A.1 – Exigences dimensionnelles spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5

Attributs	Unité	Limites	Référence
Diamètre de la gaine	µm	125 ± 1	
Non-circularité de la gaine	%	≤ 1	
Diamètre du noyau SS	µm	50 ± 2,5	
Erreur de concentricité entre le cœur et la gaine	µm	≤ 2	
Non-circularité du cœur	%	≤ 6	5.2
Diamètre du revêtement primaire – incolore SS	µm	245 ± 10	5.2
Diamètre du revêtement primaire – coloré SS	µm	250 ± 15	5.2
Erreur de concentricité gaine-revêtement primaire	µm	≤ 12,5	5.2
Longueur	km	(voir 5.2)	5.2
SS Voir les notes du corps du présent document.			

A.3 Exigences mécaniques

Le Tableau A.2 contient les exigences mécaniques qui sont spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5.

Tableau A.2 – Exigences mécaniques spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5

Attributs	Unité	Limites	Référence
Niveau de contrainte d'épreuve SS	GPa	≥ 0,69	5.3
Force de dénudage moyenne SS	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Force de dénudage de crête SS	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
SS Voir les notes du corps du présent document.			

A.4 Exigences de transmission

Le Tableau A.3 contient les exigences de transmission qui sont spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5.

Tableau A.3 – Exigences de transmission spécifiques aux fibres A1-OM2, A1-OM3, A1-OM4 et A1-OM5

<table>
<tr><th colspan="3">Attributs</th><th>Unité</th><th colspan="4">Limites</th><th>Référence</th></tr>
<tr><td colspan="3">Sous-catégorie de fibre</td><td></td><td>A1-OM2</td><td>A1-OM3</td><td>A1-OM4</td><td>A1-OM5</td><td></td></tr>
<tr><td colspan="3">Longueur(s) d'onde de fonctionnement cible(s) [a]</td><td>nm</td><td colspan="3">850</td><td>850 à 950</td><td>Annexe E</td></tr>
<tr><td colspan="3">Affaiblissement linéique maximal à 850 nm</td><td>dB/km</td><td colspan="4">2,5</td><td></td></tr>
<tr><td colspan="3">Affaiblissement linéique maximal à 953 nm</td><td>dB/km</td><td colspan="3">Non spécifiées</td><td>1,8</td><td></td></tr>
<tr><td colspan="3">Affaiblissement linéique maximal à 1 300 nm</td><td>dB/km</td><td colspan="4">0,8</td><td></td></tr>
<tr><td colspan="3">Produit longueur-largeur de bande modale minimale pour injection saturée à 850 nm [SS]</td><td>MHz·km</td><td>500</td><td>1 500</td><td>3 500</td><td>3 500</td><td>Article D.6</td></tr>
<tr><td colspan="3">Produit longueur-largeur de bande modale minimale pour injection saturée à 953 nm [SS]</td><td>MHz·km</td><td colspan="3">Non spécifiées</td><td>1 850</td><td>Article D.6</td></tr>
<tr><td colspan="3">Produit longueur-largeur de bande modale minimale pour injection saturée à 1 300 nm</td><td>MHz·km</td><td colspan="4">500</td><td></td></tr>
<tr><td colspan="3">Produit longueur-largeur de bande modale effective minimale à 850 nm [SS]</td><td>MHz·km</td><td>Non spécifiées</td><td>2 000
Conforme à l'Article D.1 ou à l'Article D.2</td><td>4 700
Conforme à l'Article D.3 ou à l'Article D.4</td><td>4 700
Conforme à l'Article D.5</td><td>Annexes D, E, F, G</td></tr>
<tr><td colspan="3">Produit longueur-largeur de bande modale effective minimale à 953 nm [SS]</td><td>MHz·km</td><td colspan="3">Non spécifiées</td><td>2 470
Conforme à l'Article D.5</td><td>Annexes D, E, F, G</td></tr>
<tr><td colspan="3">Ouverture numérique [SS]</td><td>Sans dimension</td><td colspan="4">0 200 ± 0 015</td><td></td></tr>
<tr><td colspan="3">Modèle de fibre</td><td></td><td>A1-OM2a</td><td>A1-OM3a</td><td>A1-OM4a</td><td>A1-OM5a</td><td rowspan="11"></td></tr>
<tr><td rowspan="3">Pertes maximales par macro-courbures [b]</td><td>Rayon de courbure</td><td>Nombre de tours</td><td rowspan="3">dB</td><td colspan="4">Max à 850 nm / 1 300 nm</td></tr>
<tr><td>37,5 mm</td><td>100</td><td colspan="4">0,5 / 0,5</td></tr>
<tr><td>15 mm</td><td>2</td><td colspan="4">1,0 / 1,0</td></tr>
<tr><td colspan="3">Modèle de fibre</td><td></td><td>A1-OM2b</td><td>A1-OM3b</td><td>A1-OM4b</td><td>A1-OM5b</td></tr>
<tr><td rowspan="4">Pertes maximales par macro-courbures [b]</td><td>Rayon de courbure</td><td>Nombre de tours</td><td rowspan="4">dB</td><td colspan="4">Max à 850 nm / 1 300 nm</td></tr>
<tr><td>37,5 mm</td><td>100</td><td colspan="4">0,5 / 0,5</td></tr>
<tr><td>15 mm</td><td>2</td><td colspan="4">0,1 / 0,3</td></tr>
<tr><td>7,5 mm</td><td>2</td><td colspan="4">0,2 / 0,5</td></tr>
<tr><td colspan="3">Longueur d'onde de dispersion nulle, λ_0</td><td>nm</td><td colspan="3">1 295 ≤ λ_0 ≤ 1 340 [c]</td><td>1 297 ≤ λ_0 ≤ 1 328 [d]</td></tr>
<tr><td colspan="3">Longueur d'onde de dispersion nulle, S_0</td><td>ps/(nm²·km)</td><td colspan="3">S_0 ≤ 0,105 à partir de 1 295 nm ≤ λ_0 ≤ 1 310 nm, et ≤ 0,000 375 (1 590 – λ_0) à partir de 1 310 nm ≤ λ_0 ≤ 1 340 nm [c]</td><td>S_0 ≤ 4 (–103) / (840 (1 – $(\lambda_0/840)^4$)) [d]</td></tr>
</table>

[a] Les longueurs d'onde de fonctionnement cibles sont données à titre d'information uniquement.

[b] La condition d'injection pour la mesure des pertes par macrocourbures doit satisfaire à celle décrite dans l'IEC 61280-4-1.

[c] Le cas le plus défavorable pour le coefficient de dispersion chromatique à 850 nm (par exemple S_0 = 0,093 75 ps/nm²·km à λ_0 = 1 340 nm ou S_0 = 0,101 25 ps/nm²·km à λ_0 = 1 320 nm) est de –104 ps/(nm km).

[d] Les coordonnées qui génèrent la dispersion la plus défavorable pour des longueurs d'onde de fonctionnement entre 840 nm et 1 000 nm sont λ_0 = 1 328 nm, S_0 = 0,093 477 ps/(nm²·km). Le coefficient de dispersion chromatique le plus défavorable à 850 nm est –98,5 ps/(nm km)

[SS] Voir les notes du corps du présent document.

A.5 Exigences environnementales

Les exigences de 5.5 doivent être satisfaites.

Annexe B
(normative)

Spécifications pour les fibres multimodales de la sous-catégorie A1-OM1

B.1 Généralités

L'Annexe B contient les exigences particulières applicables aux fibres A1-OM1. Les exigences communes, rappelées pour faciliter la référence par rapport au corps du présent document, sont notées par une entrée dans la colonne «Référence». Les notes correspondantes du corps du présent document ne sont pas répétées, mais indiquées à l'aide d'un exposant "SS".

Une fibre de la sous-catégorie A1-OM1 est une fibre à gradient d'indice de 62,5/125 µm.

B.2 Exigences dimensionnelles

Le Tableau B.1 contient les exigences dimensionnelles qui sont spécifiques aux fibres A1-OM1.

Tableau B.1 – Exigences dimensionnelles spécifiques aux fibres A1-OM1

Attributs	Unité	Limites	Référence
Diamètre de la gaine	µm	125 ± 2	
Non-circularité de la gaine	%	≤ 2	
Diamètre du noyau SS	µm	62,5 ± 3	
Erreur de concentricité entre le cœur et la gaine	µm	≤ 3	
Non-circularité du cœur	%	≤ 6	5.2
Diamètre du revêtement primaire – incolore SS	µm	245 ± 10	5.2
Diamètre du revêtement primaire – coloré SS	µm	250 ± 15	5.2
Erreur de concentricité gaine-revêtement primaire	µm	≤ 12,5	5.2
Longueur SS	km	(voir 5.2)	5,2
SS Voir les notes du corps du présent document.			

B.3 Exigences mécaniques

Le Tableau B.2 contient les exigences mécaniques qui sont spécifiques aux fibres A1-OM1.

Tableau B.2 – Exigences mécaniques spécifiques aux fibres A1-OM1

Attributs	Unité	Limites	Référence
Niveau de contrainte d'épreuve [SS]	GPa	≥ 0,69	5.3
Force de dénudage moyenne[SS]	N	$1,0 \leq F_{avg} \leq 5,0$	5.3
Force de dénudage de crête [SS]	N	$1,0 \leq F_{peak} \leq 8,9$	5.3
[SS] Voir les notes du corps du présent document.			

B.4 Exigences de transmission

Le Tableau B.3 contient les exigences de transmission qui sont spécifiques aux fibres A1-OM1.

Tableau B.3 – Exigences de transmission spécifiques aux fibres A1-OM1

Attributs	Unité	Limites	Référence
Affaiblissement linéique maximal à 850 nm	dB/km	3,0	
Affaiblissement linéique maximal à 1 300 nm	dB/km	1,0	
Produit longueur-largeur de bande modale minimale à 850 nm	MHz·km	200	
Produit longueur-largeur de bande modale minimale à 1 300 nm	MHz·km	500	
Ouverture numérique [SS]	Sans dimension	0 275 ± 0 015	
Pertes maximales par macrocourbures 100 tours sur un rayon de courbure de 37,5 mm à des longueurs d'onde de 850 nm et 1 300 nm [a]	dB	0,5	
Longueur d'onde de dispersion nulle, λ_0	nm	$1\,320 \leq \lambda_0 \leq 1\,365$ [b]	
Pente de dispersion nulle S_0 – de 1 320 nm $\leq \lambda_0 \leq$ 1 348 nm – de 1 348 nm $\leq \lambda_0 \leq$ 1 365 nm	ps/(nm²·km)	$\leq 0,11$ [b] $\leq 0,001\,(1\,458 - \lambda_0)$ [b]	

[a] La condition d'injection pour la mesure des pertes par macrocourbures doit satisfaire à celle décrite dans l'IEC 61280-4-1.

[b] Le coefficient de dispersion chromatique le plus défavorable à 850 nm (S_0 = 0,11 ps/nm²·km à λ_0 = 1 348 nm) est de –125 ps/(nm km).

[SS] Voir les notes du corps du présent document.

B.5 Exigences environnementales

Les exigences de 5.5 doivent être satisfaites.

Annexe C
(normative)

Spécifications pour les fibres multimodales de la sous-catégorie A1d

C.1 Généralités

L'Annexe C contient les exigences particulières applicables aux fibres A1d. Les exigences communes, rappelées pour faciliter la référence par rapport au corps du présent document, sont notées par une entrée dans la colonne "Référence". Les notes correspondantes du corps du présent document ne sont pas répétées, mais indiquées à l'aide d'un exposant "SS".

Une fibre de la sous-catégorie A1d est une fibre à gradient d'indice de 100/140 µm.

C.2 Exigences dimensionnelles

Le Tableau C.1 contient les exigences dimensionnelles qui sont spécifiques aux fibres A1d.

Tableau C.1 – Exigences dimensionnelles spécifiques aux fibres A1d

Attributs	Unité	Limites	Référence
Diamètre de la gaine	µm	140 ± 4	
Non-circularité de la gaine	%	≤ 4	
Diamètre du noyau SS	µm	100 ± 5	
Erreur de concentricité entre le cœur et la gaine	µm	≤ 6	
Non-circularité du cœur	%	≤ 6	5.2
Diamètre du revêtement primaire – incolore SS	µm	245 ± 10	5.2
Diamètre du revêtement primaire – coloré SS	µm	250 ± 15	5.2
Erreur de concentricité gaine-revêtement primaire	µm	≤ 12,5	5.2
Longueur SS	km	(voir 5.2)	5,2
SS Voir les notes du corps du présent document.			

C.3 Exigences mécaniques

Le Tableau C.2 contient les exigences mécaniques qui sont spécifiques aux fibres A1d.

Tableau C.2 – Exigences mécaniques spécifiques aux fibres A1d

Attributs	Unité	Limites	Référence
Niveau de contrainte d'épreuve [SS]	GPa	≥ 0,69	5,3
Force de dénudage moyenne[SS]	N	$1,0 \leq F_{avg} \leq 5,0$	5,3
Force de dénudage de crête [SS]	N	$1,0 \leq F_{peak} \leq 8,9$	5,3
[SS] Voir les notes du corps du présent document.			

C.4 Exigences de transmission

Le Tableau C.3 contient les exigences de transmission qui sont spécifiques aux fibres A1d.

Tableau C.3 – Exigences de transmission spécifiques aux fibres A1d

Attributs	Unité	Limites	Référence
Affaiblissement linéique maximal à 850 nm [a]	dB/km	3,5 à 7,0	
Affaiblissement linéique maximal à 1 300 nm [a]	dB/km	1,5 à 4,5	
Produit longueur-largeur de bande modale minimale à 850 nm [a]	MHz·km	10 à 200	
Produit longueur-largeur de bande modale minimale à 1 300 nm [a]	MHz·km	100 à 300	
Ouverture numérique [SS]	Sans dimension	0,26 ± 0,03 ou 0,29 ± 0,03	
Pertes maximales par macrocourbures	dB	Fera l'objet d'une étude ultérieure	
Longueur d'onde de dispersion nulle, λ_0	nm	$1\,330 \leq \lambda_0 \leq 1\,385$ [b]	
Pente de dispersion nulle S_0 – de $1\,330$ nm $\leq \lambda_0 \leq$ 1 365 nm – de 1 365 nm $\leq \lambda_0 \leq$ 1 385 nm	ps/(nm²·km)	 ≤ 0 105 [b] $\leq 0,000\,5\,(1\,575 - \lambda_0)$ [b]	
[a] La colonne «Limites» forme une plage de valeurs qui peuvent être spécifiées. [b] Le coefficient de dispersion chromatique le plus défavorable à 850 nm (S_0 = 0 105 ps/(nm²·km) à λ_0 = 1 365 nm) est de –126 ps/(nm km). [SS] Voir les notes du corps du présent document.			

C.5 Exigences environnementales

Les exigences de 5.5 doivent être satisfaites.