BS EN 60793-2-10:2016

BSI Standards Publication

Optical fibres

Part 2-10: Product specifications — Sectional specification for category A1 multimode fibre

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National foreword

This British Standard is the UK implementation of EN 60793-2-10:2016. It is identical to IEC 60793-2-10:2015. It supersedes BS EN 60793-2-10:2011 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GEL/86, Fibre optics, to Subcommittee GEL/86/1, Optical fibres and cables.

A list of organizations represented on this committee can be obtained on request to its secretary.

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EUROPEAN STANDARD

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Optical fibres - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibre (IEC 60793-2-10:2015)

Fibres optiques - Partie 2-10: Spécifications de produits - Spécification intermédiaire pour les fibres multimodales de catégorie A1 (IEC 60793-2-10:2015)

Lichtwellenleiter - Teil 2-10: Produktspezifikationen - Rahmenspezifikation für Mehrmodenfasern der Kategorie A1 (IEC 60793-2-10:2015)

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European foreword

The text of document 86A/1631/CDV, future edition 5 of IEC 60793-2-10, prepared by SC 86A "Fibres and cables" of IEC/TC 86 "Fibre optics" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60793-2-10:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-09-24
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-12-24

This document supersedes EN 60793-2-10:2011.

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Endorsement notice

The text of the International Standard IEC 60793-2-10:2015 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61280-1-4	NOTE	Harmonized as EN 61280-1-4.
IEC 61280-1-3	NOTE	Harmonized as EN 61280-1-3.
IEC 60793-1-1	NOTE	Harmonized as EN 60793-1-1.
IEC 60794-1-1	NOTE	Harmonized as EN 60794-1-1.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60793-1	series	Optical fibres - Part 1: Measurement methods and test procedures	EN 60793-1	series
IEC 60793-1-20	-	Optical fibres - Part 1-20: Measurement methods and test procedures - Fibre geometry	EN 60793-1-20	-
IEC 60793-1-21	-	Optical fibres - Part 1-21: Measurement methods and test procedures - Coating geometry	EN 60793-1-21	-
IEC 60793-1-22	-	Optical fibres - Part 1-22: Measurement methods and test procedures - Length measurement	EN 60793-1-22	-
IEC 60793-1-30	-	Optical fibres - Part 1-30: Measurement methods and test procedures - Fibre proof test	EN 60793-1-30	-
IEC 60793-1-31	-	Optical fibres - Part 1-31: Measurement methods and test procedures - Tensile strength	EN 60793-1-31	-
IEC 60793-1-32	-	Optical fibres - Part 1-32: Measurement methods and test procedures - Coating strippability	EN 60793-1-32	-
IEC 60793-1-33	-	Optical fibres - Part 1-33: Measurement methods and test procedures - Stress corrosion susceptibility	EN 60793-1-33	-
IEC 60793-1-34	-	Optical fibres - Part 1-34: Measurement methods and test procedures - Fibre curl	EN 60793-1-34	-
IEC 60793-1-40	-	Optical fibres - Part 1-40: Measurement methods and test procedures - Attenuation	EN 60793-1-40	-

Publication	Year	Title	EN/HD	Year
IEC 60793-1-41	-	Optical fibres - Part 1-41: Measurement methods and test procedures - Bandwidth	EN 60793-1-41	-
IEC 60793-1-42	-	Optical fibres - Part 1-42: Measurement methods and test procedures - Chromatic dispersion	EN 60793-1-42	-
IEC 60793-1-43	-	Optical fibres - Part 1-43: Measurement methods and test procedures - Numerical aperture measurement	EN 60793-1-43	-
IEC 60793-1-46	-	Optical fibres - Part 1-46: Measurement methods and test procedures - Monitoring of changes in optical transmittance	EN 60793-1-46	-
IEC 60793-1-47	-	Optical fibres - Part 1-47: Measurement methods and test procedures - Macrobending loss	EN 60793-1-47	-
IEC 60793-1-49	-	Optical fibres - Part 1-49: Measurement methods and test procedures - Differential mode delay	EN 60793-1-49	-
IEC 60793-1-50	-	Optical fibres - Part 1-50: Measurement methods and test procedures - Damp heat (steady state) tests	EN 60793-1-50	-
IEC 60793-1-51	-	Optical fibres - Part 1-51: Measurement methods and test procedures - Dry heat (steady state) tests	EN 60793-1-51	-
IEC 60793-1-52	-	Optical fibres - Part 1-52: Measurement methods and test procedures - Change of temperature tests	EN 60793-1-52	-
IEC 60793-1-53	-	Optical fibres - Part 1-53: Measurement methods and test procedures - Water immersion tests	EN 60793-1-53	-
IEC 60793-2	2011	Optical fibres - Part 2: Product specifications - General	EN 60793-2	2012
IEC 61280-4-1	-	Fibre optic communication subsystem test procedures - Part 4-1: Installed cable plant - Multimode attenuation measurement	EN 61280-4-1	-
IEC/TR 61931	-	Fibre optic - Terminology	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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 fifth edition cancels and replaces the fourth edition published in 2011. This edition constitutes a technical revision.

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

a) addition of enhanced macrobending multimode fibres A1a.1b, A1a.2b and A1a.3b;
b) inclusion of the specified test wavelength and specimen length for core diameter (CD), numerical aperture (NA), differential mode delay (DMD) and threshold values for CD and NA;
c) addition of a specimen length for 850 nm bandwidth of A1a and A1b fibres.

The text of this standard is based on the following documents:

CDV	Report on voting
86A/1631/CDV	86A/1664/RVC

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

This publication 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 publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication 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 types A1a, A1b, and A1d. These fibres are used or can be incorporated in information transmission equipment and optical fibre cables.

Type A1a applies to 50/125 μm graded index fibre. Three bandwidth grades are defined as A1a.1, A1a.2 and A1a.3. Each of these bandwidth grades is defined for two levels of macrobend loss performance that are distinguished by “a” or “b” suffix. Those with suffix “a” are specified to meet traditional macrobend loss performance levels. Those with suffix “b” are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels.

Type A1b applies to 62,5/125 μm graded index fibre and 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 standard and which are given in Clause 3;
- particular requirements applicable to individual fibre types or specific applications, which are defined in the normative family specification annexes.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 (all parts), *Optical fibres – Part 1: Measurement methods and test procedures*

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 60793-2:2011, *Optical fibres – Part 2: Product specifications – General*

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

IEC TR 61931, *Fibre optic – Terminology*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60793-2, the IEC 60793-1 series and IEC 61931 apply.

3.2 Abbreviations

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

4 Specifications

NOTE 1 The fibre consists of a glass core with a graded index profile and a glass cladding in accordance with IEC 60793-2:2011, 5.1.

NOTE 2 The term “glass” usually refers to material consisting of non-metallic oxides.

4.1 Dimensional requirements

Dimensional attributes and measurement methods are given in Table 1.

Requirements common to all fibres in category A1 are indicated in Table 2.

Table 3 lists additional attributes that shall be specified by each family specification.

Table 1 – Dimensional attributes and measurement methods

Attribute	Measurement method
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 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 fibres.

Table 2 – Dimensional requirements common to category A1 fibres

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

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

[b] The above 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

Table 3 – Additional dimensional attributes required in family specifications

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

4.2 Mechanical requirements

Mechanical attributes and measurement methods are given in Table 4.

Requirements common to all fibres in category A1 are in Table 5.

Table 4 – Mechanical attributes and measurement methods

Attribute	Test method
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 5 – Mechanical requirements common to category A1 fibres

Attribute	Unit	Limit
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 0,5m 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 fibres. For the relation between these different units, see IEC TR 62048.

[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.

4.3 Transmission requirements

Transmission attributes and measurement methods are given in Table 6.

Table 7 lists additional attributes that shall be specified by each family specification.

Table 6 – Transmission attributes and measurement methods

Attribute	Measurement method
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 (OMBc) can be used. OMBc is the reference test method for A1a fibres at 850 nm.

[b] 850 nm modal bandwidth is specified at 850 nm ± 10 nm with a test specimen length of 1 000 m ± 5 % for A1a fibres.

[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 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 fibres.

[e] Differential mode delay is specified at 850 nm ± 10 nm with a test specimen length of 1 000 m ± 5 % for A1a fibres.

Specification compliance of chromatic dispersion can be assured by compliance to the numerical aperture specification.

Table 7 – Additional transmission attributes required in family specifications

Attribute
Attenuation coefficient
Modal bandwidth
Chromatic dispersion
Numerical aperture
Macrobending loss

For attenuation coefficient and modal bandwidth, the family specification contains ranges of specifiable values instead of fixed limits. 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 be agreed between supplier and customer. For commercial purposes, the modal bandwidth is linearly normalized to 1 km.

For guidance purposes on bandwidth, Table H.1 shows a number of internationally standardised applications supported by A1 fibres, and Table H.2 gives a (limited) number of frequently used commercial bandwidth specifications for A1a and A1b fibres.

The indicated maximum attenuation values apply to uncabled optical fibres; for the maximum cabled attenuation values, reference is made to IEC 60794-1-1, which can be used in conjunction with this standard.

Remarks on the specification of modal bandwidth:

Care should be taken in writing dual wavelength bandwidth specifications. 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 60793-2:2011, 5.1). 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 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. For example, it is practically impossible to produce a fibre with the maximum of both indicated bandwidth ranges (e.g. 800 MHz·km/1 000 MHz·km for A1b multimode fibres).

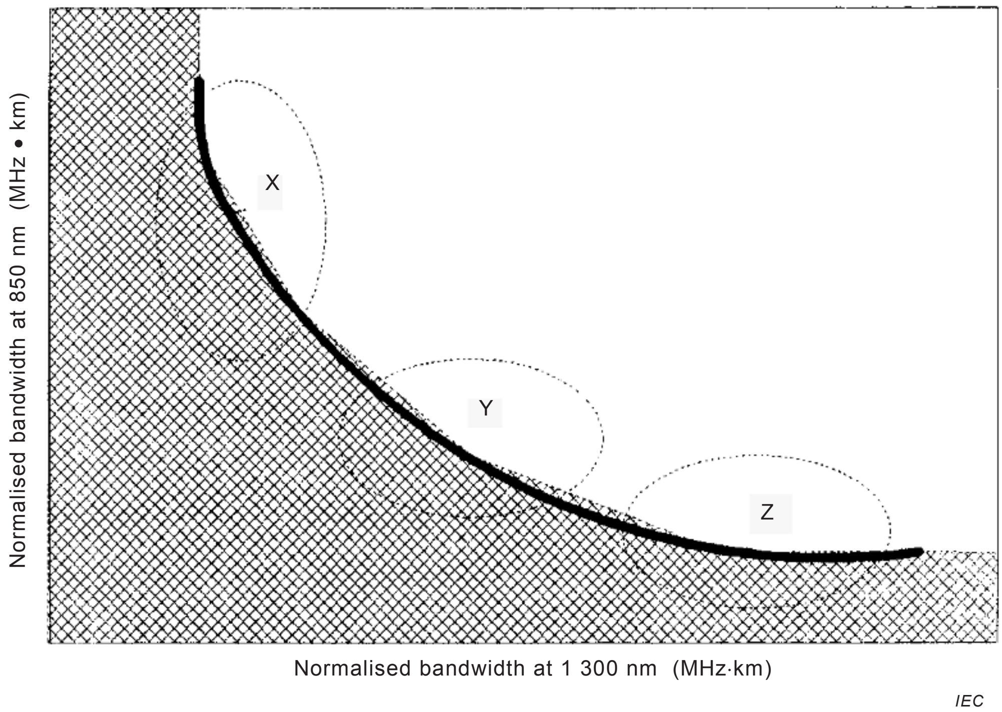

Figure 1 – Relation between bandwidths at 850 nm and 1 300 nm

4.4 Environmental requirements

4.4.1 General

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

- Relevant environmental attributes and test procedures are given in Table 8.
- Measurements of a particular mechanical or transmission attribute that may change on the application of the environment are listed in Table 9.

Table 8 – 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 9 – 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.

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

4.4.2.1 General

These tests are, in practice, the most severe requirements amongst the environments defined in Table 8.

Tables 10, 11, and 12 give the prescriptions for strip force, tensile strength and stress corrosion susceptibility respectively.

4.4.2.2 Strip force

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

Table 10 – 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	$1,0 \leq F_{avg} \leq 5,0$	$1,0 \leq F_{peak} \leq 8,9$

4.4.2.3 Tensile strength

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

Table 11 – 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		

4.4.2.4 Stress corrosion susceptibility

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

Table 12 – 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.	

4.4.3 Transmission environmental requirements

Change in attenuation from the initial value shall be less than the values in Table 13. Attenuation shall be measured periodically during the entire exposure to each environment and after removal.

Table 13 – 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)

Family specifications for A1a multimode fibres

A.1 General

Annex A contains particular requirements applicable to A1a fibres. Common requirements, repeated here for ease of reference from the sectional specification, are noted by an entry in the "Reference" column. Relevant notes from the sectional specification are not repeated but indicated with a superscript "SS".

Type A1a is a 50/125 µm graded index fibre. Three bandwidth grades are defined as models A1a.1, A1a.2, and A1a.3. All three are specified using overfilled bandwidth metrics, while types A1a.2 and A1a.3 also apply differential mode delay metrics to specify two bandwidth grades of 850 nm laser-optimised 50/125 µm fibres.

Each of these three bandwidth grades is 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 and A1a.3a) are specified to meet traditional macrobend loss performance levels. Those with suffix "b" (i.e. A1a.1b, A1a.2b and A1a.3b) are specified to meet enhanced macrobend loss (i.e. lower loss) performance levels.

The nomenclature for the A1a family establishes a coding hierarchy that permits designation of fibres with increasing specificity. For example, purchase orders for A1a fibres may be filled by any of the models specified in Annex A, while purchase orders for A1a.2 may be filled by A1a.2a or A1a.2b. As a result, where specifications and descriptions apply to all models at lower hierarchical levels, only the common root 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 fibres.

Table A.1 – Dimensional requirements specific to A1a fibres

Attribute	Unit	Limit	Reference
Cladding diameter	µm	125 ± 1	
Cladding non-circularity	%	≤ 1	
Core diameter	µm	50 ± 2,5	4.1 (Table 1)
Core-cladding concentricity error	µm	≤ 2	
Core non-circularity	%	≤ 6	4.1
Primary coating diameter – uncoloured	µm	245 ± 10	4.1
Primary coating diameter – coloured	µm	250 ± 15	4.1
Primary coating-cladding concentricity error	µm	≤ 12,5	4.1
Length	km	(see 4.1)	4.1 (Table 2)

A.3 Mechanical requirements

Table A.2 contains the mechanical requirements specific to A1a fibres.

Table A.2 – Mechanical requirements specific to A1a fibres

Attribute	Unit	Limit	Reference
Proof stress level	GPa	≥ 0,69 SS	4.2
Average strip force SS	N	$1,0 \le F_{avg} \le 5,0$	4.2
Peak strip force SS	N	$1,0 \le F_{peak} \le 8,9$	4.2

A.4 Transmission requirements

Table A.3 contains transmission requirements specific to A1a fibres.

Table A.3 – Transmission requirements specific to A1a fibres

Attribute			Unit	Limit			Reference
Fibre model				A1a.1	A1a.2	A1a.3	
Maximum attenuation coefficient at 850 nm			dB/km	2,5			
Maximum attenuation coefficient at 1 300 nm			dB/km	0,8			
Minimum modal bandwidth-length product for overfilled launch at 850 nm			MHz·km	500	1 500	3 500	4.3 (Table 6)
Minimum modal bandwidth-length product for overfilled launch at 1 300 nm			MHz·km	500			
Differential mode delay at 850 nm			ps/m	Not specified	Meet Clause D.1 or Clause D.2	Meet Clause D.3 or Clause D.4	4.3 (Table 6), Annexes D, E, F, G
Numerical aperture			Dimensionless	0,20 ± 0,015			4.3 (Table 6)
Maximum macrobending loss [a]	Bending radius	Number of turns	dB	A1a.1a	A1a.2a	A1a.3a	
				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	
				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	$1\,295 \leq \lambda_0 \leq 1\,340$ [b]			
Zero dispersion slope, S_0			ps/nm²·km				
- from $1\,295\text{ nm} \leq \lambda_0 \leq 1\,310\text{ nm}$				$\leq 0{,}105$ [b]			
- from $1\,310\text{ nm} \leq \lambda_0 \leq 1\,340\text{ nm}$				$\leq 0{,}000\,375\,(1\,590 - \lambda_0)$ [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 (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.

A.5 Environmental requirements

The requirements of 4.4 shall be met.

Annex B
(normative)

Family specifications for A1b multimode fibres

B.1 General

Annex B contains particular requirements applicable to A1b fibres. Common requirements, repeated here for ease of reference from the sectional specification, are noted by an entry in the “Reference” column. Relevant notes from the sectional specification are not repeated but indicated with a superscript ”SS”.

Type A1b fibre is a 62,5/125 µm graded index fibre.

B.2 Dimensional requirements

Table B.1 contains dimensional requirements specific to A1b fibres.

Table B.1 – Dimensional requirements specific to A1b fibres

Attribute	Unit	Limit	Reference
Cladding diameter	µm	125 ± 2	
Cladding non-circularity	%	≤ 2	
Core diameter	µm	62,5 ± 3	4.1 (Table 1)
Core-cladding concentricity error	µm	≤ 3	
Core non-circularity	%	≤ 6	4.1
Primary coating diameter – uncoloured	µm	245 ± 10	4.1
Primary coating diameter – coloured	µm	250 ± 15	4.1
Primary coating-cladding concentricity error	µm	≤ 12,5	4.1
Length	Km	(see 4.1)	4.1 (Table 2)

B.3 Mechanical requirements

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

Table B.2 – Mechanical requirements specific to A1b fibres

Attribute	Unit	Limit	Reference
Proof stress level	GPa	≥ 0,69 SS	4.2
Average strip force SS	N	$1,0 \le F_{avg} \le 5,0$	4.2
Peak strip force SS	N	$1,0 \le F_{peak} \le 8,9$	4.2

B.4 Transmission requirements

Table B.3 contains transmission requirements specific to A1b fibres.

Table B.3 – Transmission requirements specific to A1b fibres

Attribute	Unit	Limit	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 at 850 nm	MHz·km	200	
Minimum modal bandwidth at 1 300 nm	MHz·km	500	
Numerical aperture	Dimensionless	0,275 ± 0,015	4.3 (Table 6)
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	$1\,320 \le \lambda_0 \le 1\,365$ [b]	
Zero dispersion slope S_0 – from $1\,320$ nm $\le \lambda_0 \le 1\,348$ nm – from $1\,348$ nm $\le \lambda_0 \le 1\,365$ nm	ps/nm²·km	 $\le 0{,}11$ [b] $\le 0{,}001\,(1\,458 - \lambda_0)$ [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/nm^2·km at λ_0 = 1 348 nm) is -125 ps/nm.km.

B.5 Environmental requirements

The requirements of 4.4 shall be met.

Annex C
(normative)

Family specifications for A1d multimode fibres

C.1 General

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

Type 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

Attribute	Unit	Limit	Reference
Cladding diameter	µm	140 ± 4	
Cladding non-circularity	%	≤ 4	
Core diameter	µm	100 ± 5	4.1 (Table 1)
Core-cladding concentricity error	µm	≤ 6	
Core non-circularity	%	≤ 6	4.1
Primary coating diameter – uncoloured	µm	245 ± 10	4.1
Primary coating diameter – coloured	µm	250 ± 15	4.1
Primary coating-cladding concentricity error	µm	≤ 12,5	4.1
Length	km	(see 4.1)	4.1 (Table 2)

C.3 Mechanical requirements

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

Table C.2 – Mechanical requirements specific to A1d fibres

Attribute	Unit	Limit	Reference
Proof stress level	GPa	≥ 0,69 [SS]	4.2
Average strip force[SS]	N	$1,0 \leq F_{avg} \leq 5,0$	4.2
Peak strip force [SS]	N	$1,0 \leq F_{peak} \leq 8,9$	4.2

C.4 Transmission requirements

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

Table C.3 – Transmission requirements specific to A1d fibres

Attribute	Unit	Limit	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 at 850 nm [a]	MHz·km	10 to 200	
Minimum modal bandwidth at 1 300 nm [a]	MHz·km	100 to 300	
Numerical aperture	Dimensionless	0,26 ± 0,03 or 0,29 ± 0,03	4.3 (Table 6)
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.

C.5 Environmental requirements

The requirements of 4.4 shall be met.

Annex D
(normative)

Fibre differential mode delay (DMD) and calculated effective modal bandwidth (EMBc) requirements

D.1 A1a.2 fibre DMD requirements

D.1.1 General

A1a.2 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.2.

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

D.1.2 DMD templates

A1a.2 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 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 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).

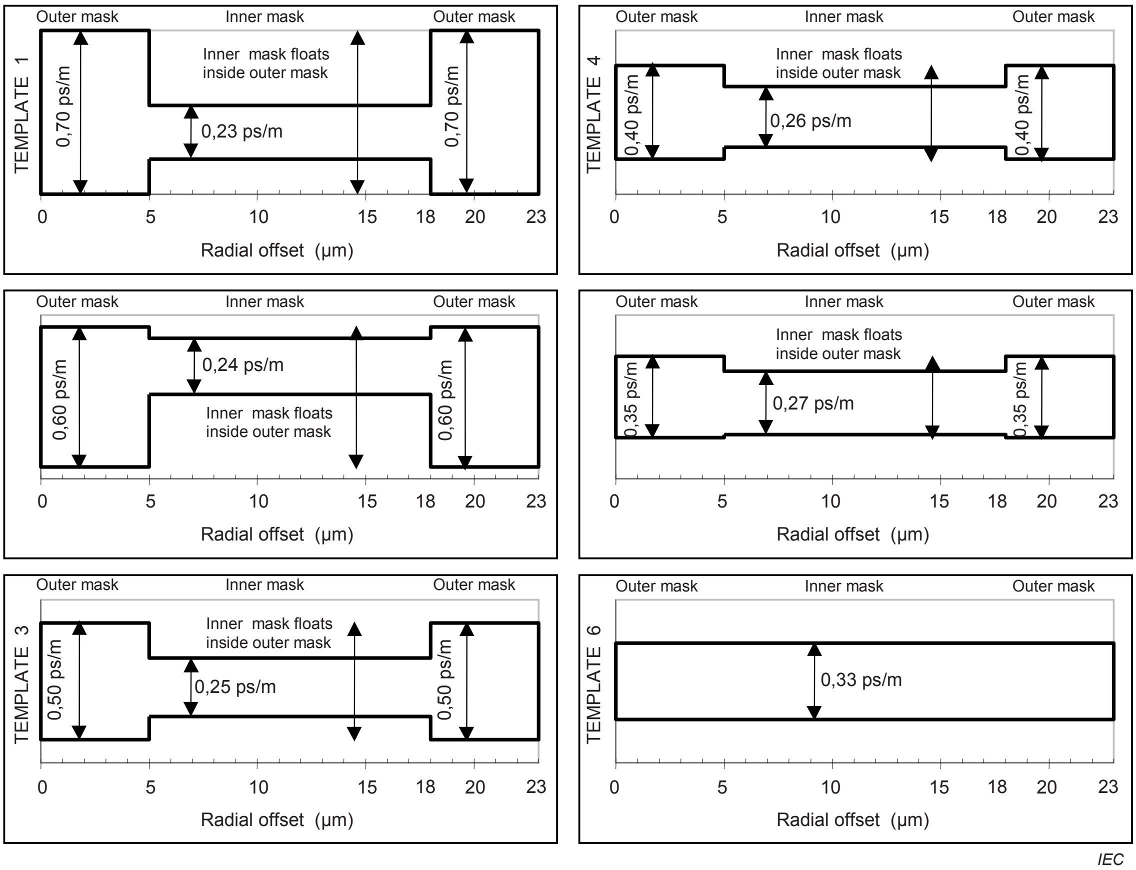

Figure D.1 – DMD template requirements

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 (see Bibliography).

The use of a template on the values of DMD achieves an effective trade-off between transmitter and fibre properties. 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 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 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 fibre EMB_c requirements

D.2.1 General

A1a.2 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:

$$\text{Minimum } EMB_c \geq 1\ 770 \text{ MHz·km} \quad \text{(D.1)}$$

where

minimum EMB_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 its value may not be optimal for use in system models. Refer to Annex E for information regarding the corresponding system parameter called the effective modal bandwidth (EMB).

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

Weightings within Table D.3 are provided for DMD measured at 1µm 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.2.

Table D.3 – DMD weightings *(1 of 2)*

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

Table D.3 *(2 of 2)*

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 DMD requirements

D.3.1 General

A1a.3 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.2.

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

D.3.2 DMD templates

A1a.3 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 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 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 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 fibre EMB_c requirements

D.4.1 General

A1a.3 fibres selected using the EMB_c method shall meet the requirements of D.4.2. See Clause D.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:

$$\text{Minimum } EMB_c \geq 4\ 160 \text{ MHz·km} \quad \text{(D.2)}$$

where

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

Annex E
(informative)

Modal bandwidth considerations and transmitter requirements

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.

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.

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][1]. 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.2 below with a 50 μm fibre meeting the specifications in Annex D.

E.2 Transmitter encircled flux (EF) and centre wavelength requirements

E.2.1 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 and D.4, were established in conjunction with the particular bounded range of laser launch conditions specified in Equations E.1 and E.2. 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.1 and E.2 when measured according to IEC 61280-1-4 [15] with the transmitter coupled into a 50-μm fibre meeting the specifications of this document.

$$\text{EF at radius } 4.5\ \mu\text{m} \leq 30\ \% \qquad \text{(E.1)}$$

$$\text{EF at radius } 19\ \mu\text{m} \geq 86\ \% \qquad \text{(E.2)}$$

E.2.2 Centre wavelength

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

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1 Numbers in square brackets refer to the Bibliography.

850 nm [6]. See TIA TSB-172 for an illustration of bandwidth roll-off for fibres with bandwidth similar to fibre type A1a.3 [14].

The laser transmitter centre wavelength (λ_c) should meet the requirements of Equation E.3 when tested according to IEC 61280-1-3 [16].

$$840 \text{ nm} \leq \lambda_c \leq 860 \text{ nm} \tag{E.3}$$

Several published or late-stage draft application standards meet the requirements of E.2 [20 to 22]

E.3 EMB

During the development of fibre type A1a.2, 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 E.2 [1 to 12]. 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 [11]. The specific ISI value was established via the IEEE 802.3ae link budget spreadsheet [13] 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 type A1a.2 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.4.

$$\text{EMB} = 1{,}13 \times \text{minimum EMB}_c \tag{E.4}$$

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 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 fibres). As such, their minimum EMB is also 2,35 times higher under the same link budget spreadsheet assumptions as stated by Equation E.5.

$$\text{EMB} \geq 2{,}35 \times 2\,000 \text{ MHz·km} \geq 4\,700 \text{ MHz·km} \tag{E.5}$$

System performance studies with actual fibres and laser sources support this relationship [17 to 19].

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 (EMBc)	The calculated modal bandwidth resulting from a particular weighting of a particular DMD.
Minimum calculated effective modal bandwidth (minimum EMBc) or (min EMBc)	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.

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 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 and A1a.3 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 and A1a.3 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 Clause E.2,
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[2] . 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, each with double the DMD temporal width in both the inner and outer masks, and an overfilled bandwidth-length product of ≥ 750 MHz·km.

2 [Smith and Personick, 1982; Brown, 1992]

Annex H
(informative)

Applications supported by A1 fibres

H.1 Internationally standardised applications

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

Table H.1 – Some internationally standardised applications supported by A1a and A1b fibres

Application	Source	Name
10BASE-F	ISO/IEC/IEEE 8802-3	FO CSMA/CD
100BASE-FX	IEEE 802.3	Fast Ethernet
1000BASE-SX	IEEE 802.3	Gigabit Ethernet
1000BASE-LX	IEEE 802.3	Gigabit Ethernet
Token Ring	ISO/IEC 8802-5	FO station attachment
FDDI	ISO/IEC 9314-3	Fibre Distributed Data Interface PMD
LCF FDDI	ISO/IEC 9314-9	Low cost Fibre PMD
HIPPI	ISO/IEC 11518-1	High Perform. Parallel I/F
FC	ISO/IEC 14165-115 ISO/IEC 14165-116	Fibre Channel
ATM LAN 155,52 Mb/s	ATM af-phy-0062.000	ATM-155 Multimode OF
ATM LAN 622,08 Mb/s	ATM af-phy-0046.000	ATM-622 Multimode OF
10GBASE-S	IEEE 802.3	10-Gigabit Ethernet
10GBASE-LX4	IEEE 802.3	10-Gigabit Ethernet
10GBASE-LRM	IEEE 802.3	10-Gigabit Ethernet
40GBASE-SR4	IEEE 802.3	40-Gigabit Ethernet
100GBASE-SR10	IEEE 802.3	100-Gigabit Ethernet
100GBASE-SR4	IEEE 802.3	100-Gigabit Ethernet

H.2 Used commercial bandwidth specifications

Table H.2 shows some frequently used commercial bandwidth specifications for A1a and A1b fibres. This list is not exhaustive and many other specifications not listed here may be used in the market.

Table H.2 – Typically used commercial bandwidth specifications for A1a and A1b graded-index multimode fibres

Fibre type	Minimum modal bandwidth for OFL[a] condition (unless otherwise indicated) at 850 nm (MHz·km)	Minimum modal bandwidth for OFL[a] condition (unless otherwise indicated) at 1 300 nm(MHz·km)	Possible application area
A1a.1	500	500	Medium bit rate/medium distance
A1a.2	1 500 2 000 EMB[b]	500	Very high bit rate (10 Gb/s) / long distance; 850 nm optimised.
A1a.3	3 500 4 700 EMB[b]	500	Very high bit rate (≥ 10 Gb/s) / long distance; 850 nm optimised.
A1b	200	500	Medium bit rate/medium distance

[a] **OFL = Overfilled launch**

[b] **EMB = Effective modal bandwidth (see Annexes D, E, F and G)**

H.3 Cross reference of fibre types in this standard and ISO/IEC 11801

This standard specifies fibre types A1a.1 and A1b with a specific core according to ISO/IEC 11801 specified cabled optical fibre performance categories OM1 and OM2 with a range of core diameters and a specific bandwidth cell. The requirements for fibre type A1a.2 contained in this standard and the ISO/IEC 11801 requirements for OM3 are identical. The requirements for fibre type A1a.3 contained in this standard and the ISO/IEC 11801 requirements for OM4 are expected to be identical when ISO/IEC 11801 is updated. The cross reference is given in Table H.3.

Table H.3 – Cross reference between this standard and ISO/IEC 11801

Attribute	IEC 60793-2-10				ISO/IEC 11801					
IEC type and ISO/IEC designation	A1b	A1a.1	A1a.2	A1a.3	OM1		OM2		OM3	OM4
Core diameter (µm)	62,5	50	50	50	50	62,5	50	62,5	50	50
IEC fibre type cross reference	-	-	-	-	A1a.1	A1b	A1a.1	A1b	A1a.2	A1a.3
Minimum modal bandwidth-length product for overfilled launch at 850 nm (MHz·km)	200	500	1 500	3 500	200		500		1 500	3 500
Minimum modal bandwidth-length product for overfilled launch at 1 300 nm (MHz·km)	500	500	500	500	500		500		500	500
Minimum effective modal bandwidth-length product at 850 nm (MHz·km)	Not specified	Not specified	2 000	4 700	Not specified		Not specified		2 000	4 700

H.4 Reference documents

Reference documents are listed in the bibliography.

Annex I
(informative)

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

Annex I is intended to outline a summary of category A1a and A1b fibre requirements and related transmission capabilities for the 1-Gigabit, 10-Gigabit, 40-Gigabit, and 100-Gigabit Ethernet application standards in development 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, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities. The rows of Table I.1 are grouped by fibre type and bit 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, ROFL is defined in IEEE 802.3.
- Encircled Flux (EF) requirements for 10 Gb/s, 40 Gb/s and 100 Gb/s 850 nm operation on fibre types A1a.2 and A1a.3 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, 40 Gb/s and 100 Gb/s Ethernet requirements and capabilities (*1 of 3*)

-Fibre type	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	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	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	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	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	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
A1b	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	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	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

-Fibre type	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	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	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
A1a.1	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	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	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	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
A1a.2	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.

-Fibre type	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	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	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	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.
A1a.3	40	3 500 for OFL	4 700	40GBASE-SR4	EF at 4,5 μm radius ≤ 30 %, EF at 19,0 μm radius ≥ 86 %	150	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1a.3	100	3 500 for OFL	4 700	100GBASE-SR10	EF at 4,5 mm radius ≤ 30 %, EF at 19,0 μm radius ≥ 86 %	150	500 for OFL	n.s.	n.s.	n.s.	n.s.
A1a.3	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.

n.s. = not specified

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

Bibliography

[1] J. Ritger, J. Abbott, "New Delay Set for TIA Modelling", White paper, June 1, 2001, available at http://www.tiaonline.org/

[2] J. Ritger, J. Abbott, "Fiber Delays for 10 Gb Risk Assessment", Presentation to FO2.2.1, June 25, 2001, available at http://www.tiaonline.org/

[3] P. Kolesar, "Source Characteristics Development", Presentation to FO2.2.1, June 2001, available at http://www.tiaonline.org/

[4] S. Golowich, J. Ritger, P. Kolesar, "Simulation of 50 µm 10 Gb Links", Presentation to FO2.2.1, June 25, 2001, available at http://www.tiaonline.org/

[5] S. Golowich, P. Kolesar, J. Ritger, G. Giaretta, "Modelling, Simulation, and Experimental Study of a 50µm Multimode Fiber 10 Gbaud Serial Link", Presentation to IEEE 802.3ae, May, 2000.
URL: http://grouper.ieee.org/groups/802/3/ae/public/may00/golowich_1_0500.pdf

[6] J. Ritger, "Risk Analysis: EF limits and Wavelength Dependence", Presentation to FO2.2.1, June 25, 2001, available at http://www.tiaonline.org/

[7] S. Golowich, P. Kolesar, J. Ritger, P. Pepeljugoski, "Modelling and Simulations for 10 Gb Multimode Optical Fiber Link Component Specifications", OFC 2001, paper WDD57

[8] P. Pepeljugoski, S. Golowich, "Measurements and simulations of intersymbol interference penalty in new high speed 50 µm multimode fiber links operating at 10 Gb/s", OFC 2001, paper WDD40

[9] J. Ritger, "Use of Differential Mode Delay in Qualifying Multi-Mode Optical Fiber for 10 Gbps Operation", OFMC 2001paper

[10] M. Hackert, "FO2.2.1 Update", March 2001 IEEE Plenary.
URL: http://grouper.ieee.org/groups/802/3/ae/public/mar01/hackert_1_0301.pdf

[11] P. Pepeljugoski, M. Hackert, J. Abbott, S. Swanson, S. Golowich, J. Ritger, P. Kolesar, C. Chen and P. Pleunis, "Development of System Specification for Laser Optimized 50 µm Multimode Fiber for Multi-gigabit Short Wavelength LANs", J. Lightwave Tech. (volume 21, No. 5, pp. 1256 – 1275, May 2003)

[12] P. Pepeljugoski, S. Golowich, J. Ritger, P. Kolesar, A. Risteski, " Modeling and Simulation of Next-Generation Multimode Fiber Links", (J. Lightwave Tech. Vol. 21, No. 5, pp. 1242 – 1255, May 2003.)

[13] IEEE P802.3ae 10Gb/s Ethernet Task Force Link Budget Spreadsheet (Version 3.1.16a) URL http://grouper.ieee.org/groups/802/3/ae/public/index.html

[14] TIA TSB-172, *High Data Rate Multimode Fiber Transmission Techniques*

[15] IEC 61280-1-4, *Fibre optic communication subsystem test procedures – Part 1-4: General communication subsystems – Light source encircled flux measurement method*

[16] IEC 61280-1-3, *Fibre optic communication subsystem test procedures – Part 1-3: General communication subsystems – Central wavelength and spectral width measurement*

[17] C. Caspar, R. Freund, F. Achten, A. Gholami, G. Kuyt ,P. Matthijsse and D. Molin "Impact of Transceiver Characteristics on the Performance of 10 GbE Links Applying OM-4 Multimode Fibers", Proceedings of the 57th IWCS Conference, p295-303, November 2008

[18] A. Sengupta, "Simulation of 10GbE Multimode Optical Communications Systems", Proceedings of the 57th IWCS Conference, p320-326, November 2008

[19] G. Oulundsen III, Y. Sun, D. Vaidya, R. Lingle, Jr., T. Irujo, D. Mazzarese, "Important Performance Characteristics of Enhanced OM3 Fiber for 10 Gb/s Operation", Proceedings of the 57th IWCS Conference, p327-334, November 2008

[20] IEEE 802.3, *Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications*, Clause 52 for 10GBASE-S

[21] ANSI INCITS 364-2003, *Fibre Channel – 10 Gigabit (10GFC)*

[22] INCITS/Project 1647-D/Rev8.00, *Fibre Channel – Physical Interface-4 (FC-PI-4)*, for 400-SN (4 gigabit), 800-SN and 800-SA (8 gigabit)

[23] IEC 60793-1-1, *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*

Non-numbered references

IEC 60794-1-1, *Optical fibre cables - Part 1-1: Generic specification – General*

IEC TR 62048, *Optical fibres – Reliability – Power law theory*

Reference documents (see Clause H.4)

ATM af-phy-0062.000 155.52 Mbps Physical Layer Interface Specification for Short Wavelength Laser", July 1996

ATM af-phy-0046.000 622.08 Mbps Physical Layer Specification", January 1996

ISO/IEC/IEEE 8802-3, *Standard for Ethernet*

ISO/IEC 9314-3, *Information processing systems – Fibre Distributed Data Interface (FDDI) – Part 3: Physical Layer Medium Dependent (PMD)*

ISO/IEC 9314-9*, Information technology – Fibre Distributed Data Interface (FDDI) – Part 9, Low cost fibre physical layer medium dependent (LCF-PMD)*

ISO/IEC 8802-5, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 5: Token ring access method and physical layer specifications*

ISO/IEC 11518-1, *Information technology – High-Performance Parallel Interface – Part 1: Mechanical, electrical and signalling protocol specification (HIPPI-PH)*

ISO/IEC 11801, *Information technology – Generic cabling for customer premises*

ISO/IEC 14165-115, *Information technology – Fibre channel – Part 115: Physical interfaces (FC-PI)*

ISO/IEC 14165-116, *Information technology – Fibre channel – Part 116: 10 Gigabit Fibre Channel (10GFC)*

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