International Telecommunication Union

ITU-T G.651.1

(11/2018)

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Transmission media and optical systems characteristics – Optical fibre cables

Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network

Recommendation ITU-T G.651.1

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Recommendation ITU-T G.651.1

Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network

Summary

Recommendation ITU-T G.651.1 recommends a quartz multimode fibre to be used for the access network in specific environments. These environments are multi-tenant building sub-networks in which broadband services have to be delivered to individual apartments. The recommended multimode fibre supports the cost-effective use of 1 Gbit/s Ethernet systems over link lengths up to 550 m, usually based upon the use of 850 nm transceivers.

The recommended fibre type is an improved version of the well-known 50/125 µm multimode graded-index fibre as recommended in Recommendation ITU-T G.651. Its cost effective use is very common in datacom systems applied in enterprise buildings throughout the world for quite a number of years.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.651.1	2007-07-29	15	11.1002/1000/9181
1.1	ITU-T G.651.1 (2007) Amd. 1	2008-12-12	15	11.1002/1000/9670
2.0	ITU-T G.651.1	2018-11-29	15	11.1002/1000/13738

Keywords

IEC 60793-2-10, IEEE 802.3 Ethernet system standards, ISO/IEC 11801-1, multimode fibre, OMx cabled fibre categories.

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* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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Introduction

Worldwide, various technologies for broadband access networks are advancing rapidly to provide the high capacity needed for the increasing customer demands with respect to new services. Apart from the technologies, the network structures and customer densities also vary considerably. A specific segment, which is in the main scope of this Recommendation, is the network in a multi-tenant building. Due to the high connection density and the short distribution cable lengths, cost-effective high capacity optical networks can be designed and installed by making use of 50/125 μm graded-index multimode fibres. Recommendation ITU-T G.651.1 was originally developed based on the previous multimode Recommendation ITU-T G.651. The use of the multimode fibre is currently uncommon for telecom networks owing to the development of the single-mode fibre as described in Appendix I of this Recommendation. On the other hand, the multimode fibres continue to be widely used in premises cabling application such as Ethernet for datacom systems in enterprise buildings, which supports system bit rate of more than 10 Gbit/s. This use is supported by a large series of IEEE system standards. The latest multimode specifications can be found in IEC or ISO/IEC fibre and cable standards, which have higher bandwidth characteristics than Recommendation ITU-T G.651.1. The cross reference table between Recommendation ITU-T G.651.1 and the latest multimode fibre standards is summarized in ITU-T G-series Supplement 40.

Recommendation ITU-T G.651.1

Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network

1 Scope

This Recommendation describes a 50/125 µm graded-index multimode optical fibre cable which is suitable to be used in the 850 nm or 1300 nm region, or alternatively may be used in both wavelength regions simultaneously.

The geometrical, optical, transmission and mechanical parameters are described below in two categories of attributes:

- fibre attributes are those attributes that are retained throughout cabling and installation;
- cable attributes that are recommended for cables as they are delivered.

This Recommendation, and the different performance categories found in Table 1, is intended to support the following related system Recommendations and standards:

- [b-IEEE 802.3].

The characteristics of this fibre, including the definitions of the relevant parameters, their test methods and relevant values, will be refined as studies and experience progress.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[IEC 60793-1-1] IEC 60793-1-1 (2017), *Optical fibres – Part 1-1: Measurement methods and test procedures – General and guidance*.

[IEC 60793-1-20] IEC 60793-1-20 (2014), *Optical fibres – Part 1-20: Measurement methods and test procedures – Fibre geometry*.

[IEC 60793-1-30] IEC 60793-1-30 (2010), *Optical fibres – Part 1-30: Measurement methods and test procedures – Fibre proof test*.

[IEC 60793-1-40] IEC 60793-1-40 (2001), *Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation*.

[IEC 60793-1-41] IEC 60793-1-41 (2010), *Optical fibres – Part 1-41: Measurement methods and test procedures – Bandwidth*.

[IEC 60793-1-42] IEC 60793-1-42 (2013), *Optical fibres – Part 1-42: Measurement methods and test procedures – Chromatic dispersion*.

[IEC 60793-1-43] IEC 60793-1-43 (2015), *Optical fibres – Part 1-43: Measurement methods and test procedures – Numerical aperture*.

[IEC 60793-1-47] IEC 60793-1-47 (2017), *Optical fibres – Part 1-47: Measurement methods and test procedures – Macrobending loss*.

[IEC 60793-1-49] IEC 60793-1-49 (2018), *Optical fibres – Part 1-49: Measurement methods and test procedures – Differential mode delay*.

[IEC 60793-2] IEC 60793-2 (2015), *Optical fibres − Part 2: Product specifications – General*.

[IEC 60793-2-10] IEC 60793-2-10 (2017), *Optical fibres – Part 2-10: Product specifications – Sectional specification for category A1 multimode fibres*.

[IEC 60794-2] IEC 60794-2 (2017), *Optical fibre cables – Part 2: Indoor cables – Sectional specification*.

[IEC 60794-2-11] IEC 60794-2-11 (2012), *Optical fibre cables – Part 2-11: Indoor cables – Detailed specification for simplex and duplex cables for use in premises cabling*.

[IEC 60794-2-21] IEC 60794-2-21 (2012), *Optical fibre cables – Part 2-21: Indoor cables – Detailed specification for multi-fibre optical distribution cables for use in premises cablin*g.

[IEC 60794-2-31] IEC 60794-2-31 (2012), *Optical fibre cables – Part 2-31: Indoor cables – Detailed specification for optical fibre ribbon cables for use in premises cabling*.

[IEC 60794-3-12] IEC 60794-3-12 (2012), *Optical fibre cables – Part 3-12: Outdoor cables – Detailed specification for duct and directly buried optical telecommunication cables for use in premises cabling*.

[IEC 61280-4-1] IEC 61280-4-1 (2009), *Fibre-optic communication subsystem test procedures – Part 4-1: Cable plant and links – Multimode fibre-optic cable plant attenuation measurement*.

3 Terms and definitions

For the purposes of this Recommendation, the definitions and the guidelines to be followed in the measurement to verify the various characteristics are given in the IEC standards series [IEC 60793], [IEC 60794] and [IEC 61280-4-1]. Values shall be rounded to the number of digits given in Table 1 before conformance is evaluated.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

NA Numerical Aperture

5 Fibre attributes

The characteristics of the fibre providing a minimum essential design framework for fibre manufacture, system design and use are recommended in this clause and in clause 7. Ranges or limits on values are presented in Table 1. In this clause those attributes have been listed only where additional information is helpful.

The recommended characteristics will not be significantly affected by cable manufacture or installation and therefore apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in an installed cable.

5.1 Cladding diameter

The recommended nominal value of the cladding diameter is 125 μm. A tolerance is also specified and shall not exceed the value in clause 7. The cladding diameter deviation from nominal shall not exceed the specified tolerance. For measuring the value of this attribute, reference is made to [IEC 60793-1-20].

5.2 Core diameter

The recommended nominal value of the core diameter is 50 μm. A tolerance is also specified and shall not exceed the value in clause 7. The core diameter deviation from nominal shall not exceed the specified tolerance. For measuring the value of this attribute, reference is made to [IEC 60793-1-20].

5.3 Core concentricity error

The core concentricity error shall not exceed the value specified in clause 7. For measuring the value of this attribute, reference is made to [IEC 60793-1-20].

5.4 Non-circularity

5.4.1 Cladding non-circularity

The cladding non-circularity shall not exceed the value found in clause 7. For measuring the value of this attribute, reference is made to [IEC 60793-1-20].

5.4.2 Core non-circularity

The core non-circularity shall not exceed the value found in clause 7. For measuring the value of this attribute, reference is made to [IEC 60793-1-20].

5.5 Numerical aperture

The numerical aperture (NA) is the sine of the vertex half-angle of the largest cone of rays that can enter or leave the core of an optical fibre, multiplied by the refractive index of the medium in which the vertex of the cone is located. All values measured at 850 nm. The value of the numerical aperture is about 5% lower than the value of the maximum theoretical numerical aperture ($NA_{t\max}$) which is derived from a refractive index measurements trace of the core and cladding.

$$NA_{t\max} = \left(n_1^2 - n_2^2\right)^{1/2}$$

in which n_1 is the maximum refractive index of the core and n_2 is the refractive index of the innermost homogeneous cladding. For measuring the value of this attribute, reference is made to [IEC 60793-1-43].

5.6 Macrobending loss

Macrobending loss varies with bend radius and number of turns about a mandrel with a specified radius but is rather independent of the measuring wavelength. Therefore, testing at one of the wavelengths specified in clause 7 may be sufficient to ensure compliance with this Recommendation.

When testing multiple macrobends, the mode distribution encountered at a specific macrobend may depend on how many macrobends precede it. For example, the first bend might influence the launch condition at the second bend, and the second bend might influence the launch condition at the third bend, etc. Consequently, the macrobending-added loss at a given bend might be different than the macrobending-added loss at another bend. In particular, the first bend may have the largest influence on following bends. Consequently, the macrobending-added loss produced by multiple bends should not be expressed in the units of "dB/bend" by dividing the total added loss by the number of bends,

but in dB for the specified number of bends. For measuring the value of this attribute, reference is made to [IEC 60793-1-47] and [IEC 61280-4-1].

The macrobending-added loss for the multimode fibre within the scope of this Recommendation is fully determined by its NA value (see Table 1) and the launching conditions at the position in the cable network where a bend is present.

NOTE – A qualification test may be sufficient to ensure that this requirement is being met.

5.7 Material properties of the fibre

5.7.1 Fibre materials

The substances of which the fibres are made should be indicated.

NOTE – Care may be needed in fusion splicing fibres of different substances. Provisional results indicate that adequate splice loss and strength can be achieved when splicing different high-silica fibres.

5.7.2 Protective materials

The physical and chemical properties of the material used for the fibre primary coating and the best way of removing it (if necessary) should be indicated. In the case of single jacketed fibre, similar indications shall be given.

5.8 Refractive index profile

The refractive index profile of the fibre does not generally need to be known.

5.9 Modal bandwidth

The modal bandwidth is specified with a minimum value at one or more wavelengths in both the 850 nm and 1300 nm regions. The optical fibre modal bandwidth shall not be lower than the values recommended in clause 7.

By convention, the modal bandwidth is linearly normalized to 1 km. For measuring the value of this attribute, reference is made to [IEC 60793-1-41].

5.10 Chromatic dispersion coefficient

The chromatic dispersion coefficient, $D(\lambda)$, is specified by putting limits on the parameters of a chromatic dispersion curve that is a function of wavelength in the 1300 nm region. The chromatic dispersion coefficient limit for any wavelength, λ, is calculated with the minimum zero-dispersion wavelength, λ_{0min}, the maximum zero-dispersion wavelength, λ_{0max}, and the maximum zero-dispersion slope coefficient, S_{0max}, according to:

$$\frac{\lambda S_{0max}}{4}\left[1-\left(\frac{\lambda_{0max}}{\lambda}\right)^4\right] \le D(\lambda) \le \frac{\lambda S_{0max}}{4}\left[1-\left(\frac{\lambda_{0min}}{\lambda}\right)^4\right]$$

The values of λ_{0min}, λ_{0max} and S_{0max} shall be within the limits indicated in Table 1. For measuring the value of this attribute, reference is made to [IEC 60793-1-42].

NOTE 1 – The worst-case chromatic dispersion coefficient at 850 nm as derived from the recommended values in clause 7 is −104 ps/nm · km (e.g., S_0 = 0.09375 ps/nm^2 · km at λ_0 = 1340 nm or S_0 = 0.10125 ps/nm^2 · km at λ_0 = 1320 nm).

NOTE 2 – Specification compliance of chromatic dispersion can be assured by compliance to the numerical aperture specification.

6 Cable attributes

Since the geometrical and optical characteristics of fibres given in clause 5 are barely affected by the cabling process, this clause gives recommendations mainly relevant to transmission characteristics of cabled fibres.

Environmental and test conditions are paramount and are described in the guidelines for test methods.

6.1 Attenuation coefficient

The attenuation coefficient is specified with a maximum value at one or more wavelengths in both the 850 nm and 1300 nm regions. The optical fibre cable attenuation coefficient values shall not exceed the values recommended in clause 7. For measuring the value of this attribute, reference is made to [IEC 60793-1-40].

6.2 Modal bandwidth

The cable requirement for modal bandwidth is that the cable shall include fibre that complies with the fibre modal bandwidth-length product as recommended in clause 7.

7 Tables of recommended values

Table 1 summarizes the recommended values for the 50/125 μm graded-index multimode fibres that satisfy the objectives of this Recommendation. They support the application in Ethernet-based systems with transmission speeds ranging up to 1 Gbit/s, either in the 850 nm or in the 1300 nm wavelength window. For the 1 Gbit/s systems, the link length is 550 m both at 850 nm (1000BASE-SX) and at 1300 nm (1000BASE-LX).

The modal bandwidth-length product requirements as stated in Table 1 have been coded as "OM2" in [b-ISO/IEC 11801] and have also been normatively defined in the optical fibre cable standards listed in clause 2. The use of any other "OM-x" grade multimode fibre, with higher bandwidth than that of "OM2", satisfies the requirements of this Recommendation.

Longer link lengths up to 1000 or 2000 m at either one of the two or both wavelength regions can be supported if the customer and the manufacturer agree on improved attribute values, modal bandwidth in particular.

NOTE 1 – The cross-reference table for multimode fibres developed in ITU-T, IEC, ISO/IEC can be found in Appendix V of [b-ITU-T G-Sup.40].

NOTE 2 – ITU-T G.651.1 was initially specified in compliance with OM2 category fibre in the 2002 version of [b-ISO/IEC 11801]. The current specification of ITU-T G.651.1 is compatible with OM2 category fibre in the 2017 version of [b-ISO/IEC 11801-1], in particular in Annex F, Table F.1 – Grandfathered OM1, OM2 and OS1 specifications.

Table 1 – Attributes

Fibre attributes			
Attribute	**Detail**	**Value**	**Unit**
Cladding diameter	Nominal	125	µm
	Tolerance	±1	µm
Core diameter	Nominal	50	µm
	Tolerance	±2.5	µm
Core-cladding concentricity error	Maximum	2	µm
Core non-circularity	Maximum	6	%
Cladding non-circularity	Maximum	2	%
Numerical aperture	Nominal	0.20	
	Tolerance	±0.015	
Macrobend loss	Radius	15	mm
	Number of turns	2	
	Maximum at 850 nm	1.0	dB
(Notes 1 and 2)	Maximum at 1300 nm	1.0	dB
Proof stress	Minimum	0.69	GPa
Modal bandwidth-length product for overfilled launch	Minimum at 850 nm	500	MHz · km
	Minimum at 1300 nm	500	MHz · km
Chromatic dispersion coefficient	λ_{0min}	1295	nm
	λ_{0max}	1340	nm
	S_{0max} for $1295 \le \lambda_0 \le 1310$ nm	≤ 0.105	ps/nm^2 × km
(Note 3)	S_{0max} for $1310 \le \lambda_0 \le 1340$ nm	$\le 375 \times (1590 - \lambda_0) \times 10^{-6}$	ps/nm^2 · km
Cable attributes			
Attribute	**Detail**	**Value**	**Unit**
Attenuation coefficient	Maximum at 850 nm	3.5	dB/km
	Maximum at 1300 nm	1.0	dB/km

NOTE 1 – In case of use of the multimode fibre outside the scope of this Recommendation, other macrobending loss values may be valid as specified in [IEC 60793-2-10].

NOTE 2 – For testing the macrobending loss value, the launching conditions as specified for the attenuation measurement in [IEC 61280-4-1] shall be used.

NOTE 3 – The worst-case chromatic dispersion coefficient at 850 nm (e.g., $S_0 = 0.09375$ ps/nm^2 · km at $\lambda_0 = 1340$ nm or $S_0 = 0.10125$ ps/nm^2 · km at $\lambda_0 = 1320$ nm) is −104 ps/nm · km.

Appendix I

Historical perspective on the evolution of the specification of Recommendation ITU-T G.651.1 multimode optical fibre cable

(This appendix does not form an integral part of this Recommendation.)

[b-ITU-T G.651], originally published in 1980, covered the geometrical and transmissive properties of multimode fibres having a 50 μm nominal core diameter and a 125 μm nominal cladding diameter. Test methods and the meanings of the terms used were in the text.

That Recommendation, which had not been significantly changed from the original in the four subsequent editions through 1998, was developed during the infancy of optical fibre solutions for publicly switched networks. At that time (pre-1984), these fibres were considered as the only practical solution for transmission distances in the 10's of kilometres and bit-rates of up to 40 Mbit/s. Single-mode ITU-T G.652 fibres, which became available shortly after the publication of [b-ITU-T G.651], have almost completely replaced multimode fibres in the public switched networks.

Currently, multimode fibres continue to be widely used in premises cabling applications such as Ethernet in lengths from 300 to 2000 m, depending on bit rate. With a change in the applications, the multimode fibre definitions, requirements, and measurements evolved away from the original [b-ITU-T G.651] in some ways and were maintained or improved in others.

The transmission characteristics from this Recommendation have also been moved to the modern equivalent, Recommendation ITU-T G.651.1. A complete documentation for the modern requirements is found in [IEC 60793-2-10].

The contents of [b-ITU-T G.651] included the early parameter definitions for glass geometry, numerical aperture, attenuation and baseband response (the combination of modal bandwidth and chromatic dispersion). Some limits on these parameters were also given. Formulas for the attenuation and bandwidth of installed links that comprised of concatenations of cables were given. Measurement methods for the parameters were also described.

Some differences between [b-ITU-T G.651] and the modern requirements include:

i) the core diameter is defined in terms of the near field profile, rather than the refractive index profile;

ii) parameters such as core/cladding tolerance field and intrinsic quality factor are no longer used;

iii) the proof test stress is now twice what it was;

iv) bandwidth limits were then 200 MHz · km, whereas now limits can be as large as 2000 MHz · km.

With the acceptance of more modern and more tightly specified Recommendation ITU-T G.651.1 in 2007, the old [b-ITU-T G.651] was felt to be obsolete, and therefore was withdrawn in February 2008. This appendix indicates some background information about the old [b-ITU-T G.651].

Table I.1 – Fibre characteristics of the withdrawn Recommendation ITU-T G.651

Attribute	Detail	Value	Unit
Cladding diameter	Nominal	125	µm
	Tolerance	±3	µm
Core diameter	Nominal	50	µm
	Tolerance	± 3	µm
Core-cladding concentricity error	Maximum	6	%
Core non-circularity	Maximum	6	%
Cladding non-circularity	Maximum	2	%
Numerical aperture	Nominal	0.20 or 0.23	
	Tolerance	±0.02	
Proof stress	Minimum	0.35	GPa
Modal bandwidth-length product for overfilled launch	Minimum at 850 nm	200	MHz · km
	Minimum at 1300 nm	200	MHz · km
Chromatic dispersion coefficient	Typical at 850 nm	≤ 120	ps/(nm · km)
	Typical at 1300 nm	≤ 6	ps/(nm · km)
Cable attributes			
Attribute	**Detail**	**Value**	**Unit**
Attenuation coefficient	Maximum at 850 nm	4	dB/km
	Maximum at 1300 nm	2	dB/km

Bibliography

[b-ITU-T G.651] Recommendation ITU-T G.651(1998), *Characteristics of a 50/125 µm multimode graded index optical fibre cable*. <http://handle.itu.int/11.1002/1000/4248>

[b-ITU-T G.983.x] ITU-T G.983.x series of Recommendations (2001-2005), *Broadband optical access systems based on Passive Optical Networks (PON)*.

[b-ITU-T G.984.x] ITU-T G.984.x series of Recommendations (2003-2007), *Gigabit-capable Passive Optical Networks (G-PON)*.

[b-ITU-T L.67] Recommendation ITU-T L.67 (2006), *Small count optical fibre cables for indoor applications*.

[b-ITU-T G-Sup.40] ITU-T G-series Supplement 40 (2018), *Optical fibre and cable Recommendations and standards guideline*.

[b-ITU-T ANT] ITU-T SG 15 WP 1; *ANT standards overview*. <itu.int/en/ITU-T/studygroups/2013-2016/15/Documents/Overviews_WorkPlans/ANT-Standards-Overview-V29.docx>

[b-IEC 62048] IEC 62048 (2002), *Optical fibres – Reliability – Power law theory*.

[b-IEEE 802.3] IEEE std. 802.3 (2005), *Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*.

[b-ISO/IEC 11801] ISO/IEC 11801:2002, *Information technology – Generic cabling for customer premises*.

[b-ISO/IEC 11801-1] ISO/IEC 11801-1:2017, *Information technology – Generic cabling for customer premises – Part 1: General requirements.*

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Printed in Switzerland
Geneva, 2019