International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.652

(11/2009)

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

Transmission media and optical systems characteristics – Optical fibre cables

---

Characteristics of a single-mode optical fibre and cable

Recommendation ITU-T G.652

ITU-T

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
General	G.600–G.609
Symmetric cable pairs	G.610–G.619
Land coaxial cable pairs	G.620–G.629
Submarine cables	G.630–G.639
Free space optical systems	G.640–G.649
Optical fibre cables	**G.650–G.659**
Characteristics of optical components and subsystems	G.660–G.679
Characteristics of optical systems	G.680–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.652

Characteristics of a single-mode optical fibre and cable

Summary

Recommendation ITU-T G.652 describes the geometrical, mechanical and transmission attributes of a single-mode optical fibre and cable which has zero-dispersion wavelength around 1310 nm. The ITU-T G.652 fibre was originally optimized for use in the 1310 nm wavelength region, but can also be used in the 1550 nm region. This is the latest revision of a Recommendation that was first created in 1984 and deals with some relatively minor modifications. This revision is intended to maintain the continuing commercial success of this fibre in the evolving world of high-performance optical transmission systems.

History

Version	Approval date	
Version 1	(10/1984)	
Version 2	(11/1988)	
Version 3	(03/1993)	
Version 4	(04/1997)	
Version 5	(10/2000)	This revision includes the addition of tables for different levels of system support.
Version 6	(03/2003)	This revision clarified the nomenclature for the different categories or fibre. Also, in accordance with the agreement on spectral band description, the upper limit of the L-band is changed from 16XX to 1625 nm. The attenuation characteristics for reduced water peak categories, (G.652.C and G.652.D) are generalized to a broad region from a single wavelength. PMD requirements are added for all categories and two categories have reduced limits (compared to 0.5 ps/$\sqrt{\text{km}}$). For the macrobending test, mandrel diameter is reduced to 30 mm radius. As seen above, this Recommendation has evolved considerably over the years; therefore the reader is warned to consider the appropriate version to determine the characteristics of already deployed product, taking into account the year of production. In fact, products are expected to comply with the Recommendation that was in force at the time of their manufacture, but may not fully comply with subsequent versions of the Recommendation.
Version 7	(06/2005)	Support of G.695 applications is noted. A clarification of the method of fitting chromatic dispersion coefficient values and their use is provided in 5.10, along with some text on use of the statistics of chromatic dispersion for system design. A clarification of the relationship of the PMD_Q of uncabled fibre to cabled fibre is provided in 6.2. In the tables of requirements: The uncabled fibre PMD line item is removed from the tables and the note on the requirement for uncabled fibre PMD is modified. The tolerance of MFD at 1310 nm is reduced. The maximum dispersion slope at the zero dispersion wavelength is reduced. The maximum concentricity error is reduced. The maximum macrobending loss is reduced. The wording for the water peak requirement in Tables 3 and 4 are modified to reflect a reference to the specification over the range vs the specification at 1310 nm.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

CONTENTS

Recommendation ITU-T G.652

Characteristics of a single-mode optical fibre and cable

1 Scope

This Recommendation describes a single-mode optical fibre and cable which has zero-dispersion wavelength around 1310 nm and which is optimized for use in the 1310 nm wavelength region, and which can also be used in the 1550 nm region (where this fibre is not optimized). Both analogue and digital transmission can be used with this fibre.

The geometrical, optical, transmission and mechanical parameters are described below in three 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;
- link attributes that are characteristic of concatenated cables, describing estimation methods of system interface parameters based on measurements, modelling or other considerations. Information for link attributes and system design are in Appendix I.

This Recommendation and the different performance categories found in the tables of clause 7 are intended to support the following related system Recommendations:

- [ITU-T G.957].
- [ITU-T G.691].
- [ITU-T G.692].
- [ITU-T G.693].
- [ITU-T G.959.1].
- [ITU-T G.695].

NOTE – Depending on the length of the links, dispersion accommodation can be necessary for some ITU-T G.691, ITU-T G.692 or ITU-T G.959.1 application codes.

The meaning of the terms used in this Recommendation and the guidelines to be followed in the measurement to verify the various characteristics are given in [ITU-T G.650.1] and [ITU-T G.650.2]. 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

2.1 Normative 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.

[ITU-T G.650.1] Recommendation ITU-T G.650.1 (2004), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable*.

[ITU-T G.650.2] Recommendation ITU-T G.650.2 (2005), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.

[IEC 60793-2-50] IEC 60793-2-50 (2004), *Optical fibres – Part 2-50: Product specifications – Sectional specification for class B single mode fibres*.

2.2 Informative references

[ITU-T G.663] Recommendation ITU-T G.663 (2000), *Application related aspects of optical amplifier devices and subsystems*.

[ITU-T G.691] Recommendation ITU-T G.691 (2003), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*.

[ITU-T G.692] Recommendation ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[ITU-T G.693] Recommendation ITU-T G.693 (2005), *Optical interfaces for intra-office systems*.

[ITU-T G.695] Recommendation ITU-T G.695 (2005), *Optical interfaces for coarse wavelength division multiplexing applications*.

[ITU-T G.957] Recommendation ITU-T G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2003), *Optical transport network physical layer interfaces*.

[IEC 60794-2-11] IEC 60794-2-11 (2005), *Optical fibre cables – Part 2-11: Indoor cables – Detailed specification for simplex and duplex cables for use in premises cabling*.

3 Terms and definitions

For the purposes of this Recommendation, the definitions given in [ITU-T G.650.1] and [ITU-T G.650.2] apply. Values shall be rounded to the number of digits given in the tables of Recommended values before conformance is evaluated.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

A_{eff} Effective Area

DGD Differential Group Delay

DWDM Dense Wavelength Division Multiplexing

GPa GigaPascal

PMD Polarization Mode Dispersion

PMD_Q Statistical parameter for link PMD

SDH Synchronous Digital Hierarchy

TBD To Be Determined

WDM Wavelength Division Multiplexing

5 Fibre attributes

Only those characteristics of the fibre providing a minimum essential design framework for fibre manufacture are recommended in this clause. Ranges or limits on values are presented in the tables of clause 7. Of these, cable manufacture or installation may significantly affect the cabled fibre cut-off wavelength and PMD. Otherwise, the recommended characteristics will apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in an installed cable.

5.1 Mode field diameter

Both a nominal value and tolerance about that nominal value shall be specified at 1310 nm. The nominal value that is specified shall be within the range found in clause 7. The specified tolerance shall not exceed the value in clause 7. The deviation from nominal shall not exceed the specified tolerance.

5.2 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 deviation from nominal shall not exceed the specified tolerance.

5.3 Core concentricity error

The core concentricity error shall not exceed the value specified in clause 7.

5.4 Non-circularity

5.4.1 Mode field non-circularity

In practice, the mode field non-circularity of fibres having nominally circular mode fields is found to be sufficiently low that propagation and jointing are not affected. It is, therefore, not considered necessary to recommend a particular value for the mode field non-circularity. It is not normally necessary to measure the mode field non-circularity for acceptance purposes.

5.4.2 Cladding non-circularity

The cladding non-circularity shall not exceed the value found in clause 7.

5.5 Cut-off wavelength

Two useful types of cut-off wavelength can be distinguished:

a) cable cut-off wavelength λ_{cc};

b) fibre cut-off wavelength λ_c.

NOTE – For some specific submarine cable applications, other cable cut-off wavelength values may be required.

The correlation of the measured values of λ_c and λ_{cc} depends on the specific fibre and cable design and the test conditions. While in general $\lambda_{cc} < \lambda_c$, a general quantitative relationship cannot be easily established. The importance of ensuring single-mode transmission in the minimum cable length between joints at the minimum operating wavelength is paramount. This may be performed by recommending the maximum cable cut-off wavelength λ_{cc} of a cabled single-mode fibre to be 1260 nm or for worst case length and bends, by recommending a maximum fibre cut-off wavelength to be 1250 nm.

The cable cut-off wavelength, λ_{cc}, shall be less than the maximum specified in clause 7.

5.6 Macrobending loss

Macrobending loss varies with wavelength, bend radius and number of turns about a mandrel with a specified radius. Macrobending loss shall not exceed the maximum given in clause 7 for the specified wavelength(s), bend radius and number of turns.

NOTE 1 – A qualification test may be sufficient to ensure that this requirement is being met.

NOTE 2 – The recommended number of turns corresponds to the approximate number of turns deployed in all splice cases of a typical repeater span. The recommended radius is equivalent to the minimum bend-radius widely accepted for long-term deployment of fibres in practical systems installations to avoid static-fatigue failure.

NOTE 3 – If, for practical reasons, fewer than the recommended number of turns are chosen to be implemented, it is suggested that not less than 40 turns, and that a proportionately smaller loss increase be required.

NOTE 4 – The macrobending loss recommendation relates to the deployment of fibres in practical single-mode fibre installations. The influence of the stranding-related bending radii of cabled single-mode fibres on the loss performance is included in the loss specification of the cabled fibre.

NOTE 5 – In the event that routine tests are required, a smaller diameter loop with one or several turns can be used instead of the recommended test, for accuracy and measurement ease. In this case, the loop diameter, number of turns and the maximum permissible bend loss for the several-turn test should be chosen so as to correlate with the recommended test and allowed loss.

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.

5.7.3 Proofstress level

The specified proofstress σ_p shall not be less than the minimum specified in clause 7.

NOTE – The definitions of the mechanical parameters are contained in clauses 3.2 and 5.6 of [ITU-T G.650.1].

5.8 Refractive index profile

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

5.9 Longitudinal uniformity of chromatic dispersion

Under study.

NOTE – At a particular wavelength, the local absolute value of the chromatic dispersion coefficient can vary away from the value measured on a long length. If the value decreases to a small value at a wavelength that is close to an operating wavelength in a wavelength division multiplexing (WDM) system, four-wave mixing can induce the propagation of power at other wavelengths including, but not limited to, other operating wavelengths. The magnitude of the four-wave mixing power is a function of the absolute value of the chromatic dispersion coefficient, the chromatic dispersion slope, the operating wavelengths, the optical power, and the distance over which four-wave mixing occurs.

For dense wavelength division multiplexing (DWDM) operations in the 1550 nm region, the chromatic dispersion of ITU-T G.652 fibres is large enough to avoid four-wave mixing. Chromatic dispersion uniformity is, therefore, not a functional issue.

5.10 Chromatic dispersion coefficient

The measured group delay or chromatic dispersion coefficient versus wavelength shall be fitted by the three-term Sellmeier equation as defined in Annex A of [ITU-T G.650.1] (see clause 5.5 of [ITU-T G.650.1] for guidance on the interpolation of dispersion values to unmeasured wavelengths).

The Sellmeier equation can be used to fit the data in each range (1310 nm and 1550 nm) separately in two fits, or as one common fit, with data from both ranges.

The Sellmeier fit in the 1310 nm region may not be sufficiently accurate when extrapolated to the 1550 nm region. Because the chromatic dispersion in the latter region is large, the reduced accuracy may be acceptable; if not, it can be improved by including data from the 1550 nm region when performing the common fit, or by using a separate fit for the 1550 nm region. It should be noted that a common fit may reduce the accuracy in the 1310 nm region.

The chromatic dispersion coefficient, D, is specified by putting limits on the parameters of a chromatic dispersion curve that is a function of wavelength in the 1310 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:

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

The values of λ_{0min}, λ_{0max} and S_{0max} shall be within the limits indicated in the tables of clause 7.

The chromatic dispersion coefficient values at wavelengths ranging from 1500 nm to 1625 nm are also used in system design or chromatic dispersion compensator design. Chromatic dispersion coefficient values at selected wavelengths in this range are evaluated by using either the five-term Sellmeier or the fourth order polynomial model based on measurements across these wavelength ranges. Designs with chromatic dispersion coefficient values are normally based on a statistical approach such as that found in Supplement 39 to ITU-T G-series Recommendations. Appendix I lists typical values for a band about 1550 nm.

NOTE – It is not necessary to measure the chromatic dispersion coefficient of single-mode fibre on a routine basis.

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 factory lengths.

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 1310 nm and 1550 nm regions. The optical fibre cable attenuation coefficient values shall not exceed the values found in clause 7.

NOTE – The attenuation coefficient may be calculated across a spectrum of wavelengths, based on measurements at a few (3 to 4) predictor wavelengths. This procedure is described in clause 5.4.4 of [ITU-T G.650.1] and an example is given in Appendix III of [ITU-T G.650.1].

6.2 Polarization mode dispersion coefficient

Cabled fibre polarization mode dispersion shall be specified on a statistical basis, not on an individual fibre basis. The requirements pertain only to the aspect of the link calculated from cable information. The metrics of the statistical specification are found below. Methods of calculations are found in [b-IEC/TR 61282-3], and are summarized in Appendix IV of [ITU-T G.650.2].

The manufacturer shall supply a PMD link design value, PMD_Q, that serves as a statistical upper bound for the PMD coefficient of the concatenated optical fibre cables within a defined possible link of M cable sections. The upper bound is defined in terms of a small probability level, Q, which is the probability that a concatenated PMD coefficient value exceeds PMD_Q. For the values of M and Q given in clause 7, the value of PMD_Q shall not exceed the maximum PMD coefficient specified in clause 7.

Measurements and specifications on uncabled fibre are necessary, but not sufficient to ensure the cabled fibre specification. The maximum link design value specified on uncabled fibre shall be less than or equal to that specified for the cabled fibre. The ratio of PMD values for uncabled fibre to cabled fibre depends on the details of the cable construction and processing, as well as on the mode coupling condition of the uncabled fibre. [ITU-T G.650.2] recommends a low mode coupling deployment requiring a low tension wrap on a large diameter spool for uncabled fibre PMD measurements.

The limits on the distribution of PMD coefficient values can be interpreted as being nearly equivalent to limits on the statistical variation of the differential group delay (DGD), that varies randomly with time and wavelength. When the PMD coefficient distribution is specified for optical fibre cable, equivalent limits on the variation of DGD can be determined. The metrics and values for link DGD distribution limits are found in Appendix I.

NOTE 1 – PMD_Q specification would be required only where cables are employed for systems that have the specification of the max DGD, i.e., for example, PMD_Q specification would not be applied to systems recommended in [ITU-T G.957].

NOTE 2 – PMD_Q should be calculated for various types of cables, and they should usually be calculated using sampled PMD values. The samples would be taken from cables of similar construction.

NOTE 3 – The PMD_Q specification should not be applied to short cables such as jumper cables, indoor cables and drop cables.

7 Tables of recommended values

The following tables summarize the recommended values for a number of categories of fibres that satisfy the objectives of this Recommendation. These categories are largely distinguished on the basis of PMD requirements and attenuation requirement at 1383 nm. See Appendix I for information about transmission distances and bit-rates relative to PMD requirements.

Table 1, ITU-T G.652.A attributes, contains the recommended attributes and values needed to support applications such as those recommended in [ITU-T G.957] and [ITU-T G.691] up to STM-16, as well as 10 Gbit/s up to 40 km (Ethernet) and STM-256 for [ITU-T G.693].

Table 2, ITU-T G.652.B attributes, contains recommended attributes and values needed to support higher bit rate applications, up to STM-64, such as some in [ITU-T G.691] and [ITU-T G.692], STM-256 for some applications in [ITU-T G.693] and [ITU-T G.959.1]. Depending on the application, chromatic dispersion accommodation may be necessary.

Table 3, ITU-T G.652.C attributes, is similar to ITU-T G.652.A, but allows transmissions in portions of an extended wavelength range from 1360 nm to 1530 nm.

Table 4, ITU-T G.652.D attributes, is similar to ITU-T G.652.B, but allows transmissions in portions of an extended wavelength range from 1360 nm to 1530 nm.

Table 1 – ITU-T G.652.A attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1310 nm
	Range of nominal values	8.6-9.5 µm
	Tolerance	±0.6 µm
Cladding diameter	Nominal	125.0 µm
	Tolerance	±1 µm
Core concentricity error	Maximum	0.6 µm
Cladding noncircularity	Maximum	1.0%
Cable cut-off wavelength	Maximum	1260 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1550 nm	0.1 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	λ_{0min}	1300 nm
	λ_{0max}	1324 nm
	S_{0max}	0.092 ps/nm^2 × km
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1310 nm	0.5 dB/km
	Maximum at 1550 nm	0.4 dB/km
PMD coefficient (Note 2)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.5 ps/$\sqrt{km}$
NOTE 1 – The attenuation coefficient values listed in this table should not be applied to short cables such as jumper cables, indoor cables and drop cables. For example, [IEC 60794-2-11] specifies the attenuation coefficient of indoor cable as 1.0 dB/km or less at both 1310 and 1550 nm. NOTE 2 – According to clause 6.2, a maximum PMD_Q value on uncabled fibre is specified in order to support the primary requirement on cable PMD_Q.		

Table 2 – ITU-T G.652.B attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1310 nm
	Range of nominal values	8.6-9.5 µm
	Tolerance	±0.6 µm
Cladding diameter	Nominal	125.0 µm
	Tolerance	±1 µm
Core concentricity error	Maximum	0.6 µm
Cladding noncircularity	Maximum	1.0%
Cable cut-off wavelength	Maximum	1260 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.1 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	λ_{0min}	1300 nm
	λ_{0max}	1324 nm
	S_{0max}	0.092 ps/nm^2 × km
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1310 nm	0.4 dB/km
	Maximum at 1550 nm	0.35 dB/km
	Maximum at 1625 nm	0.4 dB/km
PMD coefficient (Note 2)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/$\sqrt{km}$
NOTE 1 – The attenuation coefficient values listed in this table should not be applied to short cables such as jumper cables, indoor cables and drop cables. For example, [IEC 60794-2-11] specifies the attenuation coefficient of indoor cable as 1.0 dB/km or less at both 1310 and 1550 nm. NOTE 2 – According to clause 6.2, a maximum PMD_Q value on uncabled fibre is specified in order to support the primary requirement on cable PMD_Q.		

Table 3 – ITU-T G.652.C attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1310 nm
	Range of nominal values	8.6-9.5 µm
	Tolerance	±0.6 µm
Cladding diameter	Nominal	125.0 µm
	Tolerance	±1 µm
Core concentricity error	Maximum	0.6 µm
Cladding noncircularity	Maximum	1.0%
Cable cut-off wavelength	Maximum	1260 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.1 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	λ_{0min}	1300 nm
	λ_{0max}	1324 nm
	S_{0max}	0.092 ps/nm^2 × km
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum from 1310 nm to 1625 nm (Note 2)	0.4 dB/km
	Maximum at 1383 nm ±3 nm (Note 3)	0.4 dB/km
	Maximum at 1550 nm	0.3 dB/km
PMD coefficient (Note 4)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.5 ps/$\sqrt{km}$

NOTE 1 – The attenuation coefficient values listed in this table should not be applied to short cables such as jumper cables, indoor cables and drop cables. For example, [IEC 60794-2-11] specifies the attenuation coefficient of indoor cable as 1.0 dB/km or less at both 1310 and 1550 nm.

NOTE 2 – This wavelength region can be extended to 1260 nm by adding 0.07 dB/km induced Rayleigh scattering loss to the attenuation value at 1310 nm. In this case, the cable cut-off wavelength should not exceed 1250 nm.

NOTE 3 – The average attenuation coefficient at this wavelength shall be less than or equal to the maximum value specified for the range of 1310 nm to 1625 nm, after hydrogen ageing. The hydrogen ageing is a type test that shall be done to a sampled fibre, according to [IEC 60793-2-50] regarding the B1.3 fibre category.

NOTE 4 – According to clause 6.2, a maximum PMD_Q value on uncabled fibre is specified in order to support the primary requirement on cable PMD_Q.

Table 4 – ITU-T G.652.D attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1310 nm
	Range of nominal values	8.6-9.5 µm
	Tolerance	±0.6 µm
Cladding diameter	Nominal	125.0 µm
	Tolerance	±1 µm
Core concentricity error	Maximum	0.6 µm
Cladding noncircularity	Maximum	1.0%
Cable cut-off wavelength	Maximum	1260 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.1 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	λ_{0min}	1300 nm
	λ_{0max}	1324 nm
	S_{0max}	0.092 ps/nm^2 × km
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum from 1310 nm to 1625 nm (Note 2)	0.4 dB/km
	Maximum at 1383 nm ±3 nm (Note 3)	0.4 dB/km
	Maximum at 1550 nm	0.3 dB/km
PMD coefficient (Note 4)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/$\sqrt{km}$

NOTE 1 – The attenuation coefficient values listed in this table should not be applied to short cables such as jumper cables, indoor cables and drop cables. For example, [IEC 60794-2-11] specifies the attenuation coefficient of indoor cable as 1.0 dB/km or less at both 1310 and 1550 nm.

NOTE 2 – This wavelength region can be extended to 1260 nm by adding 0.07 dB/km induced Rayleigh scattering loss to the attenuation value at 1310 nm. In this case, the cable cut-off wavelength should not exceed 1250 nm.

NOTE 3 – The average attenuation coefficient at this wavelength shall be less than or equal to the maximum value specified for the range of 1310 nm to 1625 nm, after hydrogen ageing. The hydrogen ageing is a type test that shall be done to a sampled fibre, according to [IEC 60793-2-50] regarding the B1.3 fibre category.

NOTE 4 – According to clause 6.2, a maximum PMD_Q value on uncabled fibre is specified in order to support the primary requirement on cable PMD_Q.

Appendix I

Information for link attributes and system design

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

A concatenated link usually includes a number of spliced factory lengths of optical fibre cable. The requirements for factory lengths are given in clauses 5 and 6. The transmission parameters for concatenated links must take into account not only the performance of the individual cable lengths but also the statistics of concatenation.

The transmission characteristics of the factory length optical fibre cables will have a certain probability distribution which often needs to be taken into account if the most economic designs are to be obtained. This appendix should be read with this statistical nature of the various parameters in mind.

Link attributes are affected by factors other than optical fibre cables, by such things as splices, connectors and installation. These factors cannot be specified in this Recommendation. For the purpose of link attribute values estimation, typical values of optical fibre links are provided in the tables below. The estimation methods of parameters needed for system design are based on measurements, modelling or other considerations.

I.1 Attenuation

The attenuation, A, of a link is given by:

$$A = \alpha L + \alpha_s x + \alpha_c y$$

where:

- α typical attenuation coefficient of the fibre cables in a link;
- α_s mean splice loss;
- x number of splices in a link;
- α_c mean loss of line connectors;
- y number of line connectors in a link (if provided);
- L link length.

A suitable margin should be allocated for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.). The above equation does not include the loss of equipment connectors. The typical values found in clause I.5 are for the attenuation coefficient of optical fibre links. The attenuation budget used in designing an actual system should account for the statistical variations in these parameters.

I.2 Chromatic dispersion

The chromatic dispersion in ps/nm can be calculated from the chromatic dispersion coefficients of the factory lengths, assuming a linear dependence on length, and with due regard for the signs of the coefficients (see clause 5.10).

When these fibres are used for transmission in the 1550 nm region, some forms of chromatic dispersion compensation are often employed. In this case, the average link chromatic dispersion is used for design purposes. The measured dispersion in the 1550 nm window can be characterized within the 1550 nm window by a linear relationship with wavelength. The relationship is described in terms of the typical chromatic dispersion coefficient and dispersion slope coefficient at 1550 nm.

Typical values for the chromatic dispersion coefficient, D_{1550}, and chromatic dispersion slope coefficient, S_{1550}, at 1550 nm are found in Table I.1. These values, together with link length, L_{Link}, can be used to calculate the typical chromatic dispersion for use in optical link design.

$$D_{Link}(\lambda) = L_{Link}\left[D_{1550} + S_{1550}(\lambda - 1550)\right] \text{ [ps/nm]}$$

I.3 Differential group delay (DGD)

The differential group delay is the difference in arrival times of the two polarization modes at a particular wavelength and time. For a link with a specific PMD coefficient, the DGD of the link varies randomly with time and wavelength as a Maxwell distribution that contains a single parameter, which is the product of the PMD coefficient of the link and the square root of the link length. The system impairment due to PMD at a specific time and wavelength depends on the DGD at that time and wavelength. So, means of establishing useful limits on the DGD distribution as it relates to the optical fibre cable PMD coefficient distribution and its limits have been developed and are documented in [b-IEC/TR 61282-3] and are summarized in Appendix IV of [ITU-T G.650.2]. The metrics of the limitations of the DGD distribution follow:

NOTE – The determination of the contribution of components other than optical fibre cable is beyond the scope of this Recommendation, but is discussed in [b-IEC/TR 61282-3].

Reference link length, L_{Ref}: A maximum link length to which the maximum DGD and probability will apply. For longer link lengths, multiply the maximum DGD by the square root of the ratio of actual length to the reference length.

Typical maximum cable length, L_{Cab}: The maxima are assured when the typical individual cables of the concatenation or the lengths of the cables that are measured in determining the PMD coefficient distribution are less than this value.

Maximum DGD, $DGD_{\max}$: The DGD value that can be used when considering optical system design.

Maximum probability, P_F: The probability that an actual DGD value exceeds $DGD_{\max}$.

I.4 Non-linear coefficient

The effect of chromatic dispersion is interactive with the non-linear coefficient, n_2/A_{eff}, regarding system impairments induced by non-linear optical effects (see [ITU-T G.663] and [ITU-T G.650.2]). Typical values vary with the implementation. The test methods for non-linear coefficient remain under study.

I.5 Tables of common typical values

The values in Tables I.1 and I.2 are representative of concatenated optical fibre links according to clauses I.1 and I.3, respectively. The implied fibre induced maximum DGD values in Table I.2 are intended for guidance in regard to the requirements for other optical elements that may be in the link.

NOTE – Cable section length is 10 km except for the 0.10 ps/$\sqrt{\text{km}}$ /> 4000 km link, where it is set to 25 km, the error probability level is 6.5×10^{-8}.

Table I.1 – Representative value of concatenated optical fibre links

Attenuation coefficient	Wavelength region	Typical link value
(Note)	1260 nm-1360 nm	0.5 dB/km
	1530 nm-1565 nm	0.275 dB/km
	1565 nm-1625 nm	0.35 dB/km
Chromatic dispersion coefficient	D_{1550}	17 ps/nm × km
	S_{1550}	0.056 ps/nm^2 × km
NOTE – Typical link value corresponds to the link attenuation coefficient used in [ITU-T G.957] and [ITU-T G.691].		

Table I.2 – Differential group delay

Maximum PMD_Q [ps/$\sqrt{km}$]	Link length [km]	Implied fibre induced maximum DGD [ps]	Channel bit rates
No specification			Up to 2.5 Gbit/s
0.5	400	25.0	10 Gbit/s
	40	19.0 (Note)	10 Gbit/s
	2	7.5	40 Gbit/s
0.20	3000	19.0	10 Gbit/s
	80	7.0	40 Gbit/s
0.10	>4000	12.0	10 Gbit/s
	400	5.0	40 Gbit/s
NOTE – This value applies also for 10 Gigabit Ethernet systems.			

Bibliography

[b-IEC 60793-2] IEC 60793-2 (2003), *Optical fibres – Part 2: Product specifications – General*.

[b-IEC/TR 61282-3] IEC/TR 61282-3 (2002), *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Terminals and subjective and objective assessment methods
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2010