International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.654

(10/2012)

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

Transmission media and optical systems characteristics – Optical fibre cables

Characteristics of a cut-off shifted single-mode optical fibre and cable

Recommendation ITU-T G.654

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.654

Characteristics of a cut-off shifted single-mode optical fibre and cable

Summary

Recommendation ITU-T G.654 describes the geometrical, mechanical and transmission attributes of a single-mode optical fibre and cable which has the zero-dispersion wavelength around 1300 nm wavelength, and which is loss-minimized and cut-off wavelength shifted at around the 1550 nm wavelength region. This is the latest revision of this Recommendation that was first created in 1988.

Version 9.0 introduces category D ITU-T G.654 fibre in order to improve the optical signal to noise ratio (OSNR) characteristics, e.g., which can be applied to higher bit-rate submarine systems. It is intended to maintain the continuing commercial success of this fibre in the evolving world of high-performance optical transmission systems.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.654	1988-11-25	XV
2.0	ITU-T G.654	1993-03-12	XV
3.0	ITU-T G.654	1997-04-08	15
4.0	ITU-T G.654	2000-10-06	15
5.0	ITU-T G.654	2002-06-29	15
6.0	ITU-T G.654	2004-06-13	15
7.0	ITU-T G.654	2006-12-14	15
8.0	ITU-T G.654	2010-07-29	15
9.0	ITU-T G.654	2012-10-29	15

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/.

Table of Contents

Recommendation ITU-T G.654

Characteristics of a cut-off shifted single-mode optical fibre and cable

1 Scope

This Recommendation describes a single-mode optical fibre and cable which has the zero-dispersion wavelength around 1300 nm wavelength, which is loss-minimized and cut-off shifted at a wavelength around 1550 nm, and which is optimized for use in the 1530-1625 nm region.

This very low loss cut-off shifted fibre (CSF) can be used for long-distance digital transmission applications such as long-haul terrestrial line systems and submarine cable systems using optical amplifiers. The geometrical, optical (attenuation, cut-off wavelength, chromatic dispersion and polarization mode dispersion, etc.), transmission and mechanical characteristics of this CSF are described below.

Some provisions are made to support transmission at higher wavelengths up to 1625 nm. 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 characteristics 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 given 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:

- [b-ITU-T G.957];
- [b-ITU-T G.691];
- [b-ITU-T G.692];
- [b-ITU-T G.959.1];
- [b-ITU-T G.973];
- [b-ITU-T G.973.1];
- [b-ITU-T G.973.2];
- [b-ITU-T G.977].

The meaning of the terms used in this Recommendation, and the guidelines to be followed in the measurements 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

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 (2010), *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 (2007), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.

3 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 table of recommended values before conformance is evaluated.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CSF Cut-off Shifted Fibre

DGD Differential Group Delay

DWDM Dense Wavelength Division Multiplexing

MFD Mode Field Diameter

OSNR Optical Signal to Noise Ratio

PMD Polarization Mode Dispersion

PMD_Q Statistical parameter for PMD link

RTM Reference Test Method

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 manufacturers 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 polarization mode dispersion (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 of mode field diameter (MFD) shall be specified at 1550 nm. The nominal values of the MFD that is specified shall be within the range found in clause 7. The specified tolerance of the MFD 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 1 – 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 can be approached in two alternate ways:

1) recommending λ_c to be less than 1600 nm: when a lower limit is appropriate, λ_c should be greater than 1350 nm;

2) recommending the maximum value of λ_{cc} to be 1530 nm.

NOTE 2 – The above values ensure single-mode transmission at around 1550 nm. For WDM applications requiring operation at a wavelength of (1550 nm-x), the above values should be reduced by x nm.

These two specifications need not both be invoked. Since specification of λ_{cc} is a more direct way of ensuring single-mode cable operation, it is the preferred option. When circumstances do not readily permit the specification of λ_{cc} (e.g., in single-mode optical fibre cables such as jumper cables or cables to be deployed in a significantly different manner than in the λ_{cc} RTM), then the specification of λ_c is appropriate.

When the user chooses to specify λ_{cc} as in item 2), it should be understood that λ_c may exceed 1600 nm.

When the user chooses to specify λ_c as in item 1), then λ_{cc} need not be specified.

In the case where the user chooses to specify λ_{cc}, it may be permitted that λ_c be higher than the minimum operating wavelength relying on the effects of cable fabrication and installation to yield λ_{cc} values below the minimum operating wavelength for the shortest length of cable between two joints.

In the case where the user chooses to specify λ_{cc}, a qualification test may be sufficient to verify that the λ_{cc} requirement is being met.

The cable cut-off wavelength, λ_{cc}, shall not exceed 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 for implementation, it is suggested that not less than 40 turns and 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 5.7 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 DWDM 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 DWDM operations in the 1550 nm region, the chromatic dispersion of ITU-T G.654 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 per unit fibre length versus wavelength shall be fitted by the quadratic 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.)

Depending on accuracy requirements, for wavelength intervals of up to 35 nm, the quadratic equation is allowed in the 1550 nm region. For longer wavelength intervals, either the 5-term Sellmeier model or the 4th order polynomial model is recommended. It is not meant to be used in the 1310 nm region.

NOTE – It is not necessary to measure the chromatic dispersion coefficient 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 will give 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 the 1530-1625 nm region. The optical fibre cable attenuation coefficient values shall not exceed the values found in clause 7.

NOTE 1 – The lowest values depend on the fabrication process, fibre composition and design, and cable design.

Values of 0.15 to 0.19 dB/km in the 1550 nm region have been achieved.

NOTE 2 – The attenuation coefficient may be calculated across a spectrum's 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 for ITU-T G.652 fibre is given in Appendix III of [ITU-T G.650.1].

NOTE 3 – For applications of submarine systems with remotely pumped optical amplifier described in [b-ITU-T G.973], other attenuation coefficients in the pump wavelength region may be required.

6.2 Polarization mode dispersion (PMD) 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 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 2 – 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 requirements for mode field diameter, chromatic dispersion coefficient and PMD. See Appendix I for information about transmission distances and bit rates relative to PMD requirements.

Table 1, ITU-T G.654.A Attributes, is the base category for a cut-off shifted single-mode optical fibre and cable. This category is suitable for the system in [b-ITU-T G.691], [b-ITU-T G.692], [b-ITU-T G.957] and [b-ITU-T G.977] in the 1550 nm wavelength region.

Table 2, ITU-T G.654.B Attributes, is suitable for the system described in [b-ITU-T G.691], [b-ITU-T G.692], [b-ITU-T G.957], [b-ITU-T G.977] and [b-ITU-T G.959.1] long-haul application in the 1550 nm wavelength region. This category can be applied to longer distance and larger capacity WDM transmission systems, e.g., repeaterless submarine systems with remotely pumped optical amplifier described in [b-ITU-T G.973] and submarine systems with optical amplifiers described in [b-ITU-T G.977].

Table 3, ITU-T G.654.C Attributes, is similar to ITU-T G.654.A, but the reduced PMD requirement supports higher bit-rate and long-haul applications in [b-ITU-T G.959.1].

Table 4, ITU-T G.654.D Attributes, is similar to ITU-T G.654.B, but has a modified macrobend loss specification as well as lower attenuation and larger MFD to improve the OSNR characteristics. This category is recommended for higher bit-rate submarine systems described in [b-ITU-T G.973], [b-ITU-T G.973.1], [b-ITU-T G.973.2], and [b-ITU-T G.977].

NOTE – ITU-T G.654 fibre with larger MFD than category B for terrestrial use is for further discussion.

Table 1 – ITU-T G.654.A

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-10.5 μm
	Tolerance	±0.7 μm
Cladding diameter	Nominal	125 μm
	Tolerance	±1 μm
Core concentricity error	Maximum	0.8 μm
Cladding non-circularity	Maximum	2.0%
Cable cut-off wavelength	Maximum	1530 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.50 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	$D_{1550max}$	20 ps/nm · km
	$S_{1550\ max}$	0.070 ps/nm^2 · km
Uncabled fibre PMD coefficient	Maximum	(Note 2)
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1550 nm	0.22 dB/km
PMD coefficient (Note 2)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.5 ps/√km
NOTE 1 – The attenuation coefficient values listed in this table should not be applied to short cables such as jumper cables. For example, [b-IEC 60794-2-11] specifies the attenuation coefficient of indoor cable as 1.0 dB/km or less. 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.654.B

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-13.0 μm
	Tolerance	±0.7 μm
Cladding diameter	Nominal	125 μm
	Tolerance	±1 μm
Core concentricity error	Maximum	0.8 μm
Cladding non-circularity	Maximum	2.0%
Cable cut-off wavelength	Maximum	1530 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.50 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	$D_{1550max}$	22 ps/nm · km
	$S_{1550max}$	0.070 ps/nm^2 · km
Uncabled fibre PMD coefficient	Maximum	(Note 2)
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1550 nm	0.22 dB/km
PMD coefficient (Note 2)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/√km

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

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.654.C

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-10.5 μm
	Tolerance	±0.7 μm
Cladding diameter	Nominal	125 μm
	Tolerance	±1 μm
Core concentricity error	Maximum	0.8 μm
Cladding non-circularity	Maximum	2.0%
Cable cut-off wavelength	Maximum	1530 nm
Macrobend loss	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	0.50 dB
Proof stress	Minimum	0.69 GPa
Chromatic dispersion coefficient	$D_{1550max}$	20 ps/nm · km
	$S_{1550max}$	0.070 ps/nm^2 · km
Uncabled fibre PMD coefficient	Maximum	(Note 2)
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1550 nm	0.22 dB/km
PMD coefficient (Note 2)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/√km

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

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 4 – ITU-T G.654.D

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	11.5-15.0 μm
	Tolerance	±0.7 μm
Cladding diameter	Nominal	125 μm
	Tolerance	±1 μm
Core concentricity error	Maximum	0.8 μm
Cladding non-circularity	Maximum	2.0%
Cable cut-off wavelength	Maximum	1530 nm
Macrobend loss (Note 4)	Radius	To be determined
	Number of turns	To be determined
	Maximum at 1550 nm	To be determined
	Radius	30 mm
	Number of turns	100
	Maximum at 1625 nm	2.0 dB
Proof stress (Note 2)	Minimum	0.69 GPa
Chromatic dispersion coefficient	$D_{1550max}$	23 ps/nm · km
	$S_{1550max}$	0.070 ps/nm^2 · km
Uncabled fibre PMD coefficient	Maximum	(Note 3)
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient (Note 1)	Maximum at 1550 nm	0.20 dB/km
PMD coefficient (Note 3)	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/√km

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

NOTE 2 – A higher proof stress may be considered depending on the applied system requirements.

NOTE 3 – 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.

NOTE 4 – Macrobend loss specification at 1550 nm may be useful in some systems. The specification values are to be determined including bending radius and number of turns.

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. The following clauses 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 estimation of link attribute values, typical values of optical fibre links are provided in clause I.5. 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:

$$A = \alpha L + \alpha_s x + \alpha_c y \qquad \text{(I-1)}$$

where:

α = typical attenuation coefficient of fibre cables in a link

L = length of 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)

A suitable margin should be allocated for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.). Equation I-1 does not include the loss of equipment connectors. The typical values found in clause I.5 are for the attenuation coefficient of an optical fibre link. 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. 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 clause I.5. These values, together with link length, Link, can be used to calculate the typical chromatic dispersion for use in optical link design.

$$D_{Link}(\lambda) = L_{Link}[D_{1550} + S_{1550}(\lambda - 1550)] \quad \text{(ps/nm)} \qquad \text{(I-2)}$$

I.3 Differential group delay (DGD)

The differential group delay (DGD) 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]. 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 [b-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 with regard to the requirement for other optical elements that may be in the link.

Table I.1 – Representative value of a concatenated optical fibre link

Attribute	Detail	Value
Attenuation coefficient	Wavelength	Typical link value (Note)
	1550 nm	0.25 dB/km
	1625 nm	To be determined
Typical dispersion coefficient	D_{1550} S_{1550}	To be determined To be determined
NOTE – Typical link value corresponds to the link attenuation coefficient used in [b-ITU-T G.957] and [b-ITU-T G.691].		

Table I.2 – Differential group delay

Maximum PMD_Q (ps/√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.			

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

Bibliography

[b-ITU-T G.652] Recommendation ITU-T G.652 (2009), *Characteristics of a single-mode optical fibre and cable*.

[b-ITU-T G.663] Recommendation ITU-T G.663 (2011), *Application related aspects of optical amplifier devices and subsystems*.

[b-ITU-T G.691] Recommendation ITU-T G.691 (2006), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers.*

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

[b-ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[b-ITU-T G.959.1] Recommendation ITU-T G.959.1 (2012), *Optical transport network physical layer interfaces*.

[b-ITU-T G.973] Recommendation ITU-T G.973 (2010), *Characteristics of repeaterless optical fibre submarine cable systems*.

[b-ITU-T G.973.1] Recommendation ITU-T G.973.1 (2009), *Longitudinally compatible DWDM applications for repeaterless optical fibre submarine cable systems*.

[b-ITU-T G.973.2] Recommendation ITU-T G.973.2 (2011), *Multichannel DWDM applications with single channel optical interfaces for repeaterless optical fibre submarine cable systems.*

[b-ITU-T G.977] Recommendation ITU-T G.977 (2011), *Characteristics of optically amplified optical fibre submarine cable systems.*

[b-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.*

[b-IEC/TR 61282-3] IEC/TR 61282-3 (2006), *Fibre optic communication system design guides – Part 3: Calculation of link 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, 2013