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Transmission media characteristics – Optical fibre cables

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

ITU-T Recommendation G.654



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## ITU-T Recommendation G.654

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

#### Summary

This Recommendation 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 the Recommendation that was first created in 1988.

This revision changes the notation of PMD in order to make it consistent with that of ITU-T Rec. G.652. This revision is intended to maintain the continuing commercial success of this fibre in the evolving world of high-performance optical transmission systems.

#### Source

ITU-T Recommendation G.654 was approved on 14 December 2006 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

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See details page 14

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# ITU-T Recommendation G.654

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

### 1 Scope

This Recommendation describes a single-mode optical fibre which has the zero-dispersion wavelength around 1300 nm wavelength which is loss-minimized and cut-off shifted single-mode optical fibre 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, is intended to support the following related system Recommendations:

- ITU-T Rec. G.957;
- ITU-T Rec. G.691;
- ITU-T Rec. G.692;
- ITU-T Rec. G.959.1;
- ITU-T Rec. G.973;
- ITU-T Rec. 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 Recs G.650.1 and G.650.2. The characteristic 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 Recommendation G.650.1 (2004), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable.*
- ITU-T Recommendation G.650.2 (2005), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable.*

## **2.2 Informative references**

- ITU-T Recommendation G.663 (2000), *Application related aspects of optical amplifier devices and subsystems.*
- ITU-T Recommendation G.691 (2006), *Optical interfaces for single-channel STM-64 and other SDH systems with optical amplifiers.*
- ITU-T Recommendation G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers.*
- ITU-T Recommendation G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.*
- ITU-T Recommendation G.959.1 (2006), *Optical transport network physical layer interfaces.*
- ITU-T Recommendation G.973 (2003), *Characteristics of repeaterless optical fibre submarine cable systems.*
- ITU-T Recommendation G.977 (2006), *Characteristics of optically amplified optical fibre submarine cable systems.*

## **3 Terms and definitions**

For the purposes of this Recommendation, the definitions given in ITU-T Recs. G.650.1 and 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**

This Recommendation uses the following abbreviations:

CSF	Cut-off Shifted Fibre
DGD	Differential Group Delay
DWDM	Dense Wavelength Division Multiplexing
MFD	Mode Field Diameter
PMD	Polarization Mode Dispersion
PMD <sub>Q</sub>	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 table 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 of mode field diameter (MFD) shall be specified at 1550 nm. The nominal values of MFD that is specified shall be within the range found in clause 7. The specified tolerance of 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  $\mu\text{m}$ .

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

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

- a) Cable cut-off wavelength,  $\lambda_{cc}$ .
- b) Fibre cut-off wavelength,  $\lambda_c$ .
- c) Jumper cable cut-off wavelength,  $\lambda_{cj}$ .

NOTE 1 – For some specific submarine cable applications, other cable cut-off wavelength values may be required.

The correlation of the measured values of  $\lambda_c$ ,  $\lambda_{cc}$ , and  $\lambda_{cj}$  depends on the specific fibre and cable design and the test conditions. While in general,  $\lambda_{cc} < \lambda_{cj} < \lambda_c$ , 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  $\lambda_c$  to be less than 1600 nm: when a lower limit is appropriate,  $\lambda_c$  should be greater than 1350 nm;
- 2) recommending the maximum value of  $\lambda_{cc}$  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  $\lambda_{cc}$  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  $\lambda_{cc}$  (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  $\lambda_{cc}$  RTM), then the specification of  $\lambda_c$  is appropriate.

When the user chooses to specify  $\lambda_{cc}$  as in 2, it should be understood that  $\lambda_c$  may exceed 1600 nm.

When the user chooses to specify  $\lambda_c$  as in 1, then  $\lambda_{cc}$  need not be specified.

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

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

The cable cut-off wavelength,  $\lambda_{cc}$  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 to implement, 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,  $\sigma_p$ , shall not be less than the minimum specified in clause 7.

NOTE – The definitions of the mechanical parameters are contained in clauses 3.2/G.650.1 and 5.6/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 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/G.650.1. (See 5.5/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 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 wavelengths, based on measurements at a few (3 to 4) predictor wavelengths. This procedure is described in 5.4.4/G.650.1 and an example for G.652 fibre is given in Appendix III/G.650.1.

NOTE 3 – For applications of submarine systems with remotely pumped optical amplifier described in ITU-T Rec. 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 IEC 61282-3, and are summarized in Appendix IV/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 Rec. 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 Table 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, 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 ITU-T Recs G.691, G.692, G.957 and G.977 in the 1550 nm wavelength region.

Table 2, G.654.B Attributes, is suitable for the system described in ITU-T Recs G.691, G.692, G.957, G.977 and 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 ITU-T Rec. G.973 and submarine systems with optical amplifiers described in ITU-T Rec. G.977.

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

**Table 1/G.654 – G.654.A**

<b>Fibre attributes</b>		
<b>Attribute</b>	<b>Detail</b>	<b>Value</b>
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-10.5 $\mu\text{m}$
	Tolerance	$\pm 0.7 \mu\text{m}$
Cladding Diameter	Nominal	125 $\mu\text{m}$
	Tolerance	$\pm 1 \mu\text{m}$
Core concentricity error	Maximum	0.8 $\mu\text{m}$
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	$D_{1550\text{max}}$	20 ps/nm $\cdot$ km
	$S_{1550\text{max}}$	0.070 ps/nm <sup>2</sup> $\cdot$ km
Uncabled fibre PMD coefficient	Maximum	see Note
<b>Cable attributes</b>		
Attenuation coefficient	Maximum at 1550 nm	0.22 dB/km
PMD coefficient	M	20 cables
	Q	0.01%
	Maximum PMD <sub>Q</sub>	0.5 ps/ $\sqrt{\text{km}}$
NOTE – According to 6.2, a maximum PMD <sub>Q</sub> value on uncabled fibre is specified in order to support the primary requirement on cable PMD <sub>Q</sub> .		

**Table 2/G.654 – G.654.B**

<b>Fibre attributes</b>		
<b>Attribute</b>	<b>Detail</b>	<b>Value</b>
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-13.0 $\mu\text{m}$
	Tolerance	$\pm 0.7 \mu\text{m}$
Cladding Diameter	Nominal	125 $\mu\text{m}$
	Tolerance	$\pm 1 \mu\text{m}$
Core concentricity error	Maximum	0.8 $\mu\text{m}$
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	$D_{1550\text{max}}$	22 ps/nm $\cdot$ km
	$S_{1550\text{max}}$	0.070 ps/nm <sup>2</sup> $\cdot$ km
Uncabled fibre PMD coefficient	Maximum	see Note
<b>Cable attributes</b>		
Attenuation coefficient	Maximum at 1550 nm	0.22 dB/km
PMD coefficient	M	20 cables
	Q	0.01%
	Maximum PMD <sub>Q</sub>	0.20 ps/ $\sqrt{\text{km}}$
NOTE – According to 6.2, a maximum PMD <sub>Q</sub> value on uncabled fibre is specified in order to support the primary requirement on cable PMD <sub>Q</sub> .		

**Table 3/G.654 – G.654.C**

<b>Fibre attributes</b>		
<b>Attribute</b>	<b>Detail</b>	<b>Value</b>
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	9.5-10.5 $\mu\text{m}$
	Tolerance	$\pm 0.7 \mu\text{m}$
Cladding Diameter	Nominal	125 $\mu\text{m}$
	Tolerance	$\pm 1 \mu\text{m}$
Core concentricity error	Maximum	0.8 $\mu\text{m}$
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	$D_{1550\text{max}}$	20 ps/nm $\cdot$ km
	$S_{1550\text{max}}$	0.070 ps/nm <sup>2</sup> $\cdot$ km
Uncabled fibre PMD coefficient	Maximum	see Note
<b>Cable attributes</b>		
Attenuation coefficient	Maximum at 1550 nm	0.22 dB/km
PMD coefficient	M	20 cables
	Q	0.01%
	Maximum PMD <sub>Q</sub>	0.20 ps/ $\sqrt{\text{km}}$
NOTE – According to 6.2, a maximum PMD <sub>Q</sub> value on uncabled fibre is specified in order to support the primary requirement on cable PMD <sub>Q</sub> .		

## Appendix I

### Information for link attributes and system design

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 link attribute values estimation, typical values of optical fibre links are provided in 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:

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

where:

- $\alpha$  = typical attenuation coefficient of fibre cables in a link
- $\alpha_s$  = mean splice loss
- $x$  = number of splices in a link
- $\alpha_c$  = mean loss of line connectors
- $y$  = number of line connectors in a link (if provided)
- $L$  = length of a link

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 I.5 are for the attenuation coefficient of 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 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 I.5. These values, together with link length,  $L_{Link}$ , can be used to calculate the typical chromatic dispersion for use in optical link design.

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

### 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 IEC 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 IEC 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 Recs G.663 and 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 requirement for other optical elements that may be in the link.

**Table I.1/G.654 – Representative value of concatenated optical fibre link**

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

**Table I.2/G.654 – Differential group delay**

<b>Maximum PMD<sub>Q</sub> (ps/√km)</b>	<b>Link length (km)</b>	<b>Implied fibre induced maximum DGD (ps)</b>	<b>Channel bit rates</b>
No specification			Up to 2.5 Gbit/s
0.5	400	25.0	10 Gbit/s
	40	19.0 (see 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 it set to 25 km, the probability level is  $6.5 \times 10^{-8}$ .

## BIBLIOGRAPHY

- [1] IEC/TR 61282-3 (2006), *Fibre optic communication system design guides – Part 3: Calculation of polarization mode dispersion.*

## ITU-T Rec. G.654 history

- 1988 ITU-T Rec. G.654, *Characteristics of a 1550 nm wavelength loss-minimized single-mode optical fibre cable* was created by ITU-T Study Group 15 (1985-1988).
- 2000 ITU-T Rec. G.654 was revised by ITU-T Study Group 15 (1997-2000) and was approved as the 4th edition by the World Telecommunication Standardization Assembly (Montreal, 27 September-6 October 2000). This revision changed the Recommendation structure, in accordance with other fibre Recommendations such as ITU-T Recs G.652, G.653 and G.655.
- 2002 ITU-T Rec. G.654 was revised by ITU-T Study Group 15 (2001-2004) and was approved as the 5th edition under the AAP procedure on 29 June 2002. This revision added a new fibre category with changed fibre attributes of mode field diameter and chromatic dispersion coefficient as G.654.B. According to the agreement on spectral bands, description of L band upper limit was changed from 16xx nm to 1625 nm. The terms of base subcategory and subcategory are revised to base category and category, respectively.
- 2004 ITU-T Rec. G.654 was revised by ITU-T Study Group 15 (2001-2004) and was approved as the sixth version, under AAP procedure on 13 June 2004. This revision reduced PMD<sub>Q</sub> limit (compared to 0.5 ps/√km) in G.654.B and added a new category which has reduced PMD<sub>Q</sub> limit. Tolerance of mode field diameter in G.654.B was reduced to ±0.7 μm. 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.



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