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ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.656

(12/2006)

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

Transmission media characteristics – Optical fibre cables

Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport

ITU-T Recommendation G.656

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ITU-T Recommendation G.656

Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport

Summary

This Recommendation describes the geometrical, mechanical, and transmission attributes of a single-mode optical fibre which has the positive value of the chromatic dispersion coefficient greater than some non-zero value throughout the wavelength range of anticipated use 1460-1625 nm. This dispersion reduces the growth of non-linear effects which are particularly deleterious in dense wavelength division multiplexing systems.

This fibre can be used for both CWDM and DWDM systems throughout the wavelength region between 1460 and 1625 nm.

This revision adds a new category of the fibre. This category limits the chromatic dispersion coefficient by a pair of bounding curves vs wavelength for the range of 1460 nm to 1625 nm, which provides information to support CWDM and DWDM applications.

Source

ITU-T Recommendation G.656 was approved on 14 December 2006 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

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ITU-T Recommendation G.656

Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport

1 Scope

This Recommendation describes a single-mode fibre with chromatic dispersion that is greater than some non-zero value throughout the wavelength range of 1460-1625 nm. This dispersion reduces the growth of non-linear effects that can be particularly deleterious in Dense Wavelength Division Multiplexing (DWDM) systems. This fibre uses non-zero dispersion to reduce four-wave mixing and cross-phase modulation over a wider wavelength range than the fibre described in ITU-T Rec. G.655. Extensions are possible, in the future, to wavelengths beyond the 1460-1625 nm region (to be determined). 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 fibre can be utilized for CWDM and DWDM systems throughout the extended wavelength transmission region between 1460 and 1625 nm.

This Recommendation, and the category found in the table of clause 7, is intended to support the following related system Recommendations:

- ITU-T Rec. G.691;
- ITU-T Rec. G.692;
- ITU-T Rec. G.693;
- ITU-T Rec. G.695;
- ITU-T Rec. G.959.1;
- ITU-T Rec. G.698.1;
- ITU-T Rec. G.696.1.

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 [G.650.1] and [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.

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

[G.650.2] 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

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

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

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

[G.693] ITU-T Recommendation G.693 (2006), *Optical interfaces for intra-office systems*.

[G.694.1] ITU-T Recommendation G.694.1 (2002), *Spectral grids for WDM applications: DWDM frequency grid*.

[G.694.2] ITU-T Recommendation G.694.2 (2003), *Spectral grids for WDM applications: CWDM wavelength grid*.

[G.695] ITU-T Recommendation G.695 (2006), *Optical interfaces for coarse wavelength division multiplexing applications*.

[G.696.1] ITU-T Recommendation G.696.1 (2005), *Longitudinally compatible intra-domain DWDM applications.*

[G.698.1] ITU-T Recommendation G.698.1 (2006), *Multichannel DWDM applications with single-channel optical interfaces*.

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

[G.959.1] ITU-T Recommendation G.959.1 (2006), *Optical transport network physical layer interfaces*.

3 Terms and definitions

For the purposes of this Recommendation, the definitions given in [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:

A_{eff} Effective Area

CWDM Coarse Wavelength Division Multiplexing

DGD Differential Group Delay

DWDM Dense Wavelength Division Multiplexing

PMD Polarization Mode Dispersion

PMD_Q Statistical parameter for PMD link

SDH Synchronous Digital Hierarchy

TBD To be determined

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 shall be specified at 1550 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

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

a) Cable cut-off wavelength, λ_{cc}.

b) Fibre cut-off wavelength, λ_c.

c) Jumper cable cut-off wavelength, λ_{cj}.

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, λ_{cc}, and λ_{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 may be performed by recommending the maximum cable cut-off wavelength λ_{cc} of a cabled single-mode fibre to be 1450 nm, or for typical jumpers by recommending a maximum jumper cable cut-off to be 1450 nm, or for worst-case length and bends, by recommending a maximum fibre cut-off wavelength to be 1440 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 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, 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 [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.

5.10 Chromatic dispersion coefficient

The chromatic dispersion coefficient, D, is specified with a wavelength range. [G.650.1] provides measurement methods. There are two methods for specifying the limits, the original method, which is a box-like specification, and a newer method, in which the dispersion coefficient values are bound both by a pair of curves and by the value at 1550 nm.

The measured group delay or chromatic dispersion per unit fibre length versus wavelength shall be fitted by either the 5-term Sellmeier equation or the 4th order polynomial equation as defined in Annex A of [G.650.1]. (See 5.5 of [G.650.1] for guidance on the interpolation of dispersion values to unmeasured wavelengths.)

The fitted equation should not be used to predict chromatic dispersion at wavelength outside the range used for the fit.

For each wavelength, λ, the chromatic dispersion coefficient, $D(\lambda)$, shall be restricted to a range of values associated with two limiting curves, $D_{min}(\lambda)$ and $D_{max}(\lambda)$, for one or more specified wavelength ranges defined in terms of λ_{min} and λ_{max}.

An example set of curves is represented symbolically as a pair of straight lines:

$$D_{min}(\lambda) = a_{min} + b_{min}\,(\lambda - 1460) \qquad [\text{ps/nm} \cdot \text{km}]$$

$$D_{max}(\lambda) = a_{max} + b_{max}\,(\lambda - 1460) \qquad [\text{ps/nm} \cdot \text{km}]$$

$$D_{min}(\lambda) \le D(\lambda) \le D_{max}(\lambda) \qquad [\text{ps/nm} \cdot \text{km}]$$

The bounding curves may vary from one wavelength range to another.

NOTE 1 – Chromatic dispersion uniformity should be consistent with the functioning of the system.

NOTE 2 – The requirements on chromatic dispersion follow from WDM system design, which must balance first order chromatic dispersion with various non-linear effects, such as four-wave mixing, cross-phase modulation, modulation instability, stimulated Brillouin scattering, and soliton formation (see [G.663]). The effect of chromatic dispersion is interactive with the fibre non-linearity, described by the non-linear coefficient.

NOTE 3 – 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 1460 nm, 1550 nm and 1625 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 5.4.4 of [G.650.1] and an example is given in Appendix III of [G.650.1].

6.2 Polarization mode dispersion (PMD) coefficient

When required, 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/TR 61282-3], and are summarized in Appendix IV of [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. [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 [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 Table of recommended values

Table 1 summarizes the recommended values for a category of fibres that satisfy the objectives of this Recommendation.

Table 1, "G.656 attributes", defines the chromatic dispersion coefficient requirements as a pair of bounding curves vs wavelength for wavelengths from 1460 nm to 1625 nm. This is also intended to support optical interface Recommendations such as [G.691], [G.692], [G.959.1] and [G.693].

For DWDM systems, channel spacings defined in [G.694.1] are supported, depending on the minimum dispersion that is selected. The PMD requirement allows operation of STM-64 systems to lengths of up to 2000 km, depending on other system elements.

Table 1/G.656 – G.656 attributes

Fibre attributes		
Attribute	**Detail**	**Value**
Mode field diameter	Wavelength	1550 nm
	Range of nominal values	7.0-11.0 µm
	Tolerance	±0.7 µm
Cladding diameter	Nominal	125.0 µm
	Tolerance	±1 µm
Core concentricity error	Maximum	0.8 µm
Cladding non-circularity	Maximum	2.0%
Cable cut-off wavelength	Maximum	1450 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 (ps/nm · km)	$D_{min}(\lambda)$: 1460-1550 nm	$\frac{2.60}{90}(\lambda - 1460) + 1.00$
	$D_{min}(\lambda)$: 1550-1625 nm	$\frac{0.98}{75}(\lambda - 1550) + 3.60$
	$D_{max}(\lambda)$: 1460-1550 nm	$\frac{4.68}{90}(\lambda - 1460) + 4.60$
	$D_{max}(\lambda)$: 1550-1625 nm	$\frac{4.72}{75}(\lambda - 1550) + 9.28$
Uncabled fibre PMD coefficient	Maximum	(Note 2)
Cable attributes		
Attribute	**Detail**	**Value**
Attenuation coefficient	Maximum at 1460 nm	0.4 dB/km
	Maximum at 1550 nm	0.35 dB/km
	Maximum at 1625 nm	0.4 dB/km
PMD coefficient	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/√km
NOTE 1 – If a Raman pump is used outside this wavelength region, fibre properties must be suitable for accommodating this pump.		
NOTE 2 – According to 6.2, a maximum PMD_Q value on uncabled fibre is specified in order to support the primary requirement on cabled PMD_Q.		

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 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

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 = 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 clause 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, chromatic dispersion accommodation is sometimes employed. In this case, the average link chromatic dispersion is used for design.

For simplified estimation, the relationship is described in terms of the typical chromatic dispersion coefficient and chromatic 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 vary with the specific implementation. These values, together with link length, L_{Link}, can be used to calculate the typical dispersion for use in optical link design.

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

For estimation with improved accuracy, the relationship is described in terms of the typical chromatic dispersion coefficients at 1460, 1550 and 1625 nm, and chromatic dispersion slope coefficient at 1550 nm. These values, together with link length, L_{Link}, can be used to calculate the typical dispersion for use in optical link design.

See [G.Sup.39] for additional information on system design and the statistics of chromatic dispersion.

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/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 [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 [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.656 – Representative value of concatenated optical fibre link

Attribute	Wavelength region	Typical link value (Note)
Attenuation coefficient	1460 nm-1530 nm	0.35 dB/km
	1530 nm-1565 nm	0.275 dB/km
	1565 nm-1625 nm	0.35 dB/km
Typical dispersion coefficient	D_{1460} D_{1550} D_{1625} S_{1550}	TBD TBD TBD TBD
NOTE – Typical link value corresponds to the link attenuation coefficient used in [G.957] and [G.691].		

Table I.2/G.656 – 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 it set to 25 km, the probability level is 6.5×10^{-8}.

I.6 Chromatic dispersion coefficient limits

The equations bounding the chromatic dispersion coefficient vs wavelength are based on survey for the G.656 fibres. There were nine products from seven vendors. Each provided average and standard deviation as a function of wavelength for wavelengths from 1460 nm to 1625 nm in 5 nm increments. For wavelength and vendor, the average plus and minus three standard deviation was calculated. Then the minimum and maximum across vendors was calculated. These results were fitted with a line spline using a breakpoint at 1550 nm to minimize the sum of absolute values of the difference while maintaining the principle of including all the data within the envelope.

The result is shown in Figure I.1. The dashed lines are the limits from clause 7. The rest of the data represent the survey results.

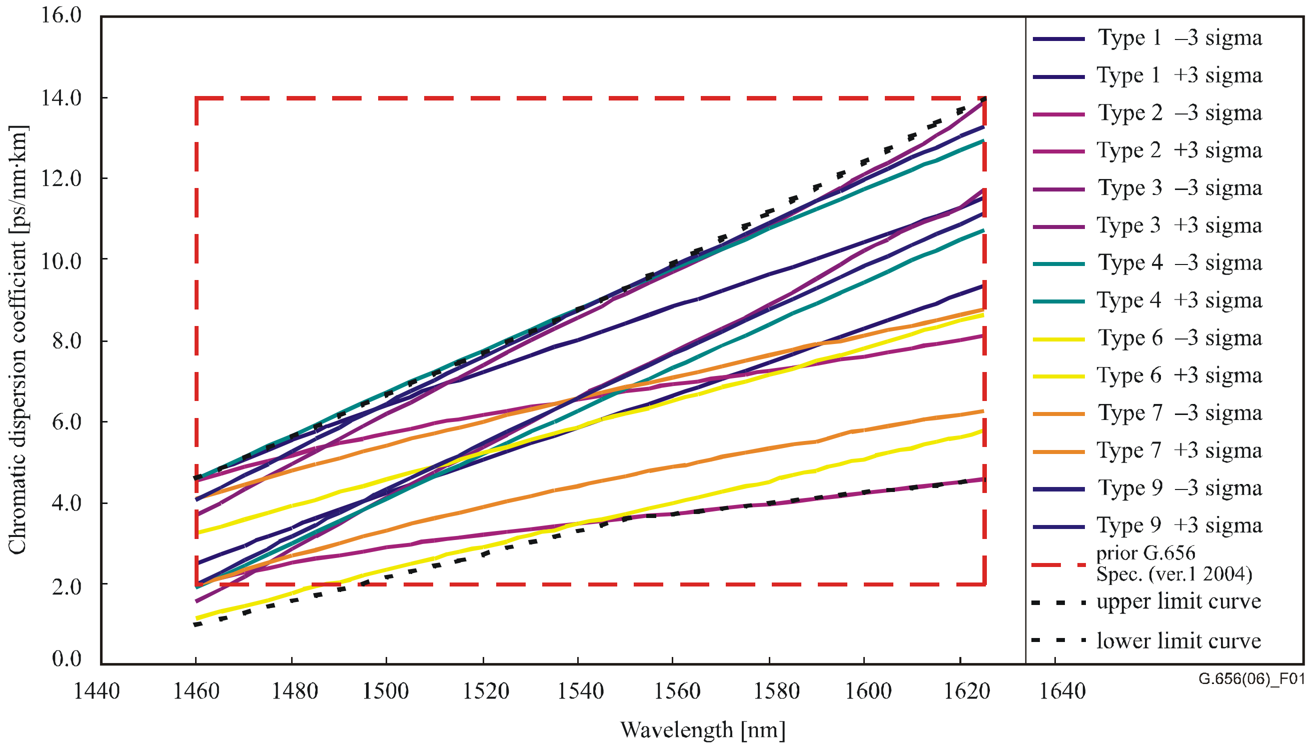

Figure I.1/G.656 – Table 1 fibre dispersion

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[G.Sup.39] ITU-T G-series Recommendations – Supplement 39 (2006), *Optical system design and engineering considerations*.

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

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Printed in Switzerland
Geneva, 2007