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

Transmission media and optical systems characteristics – Optical fibre cables

Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network

Recommendation ITU-T G.657

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Recommendation ITU-T G.657

Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network

Summary

Worldwide, technologies for broadband access networks are advancing rapidly. Among these, the technology applying single-mode fibre provides for a high-capacity transmission medium which can answer the growing demand for broadband services.

The experience with the installation and operation of single-mode fibre and cable-based networks is huge, and Recommendation ITU-T G.652 which describes its characteristics has been adapted to this experience. Nevertheless, the specific use in an optical access network puts different demands on the fibre and cable which impacts its optimal performance characteristics. Differences with respect to the use in the general transport network are mainly due to the high density network of distribution and drop cables in the access network. The limited space and the many manipulations ask for operator-friendly fibre performance and low bending sensitivity. In addition, the cabling in the crowded telecom offices where space is a limiting factor has to be improved accordingly.

It is the aim of Recommendation ITU-T G.657 to support this optimization by recommending strongly improved bending performance compared with the existing ITU-T G.652 single-mode fibre and cables. This is done by means of two categories of single-mode fibres, one of which, category A, is fully compliant with the ITU-T G.652 single-mode fibres and can be deployed throughout the access network. The other, category B, is not necessarily compliant with Recommendation ITU-T G.652 but is capable of low values of macrobending losses at very low bend radii and is intended for use inside buildings or near buildings (e.g., outside building riser cabling). These category B fibres are system compatible with ITU-T G.657.A (and ITU-T G.652.D) fibres in access networks.

This third edition of Recommendation ITU-T G.657 includes several modifications in particular concerning category B fibres. Also the new Appendix I (agreed in 2010 and published as Amendment 1 (06/2010)) has been introduced with revisions.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.657	2006-12-14	15
2.0	ITU-T G.657	2009-11-13	15
2.1	ITU-T G.657 (2009) Amd. 1	2010-06-11	15
3.0	ITU-T G.657	2012-10-29	15

FOREWORD

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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.

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As of the date of approval of this Recommendation, ITU had not 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/.

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Introduction

Worldwide, technologies for broadband access networks are advancing rapidly. Among these, the technology applying single-mode fibre provides for a high-capacity transmission medium which can answer the growing demand for broadband services.

The experience with the installation and operation of single-mode fibre and cable-based networks is huge, and Recommendation ITU-T G.652 which describes its characteristics has been adapted to this experience. Nevertheless, the specific use in an optical access network puts different demands on the fibre and cable. Due to dense distribution and drop-cable network, limited space and the many manipulations in this part of the network, fibre and cable requirements may be optimized differently from their use in a general transport network. It is the aim of this Recommendation to support this optimization by recommending different attribute values for the existing ITU-T G.652 single-mode fibre and cables and by recommending other categories of single-mode fibre types.

As for the network structures in which the single-mode optical fibre cable is used, users are referred to the extensive information that is available in the references listed in the bibliography.

Recommendation ITU-T G.657

Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network

1 Scope

This Recommendation describes two categories of single-mode optical fibre cable which are suitable for use in access networks, including inside buildings at the end of these networks. Both categories A and B contain two subcategories which differ in macrobending loss.

Category A fibres are optimized for reduced macrobending loss and tighter dimensional specifications compared to ITU-T G.652.D fibres and can be deployed throughout the access network. These fibres are suitable to be used in the O, E, S, C and L-band (i.e., throughout the 1260 to 1625 nm range). Fibres and requirements in this category are a subset of ITU-T G.652.D and therefore compliant[1] with ITU-T G.652.D fibres and have the same transmission and interconnection properties.

Subcategory ITU-T G.657.A1 fibres are appropriate for a minimum design radius of 10 mm.

Subcategory ITU-T G.657.A2 fibres are appropriate for a minimum design radius of 7.5 mm.

Category B fibres are optimized for further reduced macrobending loss and therefore are capable of being used at very low values of bend radius. These fibres are for short reach distances (less than 1000 m) at the end of access networks, in particular inside buildings or near buildings (e.g., outside building riser cabling). The application length of ITU-T G.657.B fibre depends on the deployment strategy of each network operator. These fibres are suitable for use in the O, E, S, C and L-band (i.e., throughout the 1260 to 1625 nm range). Category B fibres are not necessarily compliant with ITU-T G.652.D in terms of chromatic dispersion coefficient and PMD specifications. These fibres however, are system compatible[2] with ITU-T G.657.A (and ITU-T G.652.D) fibres in access networks.

Subcategory ITU-T G.657.B2 fibres are appropriate for a minimum design radius of 7.5 mm.

Subcategory ITU-T G.657.B3 fibres are appropriate for a minimum design radius of 5 mm.

The meaning of the terms used in this Recommendation and the guidelines to be followed in the measurement to verify the various characteristics are given in [ITU-T G.650.1] and [ITU-T G.650.2]. The characteristics of these fibre categories, including the definitions of the relevant parameters, their test methods and relevant values, will be refined as studies and experience progress.

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[1] Compliance here means adherence to the referenced Recommendation (ITU-T G.652, category D) meeting or exceeding the values of the specified attributes.

[2] Compatibility means here that the product in this category will introduce negligible system impairment or deployment issues but may not be compliant to the referenced Recommendation (ITU-T G.652, category D).

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*.

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

[ITU-T L.59] Recommendation ITU-T L.59 (2008), *Optical fibre cables for indoor applications*.

[IEC 60793-1-47] IEC 60793-1-47 (2009), *Optical fibres – Part 1-47: Measurement methods and test procedures – Macrobending loss*.

3 Terms and definitions

For the purposes of this Recommendation, the definitions and the guidelines to be followed in the measurement to verify the various characteristics are given in [ITU-T G.650.1] and [ITU-T G.650.2]. Values shall be rounded to the number of digits given in the tables of recommended values before conformance is evaluated.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

DGD Differential Group Delay

MDU Multi-dwelling Unit

PMD Polarization Mode Dispersion

5 Fibre attributes

The optical fibre characteristics that provide the essential design framework for fibre manufacture, system design and use in outside plant networks are recommended in [ITU-T G.652]. In this clause, the emphasis is on attributes that optimize the fibre and cable for its use in broadband optical access networks, especially its improved macrobending behaviour which supports small volume fibre managements systems and low radius mounting in telecom offices and customer premises in apartment buildings and single dwelling houses.

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

5.1 Mode field diameter

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

5.2 Cladding diameter

The recommended nominal value of the cladding diameter is 125 µm. A tolerance is also specified and shall not exceed the value in clause 7. The cladding deviation from the 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.

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

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

5.6 Macrobending loss

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

The actual low radius exposure of the fibre is on relatively short lengths only. As the typical choice of the bending radius and the length of the bent fibre may vary depending upon the design of the fibre management system and the installation practice, a specification at one single bending radius is no longer sufficient. Although modelling results on various fibre types have been published, no generally applicable bending loss model is available to describe the loss versus bend radius behaviour. For this reason, the recommended maximum macrobending loss is specified at different bend radii in the tables in clause 7.

While a baseline on macrobending performance can be established for uncabled fibres, the actual design and materials of cable construction can contribute to the resulting performance in the field. Macrobending loss in cabled fibre may differ from that observed in uncabled fibre measurements because of the bend-limiting effect of the cable structure on the fibre bend. The study into the macrobending effects of cabling is ongoing, which may result in the need for any additional cable specifications or parameters in the future.

Macrobending loss of installed cabled fibres in in-building networks may depend on the installation technique used. According to [ITU-T L.59], any fibre bend radius remaining after cable installation is recommended to be large enough to limit the macrobending loss and long-term strain that would reduce the lifetime of the fibre. For that purpose, certain demanding installation techniques are not recommended (e.g., stapling indoor cable using flat staples).

As optical bending losses increase with wavelengths, a loss specification at the highest envisioned wavelength, i.e., either 1550 nm or 1625 nm, suffices. If required, a customer and supplier can agree on a lower or higher specification wavelength.

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

NOTE 2 – In case another number of turns than the recommended number of turns is chosen to be implemented, it is assumed that the maximum loss that occurs in that deployment is proportional to the specified number of turns.

NOTE 3 – In the event that routine tests are required, deviating loop diameters 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.

NOTE 4 – In general, the macrobending loss is influenced by the choice of the values for other fibre attributes as the mode field diameter, chromatic dispersion coefficient and the fibre cut-off wavelength. Optimization with respect to macrobending losses usually involves a trade-off between the values of these fibre attributes.

NOTE 5 – A mandrel winding method (method A), which is described in [IEC 60793-1-47], can be utilized as a measurement method for macrobending loss by substituting the bending radius and number of turns specified in Tables 7-1 and 7-2.

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 Proof stress level

The specified proof stress, σ_p, shall not be less than the minimum specified in clause 7.

NOTE 1 – The definitions of the mechanical parameters are contained in clauses 3.2 and 5.6 of [ITU-T G.650.1].

NOTE 2 – See also Appendix I on this subject.

NOTE 3 – The failure probability for fibre under 30 mm of radius bend as described in [ITU-T G.652] increases with decreasing bend radius. The mechanical reliability of optical fibre in this application space is a function of the characteristics of the cable structure, the installation techniques and deployment conditions. Care should be given that, for some installations, additional constraints on installation, such as higher fibre proof test levels or other factors may be required to ensure the full expected life.

NOTE 4 – It is recommended that the proof stress level applied to fibre and the required reliability level during its lifetime are agreed between the supplier and customer.

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

This attribute is usually less relevant for applications in the access network. For more details, see [ITU-T G.652].

5.10 Chromatic dispersion coefficient

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

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

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

The chromatic dispersion coefficient, D, is specified by putting limits on the parameters of a chromatic dispersion curve that is a function of wavelength in the 1310 nm region. The chromatic dispersion coefficient limit for any wavelength, λ, is calculated with the minimum zero-dispersion wavelength, λ_{0min}, the maximum zero-dispersion wavelength, λ_{0max}, and the maximum zero-dispersion slope coefficient, S_{0max}, according to:

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

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

NOTE 1 – It is not necessary to measure the chromatic dispersion coefficient of single-mode fibre on a routine basis.

NOTE 2 – The chromatic dispersion for category B fibres is generally not critical for the application of this category of fibres, and therefore its value can be more relaxed compared to that of category A fibres.

6 Cable attributes

Since the geometrical and optical characteristics of fibres given in clause 5 are barely affected by the cabling process, this clause gives recommendations mainly relevant to transmission characteristics of cabled factory lengths. Environmental and test conditions are paramount and are described in the guidelines for test methods.

6.1 Attenuation coefficient

The attenuation coefficient is specified with a maximum value at one or more wavelengths in both the 1310 nm and 1550 nm regions. The optical fibre cable attenuation coefficient values shall not exceed the values found in clause 7.

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

6.2 Polarization mode dispersion coefficient

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 [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 fibres are necessary, but not sufficient to ensure the cabled fibre specification. The maximum link design value specified on uncabled fibres shall be less than or equal to that specified for the cabled fibres. The ratio of PMD values for uncabled fibres to cabled fibres depends on the details of the cable construction and processing, as well as on the mode coupling condition of the uncabled fibres. [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 the 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 of [ITU-T G.652].

NOTE 1 – A 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, a PMD_Q specification would not be applied to systems recommended in this Recommendation.

NOTE 2 – A 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.

NOTE 4 – The PMD coefficient for category B fibres is generally not critical for the application of this category of fibres and therefore its value can be more relaxed compared to that of category A fibres.

7 Tables of recommended values

The following tables summarize the recommended values for the subcategories of fibres in categories A and B that satisfy the objectives of this Recommendation.

Table 7-1, category A attributes, contains the recommended attributes and values needed to support optimized access network installation with respect to macrobending loss, while the recommended values for the other attributes still remain within the range recommended in ITU-T G.652.D.

This category has two subcategories with different macrobending requirements: ITU-T G.657.A1 fibre and ITU-T G.657.A2 fibre.

Table 7-2, category B attributes, contains the recommended attributes and values needed to support optimized access network installation with very small bending radii applied in fibre management systems and mainly utilized at the end of access networks in particular inside or near buildings. This category has two subcategories with different macrobending requirements: ITU-T G.657.B2 fibre and ITU-T G.657.B3 fibre.

Table 7-1 – ITU-T G.657 category A attributes

Fibre attributes						
Attribute	**Detail**	**Value**				
Mode field diameter	Wavelength	1310 nm				
	Range of nominal values	8.6-9.5 µm				
	Tolerance	±0.4 µm				
Cladding diameter	Nominal	125.0 µm				
	Tolerance	±0.7 µm				
Core concentricity error	Maximum	0.5 µm				
Cladding non-circularity	Maximum	1.0%				
Cable cut-off wavelength	Maximum	1260 nm				
Uncabled fibre macrobending loss (Notes 1, 2)		**ITU-T G.657.A1**		**ITU-T G.657.A2**		
	Radius (mm)	15	10	15	10	7.5
	Number of turns	10	1	10	1	1
	Max. at 1550 nm (dB)	0.25	0.75	0.03	0.1	0.5
	Max. at 1625 nm (dB)	1.0	1.5	0.1	0.2	1.0
Proof stress	Minimum	0.69 GPa				
Chromatic dispersion coefficient	λ_{0min}	1300 nm				
	λ_{0max}	1324 nm				
	S_{0max}	0.092 ps/nm^2 × km				
Cable attributes						
Attenuation coefficient (Note 3)	Maximum from 1310 nm to 1625 nm (Note 4)	0.40 dB/km				
	Maximum at 1383 nm ±3 nm (Note 5)	0.40 dB/km				
	Maximum at 1550 nm	0.30 dB/km				
PMD coefficient	M	20 cables				
	Q	0.01%				
	Maximum PMD_Q	0.20 ps/$\sqrt{km}$				

Table 7-1 – ITU-T G.657 category A attributes

NOTE 1 – ITU-T G.652 fibres deployed at a radius of 15 mm generally can have macrobending losses of several dB per 10 turns at 1625 nm.
NOTE 2 – The macrobending loss can be evaluated using a mandrel winding method (method A of [IEC 60793-1-47]), substituting the bending radius and the number of turns specified in this table.
NOTE 3 – Due to the lack of accuracy in measuring the attenuation coefficient of a short cable, its value can be taken from that of the original longer donor cable.
NOTE 4 – This wavelength region can be extended to 1260 nm by adding 0.07 dB/km induced Rayleigh scattering loss to the attenuation value at 1310 nm. In this case, the cable cut-off wavelength should not exceed 1250 nm.
NOTE 5 – The sampled attenuation average at this wavelength shall be less than or equal to the maximum value specified for the range, 1310 nm to 1625 nm, after hydrogen ageing according to [b-IEC 60793-2-50] regarding the B1.3 fibre category.

Table 7-2 – ITU-T G.657 category B attributes

Fibre attributes							
Attribute	**Detail**	**Value**					
Mode field diameter	Wavelength	1310 nm					
	Range of nominal values	8.6-9.5 µm					
	Tolerance	±0.4 µm					
Cladding diameter	Nominal	125.0 µm					
	Tolerance	±0.7 µm					
Core concentricity error	Maximum	0.5 µm					
Cladding non-circularity	Maximum	1.0%					
Cable cut-off wavelength	Maximum	1260 nm					
Uncabled fibre macrobending loss (Notes 1, 2)		**ITU-T G.657.B2**			**ITU-T G.657.B3**		
	Radius	15	10	7.5	10	7.5	5
	Number of turns	10	1	1	1	1	1
	Max. at 1550 nm (dB)	0.03	0.1	0.5	0.03	0.08	0.15
	Max. at 1625 nm (dB)	0.1	0.2	1.0	0.1	0.25	0.45
Proof stress	Minimum	0.69 GPa					
Chromatic dispersion coefficient	λ_{0min}	1250 nm					
	λ_{0max}	1350 nm					
	S_{0max}	0.11 ps/nm^2 × km					

Table 7-2 – ITU-T G.657 category B attributes

<table>
<tr><th colspan="3">Fibre attributes</th></tr>
<tr><th>Attribute</th><th>Detail</th><th>Value</th></tr>
<tr><th colspan="3">Cable attributes</th></tr>
<tr><td rowspan="3">Attenuation coefficient (Notes 3, 4)</td><td>Maximum from 1310 nm to 1625 nm (Note 5)</td><td>0.40 dB/km</td></tr>
<tr><td>Maximum at 1383 nm ± 3 nm (Note 6)</td><td>0.40 dB/km</td></tr>
<tr><td>Maximum at 1550 nm</td><td>0.30 dB/km</td></tr>
<tr><td rowspan="3">PMD coefficient</td><td>M</td><td>20 cables</td></tr>
<tr><td>Q</td><td>0.01%</td></tr>
<tr><td>Maximum PMD_Q</td><td>0.50 ps/$\sqrt{km}$</td></tr>
<tr><td colspan="3">NOTE 1 – The macrobending loss can be evaluated using a mandrel winding method (method A of [IEC 60793-1-47]), substituting the bending radius and the number of turns specified in this table.
NOTE 2 – While a baseline on macrobending performance can be established for uncabled fibres, the actual design and materials of cable construction can contribute to the resulting performance in the field. The study into the macrobending effects of cabling is ongoing, which may result in the need for any additional cable specifications or parameters in the future.
NOTE 3 – Operators may decide that compliance of ITU-T G.657.B category fibres to spectral attenuation characteristics of ITU-T G.657.A category fibres (or ITU-T G.652.D fibres) may not be necessary in their (particular) networks. For example small differences in the attenuation coefficient specification around 1380 nm (e.g., as can be found in Figure 10-4 of [b-ITU-T G. Sup39]) may not introduce system impairments or deployment issues (negligible effect on the total system performance) when applying these fibres at the end of the access network.
NOTE 4 – Due to the lack of accuracy in measuring the attenuation coefficient of a short cable, its value can be taken from that of the original longer donor cable.
NOTE 5 – This wavelength region can be extended to 1260 nm by adding 0.07 dB/km induced Rayleigh scattering loss to the attenuation value at 1310 nm. In this case, the cable cut-off wavelength should not exceed 1250 nm.
NOTE 6 – The sampled attenuation average at this wavelength shall be less than or equal to the maximum value specified for the range, 1310 nm to 1625 nm, after hydrogen ageing according to [b-IEC 60793-2-50] regarding the B1.3 fibre category.</td></tr>
</table>

To illustrate the different macrobending specifications of the various subcategories defined in this clause, the recommended values have been represented in Figures 7-1 and 7-2.

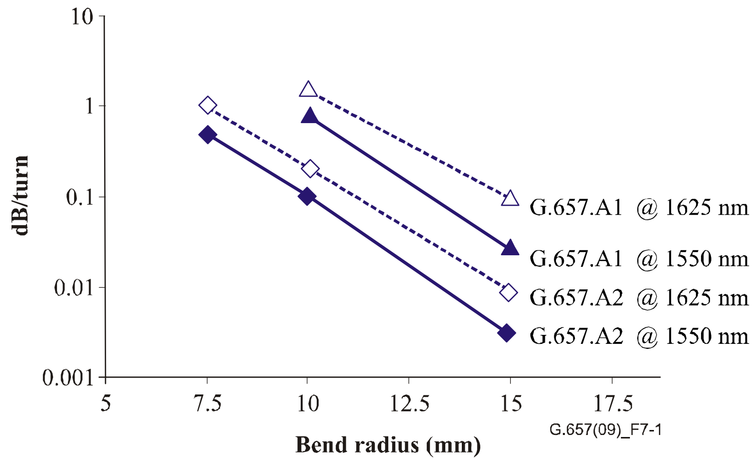

Figure 7-1 – Macrobending loss data from Table 7-1, category A

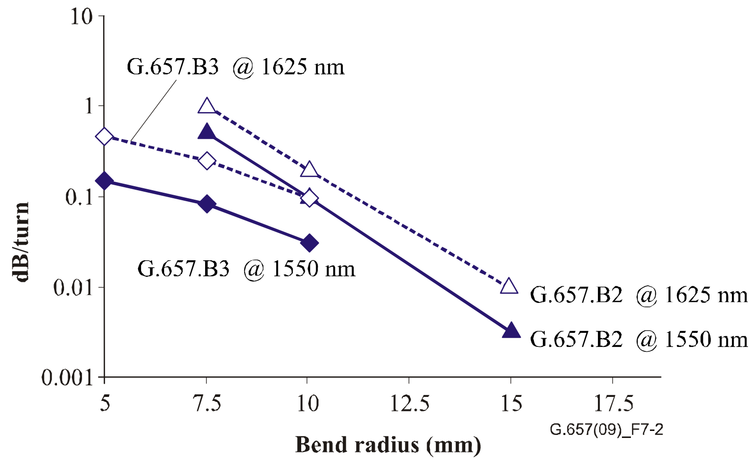

Figure 7-2 – Macrobending loss data from Table 7-2, category B

Appendix I

Lifetime expectation in case of small radius bending of single-mode fibre

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

NOTE – The reliability of a small bending radius is an ongoing topic under ITU-T and IEC study.

I.1 Introduction

Fibres under installation at a reduced bending radius including multi-dwelling units (MDUs) and closures may impose concerns with respect to fibre lifetime expectation. Important parameters that determine the expected lifetime are the extrinsic and intrinsic strength in a fibre. The required values of these parameters have to be offset against the accepted failure rate in the network, including the probability of other failures that may occur in the network during its operational lifetime (e.g., failures due to re-work or re-configuration in the link or due to other causes of cable or cabinet damage). In assessing the result of this, the major question is whether single-mode fibres as specified in this Recommendation fulfil the requirements for a sufficiently long life time expectation. More background is given to this question in this appendix.

I.2 General aspects of failure characteristics under small radius bending

In general, the estimation of mechanical failure probability or the lifetime of a bent fibre is calculated using the power law theory, as described in [b-IEC/TR 62048]. This IEC document describes two strength regions, intrinsic and extrinsic. The intrinsic strength region is length independent and dominant for very small radius bending (typically < 3 mm). In the extrinsic region, the mechanical failure probability of bent fibre increases proportionally with the fibre bending length, assuming the bending radius is constant. Transition between these regions is hard to determine and depends on many variables.

It is desirable that a bent region in a fibre link is as short as possible. An example image of failure probabilities with respect to the bending radius for 1% proof strain level is shown in Figure I.1. In this calculation, the minimum allowed dynamic stress corrosion susceptibility parameter $\boldsymbol{n_d}$ (dynamic fatigue parameter) of 18 and the mean number of break $\boldsymbol{Np}$ per length during a proof test of 0.01 km^{-1} are used as an example. In the figure, the values of mechanical failure probability within 20 years are plotted for a fibre with 1 turn bend length for each bend radius. From Figure I.1, two regions are observed: an intrinsic region and an extrinsic region tail. The failure probability in the extrinsic region is affected by the proof strain level. On the other hand, the failure probability in the intrinsic region depends on the intrinsic strength of the fibre, and is close to the theoretical strength of the glass.

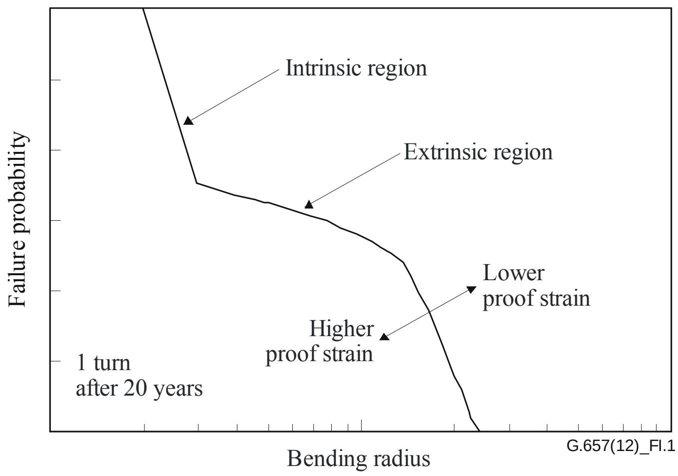

Figure I.1 – Example of calculated relationship between failure probability and bending radius for uniformly bent one-turn fibres after 20 years

Figure I.2 shows the dependence of time to failure on the bending radius. These experimental results show that very small radii cause reliability degradation.

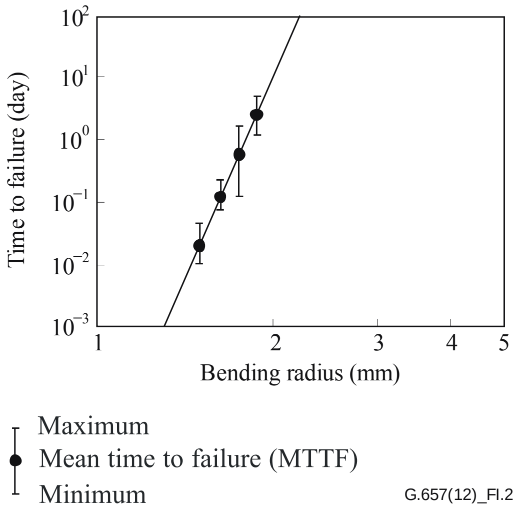

Figure I.2 – Example of time to failure under ultra-small bending radius

Fibre storage at a certain radius in fibre management systems and in closures needs evaluation with respect to fibre lifetime. For these applications, the loop size should be chosen to be large enough that fibres are in the extrinsic region.

In many applications, loose fibre storage loops have a 30 mm radius with approximately 1-10 m of fibre stored at a splice point. With improved macrobend fibre, as described in this Recommendation, the size of these loops could be reduced resulting in smaller enclosures but the amount of fibre required, 1-10 m, for splicing will likely remain the same. Smaller storage loops result in higher stress in the fibre and thus potentially induce an increased risk of mechanical failure. Table I.1 below uses the well-known power law theory of optical fibre reliability (see [b-IEC/TR 62048]) to show a 25-year failure probability as a function of loop size and fibre length, assuming a worst case value for the dynamic stress corrosion susceptibility parameter $\boldsymbol{n_d}$ = 18 as stated in [b-IEC 60793-2-50]. Typical values of $\boldsymbol{n_d}$, which are greater than the specified minimum, produce lower calculated failure probabilities than those in Table I.1. However, care should be taken that $\boldsymbol{n_d}$ values are obtained from the same test method. [b-IEC 60793-1-33].

Table I.1 – Twenty-five year failure probability for fibre stored in loose coils, proof tested at 1%

Length	15 mm radius	20 mm radius	25 mm radius	30 mm radius
1 m	5.0×10^{-6}	4.7×10^{-7}	7.9×10^{-9}	1.9×10^{-10}
10 m	5.0×10^{-5}	4.7×10^{-6}	7.9×10^{-8}	1.9×10^{-9}

One can see from this example that using smaller coils will increase the failure probability. Typical values of proof stress, which are greater than the specified minimum, produce lower calculated failure probabilities than those in Table I.1. The differences in calculated failure probabilities with a variation in proof stress levels are reduced as bend diameter is decreased.

I.3 Network and network failure examples

For lifetime calculations, for example, a simple network is considered to consist of a 1000-fibre distribution cable with a tree structure, as indicated in Figure I.3. Depending upon the installation and customer connection procedures of the operator, the individual fibres or groups of fibres are stored in cassettes in the main distribution cable or in the branches. For simplicity and as a worst-case situation, it is assumed that all 1000 fibres are passing 5 cabinets or enclosures with a storage cassette in every individual fibre link and in every cabinet or enclosure.

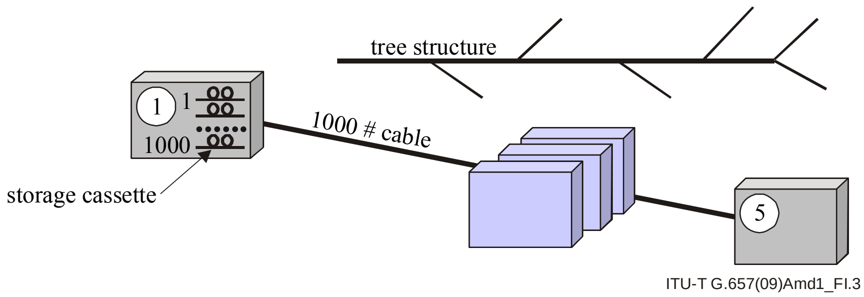

Figure I.3 – Simplified network structure

In this particular network structure, a failure rate per individual single fibre cassette of 0.001% (10^{-5}) in 20 years will result in a 5% probability that in 20 years there will be one single spontaneous break in the total network. This probability needs to be compared with the probability of other failures that may occur in the distribution network during its 20-year operational lifetime. Such failures may be due to re-work or re-configuration in the link or due to other causes of cable or cabinet damage. For most access network situations, it may be assumed that the stated failure probability due to spontaneous fibre breakage is much lower than the failure probability due to other causes. Each operator has to determine the accepted failure rate based on more precise data on the outside plant failure rate statistics.

I.4 Fibre lifetime considerations

Apart from the intrinsic fibre strength characteristics and the fibre environment, the main parameters that determine the failure rate per cassette are the length of the stored fibre and the bending radius, $\boldsymbol{R}$, of the storage. Shorter storage length will have a positive influence, whereas a reduced bending radius will have a negative influence. Applying the [b-IEC/TR 62048] lifetime model with more details in [b-OFT] on current fibres with a standard setting of proof stress and normal proof-test performance, the resulting maximum storage length for a 20-year lifetime as a function of the fibre bend radius is indicated in Figure I.4, for different values of the dynamic stress corrosion susceptibility parameter, $\boldsymbol{n_d}$ (dynamic fatigue parameter), assuming a maximum failure rate of 0.001% (10^{-5}). Note that a value of $\boldsymbol{n_d}$ = 18 is the minimum value as stated in [b-IEC 60793-2-50].

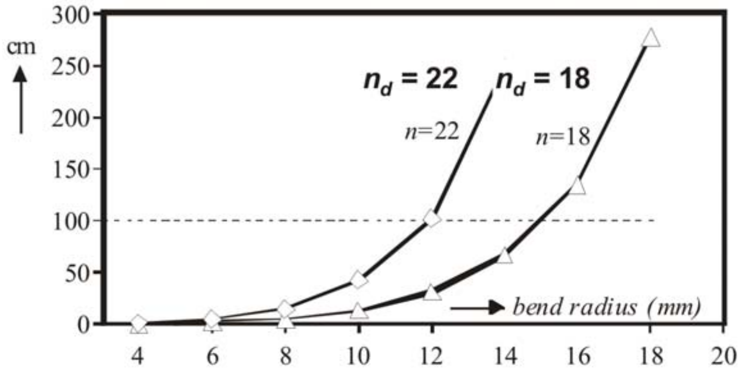

Figure I.4 – Maximum storage length for a bent fibre and different values of the dynamic fatigue parameter n_d

From an optical bend loss point of view, bend-loss insensitive fibres, as described in this Recommendation, can be stored in smaller cassettes than the usual 30 mm radius cassettes. For a storage length per cassette of, for example, 100 cm, i.e., 2 × 50 cm for one single fibre, the bend radius can be lowered from the current 30 mm value down to 15 mm or even lower depending upon the guaranteed n_d-value without violating the 0.001% mechanical failure rate per cassette in 20 years.

A second storage issue is at the entrance and exit ports in the fibre management system. The required small volume for optical access network components is not only dependent upon the storage area, but also on the minimum bend radius of the input and exit ports. The effect of this can be taken into account in several ways. For the purpose of this appendix, it is assumed that in every storage cassette four additional 90-degree bends are required for guiding the fibres into and out of the storage areas. It is also assumed that the additional failure rate due to these additional bends should be limited to less than 10% of the accepted failure rate of 0.001% per cassette (so 10^{-6}). This results in the minimum values as indicated in the middle column of Table I.2.

Table I.2 – Minimum value of non-storage bend radii

n_d-value	Four 90° bends	Single 180° bend
18	R_{min} = 15.0 mm	R_{min} = 12.6 mm
22	R_{min} = 11.1 mm	R_{min} = 9.2 mm

In the right column, the minimum radius in case of a single 180-degree erroneous bend is given. Also for this situation, a maximum additional failure rate per individual cassette of 0.1 × 0.001% is assumed. All figures relate to single fibre management and are given for two different values of the dynamic fatigue parameter, n_d.

Optical cables are traditionally designed to separate bending forces from axial tension. This assumption is not valid for drop cables used in building applications (e.g., with ITU-T G.657 fibres). These new cables may be subject to bends and tension simultaneously. In these conditions, the strain from all sources should be taken into account to accurately predict the mechanical lifetime at the bend. The resulting failure probability when bends and tension are present can be calculated using the strip calculation found in [b-IEC/TR 62048].

An example of the data regarding mechanical failure rate under tension is described in Table I.3.

Table I.3 – Failure probabilities per metre of bent fibre and per number of turns, with indicated bend radius, for bend stress only, and for bend stress + extra axial tension (30% of proof test tension) over 30 years

Bend radius (mm)	Bend stress only (without extra axial tension)		Bend stress + extra axial tension	
	(Failure prob./m)[a)]	ppm (turn)[b)]	(Failure prob./m)[a)]	ppm (turn)[b)]
5	1.02×10^{-04}	~3.2	1.87×10^{-04}	~5.5
7.5	3.54×10^{-05}	~1.7	9.00×10^{-05}	~4.2
10	1.49×10^{-05}	~0.9	5.53×10^{-05}	~3.5
15	2.64×10^{-06}	~0.3	2.90×10^{-05}	~2.7

a) Failure probabilities per metre of bent fibre.
b) Parts per million, ppm.

I.5 Conclusion

The examples given support a 20-year operational lifetime for an appropriately installed network equipped with bend-insensitive fibres as described in this Recommendation, and bend radii less than 30 mm with acceptable failure rates.

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