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

Transmission media characteristics – Optical fibre cables

Characteristics of a single-mode optical fibre cable

ITU-T Recommendation G.652

(Previously CCITT Recommendation)

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ITU-T RECOMMENDATION G.652

CHARACTERISTICS OF A SINGLE-MODE OPTICAL FIBRE CABLE

Summary

This Recommendation covers the geometrical and transmissive properties of single-mode optical fibres and cables whose dispersion and cut-off are not shifted from the 1310 nm wavelength region. Definitions and test methods are contained in a separate Recommendation G.650.

Source

ITU-T Recommendation G.652 was revised by ITU-T Study Group 15 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 8th of April 1997.

FOREWORD

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NOTE

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

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Recommendation G.652

CHARACTERISTICS OF A SINGLE-MODE OPTICAL FIBRE CABLE

(revised in 1997)

1 Scope

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

This fibre can be used for analogue and for digital transmission.

The geometrical, optical, transmission and mechanical characteristics of this fibre are described below, together with applicable test methods.

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 Recommendation G.650.

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; all 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.

– ITU-T Recommendation G.650 (1997), *Definition and test methods for the relevant parameters of single-mode fibres*.

– ITU-T Recommendation G.653 (1997), *Characteristics of a dispersion-shifted single-mode optical fibre cable*.

– ITU-T Recommendation G.654 (1997), *Characteristics of a cut-off shifted single-mode optical fibre cable*.

– ITU-T Recommendation G.655 (1996), *Characteristics of a non-zero-dispersion shifted single-mode optical fibre cable.*

– ITU-T Recommendation G.663 (1996), *Application related aspects of optical fibre amplifier devices and sub-systems.*

– ITU-T Recommendation G.681 (1996), *Functional characteristics of interoffice and long-haul line systems using optical amplifiers, including optical multiplexing*.

– ITU-T Recommendation G.955 (1996), *Digital line systems based on the 1544 kbit/s and the 2048 kbit/s hierarchy on optical fibre cables*.

– ITU-T Recommendation G.957 (1995), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

– IEC Publication 793-2, Part 2 (1992), *Optical fibres – Part 2: Product specifications*.

3 Terminology

For the purposes of this Recommendation, the definitions given in Recommendation G.650 apply.

4 Abbreviations

This Recommendation uses the following abbreviations:

GPa Gigapascals

SDH Synchronous Digital Hierarchy

WDM Wavelength Division Multiplexing

5 Fibre characteristics

Only those characteristics of the fibre providing a minimum essential design framework for fibre manufacture are recommended in this clause. Of these, the cabled fibre cut-off wavelength may be significantly affected by cable manufacture or installation. Otherwise, the recommended characteristics will apply equally to individual fibres, fibres incorporated into a cable wound on a drum, and fibres in installed cable.

This Recommendation applies to fibres having a nominally circular mode field.

5.1 Mode field diameter

The nominal value of the mode field diameter at 1310 nm shall lie within the range of 8.6 to 9.5 µm. The mode field diameter deviation should not exceed the limits of ±10% of the nominal value.

NOTE 1 – A value of 10 µm is commonly employed for matched cladding designs, and a value of 9 µm is commonly employed for depressed cladding designs. However, the choice of a specific value within the above range is not necessarily associated with a specific fibre design.

NOTE 2 – It should be noted that the fibre performance required for any given application is a function of essential fibre and systems parameters, i.e. mode field diameters, cut-off wavelength, total dispersion, system operating wavelength, and bit rate/frequency of operation, and not primarily of the fibre design.

NOTE 3 – The mean value of the mode field diameter, in fact, may differ from the above nominal values provided that all fibres fall within ±10% of the specified nominal value.

5.2 Cladding diameter

The recommended nominal value of the cladding diameter is 125 µm. The cladding deviation should not exceed the limits of ±2 µm.

For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

5.3 Mode field concentricity error

The recommended mode field concentricity error at 1310 nm should not exceed 1 µm.

NOTE 1 – For some particular jointing techniques and joint loss requirements, tolerances up to 3 µm may be appropriate.

NOTE 2 – The mode field concentricity error and the concentricity error of the core represented by the transmitted illumination using wavelengths different from 1310 nm (including white light) are equivalent. In general, the deviation of the centre of the refractive index profile and the cladding axis also represents the mode field concentricity error but, if any inconsistency appears between the mode field concentricity error, measured according to the Reference Test Method (RTM), and the core concentricity error, the former will constitute the reference.

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 should be less than 2%. For some particular jointing techniques and joint loss requirements, other tolerances may be appropriate.

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}.

The correlation of the measured values of λ_c and 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 quantitative relationship cannot easily be established. The importance of ensuring single-mode transmission in the minimum cable length between joints at the minimum system 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 either 1260 or 1270 nm.

NOTE 1 – A sufficient wavelength margin should be assured between the lowest-permissible system operating wavelength λ_s and the highest-permissible cable cut-off wavelength λ_{cc}.

NOTE 2 – To prevent modal noise effects and ensure single-mode transmission in cables of length less than 2 m (e.g. fibre pigtails, short jumper cables), the maximum λ_c for fibres to be used should not be higher than 1250 nm when measured under the conditions of the relevant RTM of Recommendation G.650.

NOTE 3 – To prevent modal noise effects and ensure single-mode transmission in cables with lengths between 2 m and 20 m (e.g. fibre pigtails, short jumper cables), the maximum λ_{cj} should not be higher than either 1260 or 1270 nm.

Since specification of cable cut-off wavelength, λ_{cc}, is a more direct way of ensuring single-mode cable operation, specifying this is preferred to specifying fibre cut-off wavelength, λ_c. However, when circumstances do not readily permit the specification of λ_{cc}, (e.g. in single-fibre cables such as pigtails, jumpers or cables to be deployed in a significantly different manner than in the λ_{cc} RTM), then specifying an upper limit for λ_c or λ_{cj} is appropriate.

When the user specifies λ_{cc} as in a), it should be understood that λ_c may exceed 1260 or 1270 nm. Furthermore, λ_c may be higher than the minimum system operating wavelength, relying on the effects of cable fabrication and installation to yield λ_{cc} values below the minimum system operating wavelength for the shortest length of cable between two joints. It is common practice that a qualification test is employed to ensure that the cable design meets the required λ_{cc} specification.

5.6 1550 nm loss performance

In order to ensure low-loss operation of deployed 1310 nm optimized fibres in the 1550 nm wavelength region, the loss increase of 100 turns of fibre loosely-wound with a 37.5 mm radius, and measured at 1550 nm, shall be less than 1.0 dB.

For SDH and WDM applications, the fibre may be used at wavelengths exceeding 1550 nm. The 1.0 dB maximum loss shall apply at the maximum wavelength of anticipated use (which would be ≤1580 nm). The loss at the maximum wavelength may be projected from a loss measurement at 1550 nm, using either spectral loss modelling or a statistical database for that particular fibre design. Alternatively, a qualification test at the longer wavelength may be performed.

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

NOTE 2 – The above value of 100 turns corresponds to the approximate number of turns deployed in all splice cases of a typical repeater span. The radius of 37.5 mm is equivalent to the minimum bend-radius widely accepted for long-term deployment of fibres in practical system installations to avoid static-fatigue failure.

NOTE 3 – If for practical reasons fewer than 100 turns are chosen to implement this 37.5 mm test, it is suggested that not less than 40 turns, and a proportionately smaller loss increase be used.

NOTE 4 – If bending radii smaller than 37.5 mm are planned to be used in splice cases or elsewhere in the system (for example, R = 30 mm), it is suggested that the same loss value of 1.0 dB shall apply to 100 turns of fibre deployed with this smaller radius.

NOTE 5 – The 1550 nm bend-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 6 – In the event that routine tests are required a small diameter loop with one or several turns can be used instead of the 100-turn test, for accuracy and measurement ease of the 1550 nm bend sensitivity. 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 1.0 dB loss recommendation of the 37.5 mm radius 100-turn functional test.

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 be at least 0.35 GPa which corresponds to a proofstrain of approximately 0.5%. Proofstress is often specified as 0.69 GPa.

NOTE – The definitions of the mechanical parameters are contained in 1.2/G.650 and 2.6/G.650.

5.8 Refractive index profile

The refractive index profile of the fibre does not generally need to be known; if one wishes to measure it, the reference test method in Recommendation G.651 may be used.

5.9 Longitudinal uniformity

Under study.

6 Factory length specifications

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.

Environment and test conditions are paramount and are described in the guidelines for test methods.

6.1 Attenuation coefficient

Optical fibre cables covered by this Recommendation generally have attenuation coefficients below 0.5 dB/km in the 1310 nm wavelength region, and below 0.4 dB/km in the 1500 nm wavelength region.

NOTE 1 – The lowest values depend on the fabrication process, fibre composition and design, and cable design. Values in the range 0.3-0.4 dB/km in the 1310 nm region and 0.17-0.25 dB/km, in the 1550 region, have been achieved.

NOTE 2 – The attenuation coefficient may be calculated across a spectrum of wavelengths, based on measurements at a few (3 to 5) predictor wavelengths. This procedure is described in Appendix I and an example is given in Appendix II.

6.2 Chromatic dispersion coefficient

The maximum chromatic dispersion coefficient shall be specified by:

– the allowed range of the zero-dispersion wavelength between λ_{0min} = 1300 nm and λ_{0max} = 1324 nm;

– the maximum value S_{0max} = –0.093 ps/(nm² · km) of the zero-dispersion slope.

The chromatic dispersion coefficient limits for any wavelength λ within the range 1260-1360 nm shall be calculated as:

$$D_1(\lambda) = \frac{S_{0\max}}{4}\left[\lambda - \frac{\lambda^4 0\min}{\lambda^3}\right]$$

$$D_2(\lambda) = \frac{S_{0\max}}{4}\left[\lambda - \frac{\lambda^4 0\max}{\lambda^3}\right]$$

NOTE 1 – As an example, the values of λ_{0min}, λ_{0max} and S_{0max} yield chromatic dispersion coefficient magnitudes $|D_1|$ and $|D_2|$ equal to or smaller than the maximum chromatic dispersion coefficients in the table:

Wavelength (nm)	Maximum chromatic dispersion coefficient [ps/(nm.km)]
1288-1339	3.5
1271-1360	5.3

NOTE 2 – Use the above expression for $D_1(\lambda)$ to estimate the maximum dispersion in the 1550 nm region.

NOTE 3 – For high capacity or long systems, a narrower range of λ_{0min}, λ_{0max} may need to be specified, or if possible, a smaller value of S_{0max} be chosen.

NOTE 4 – It is not necessary to measure chromatic dispersion coefficient of single-mode fibre on a routine basis.

6.3 Polarization mode dispersion coefficient

Under study.

NOTE – Optical fibre cables covered by this Recommendation generally have a polarization mode dispersion coefficient below 0.5 ps/km$^{1/2}$. This corresponds to a PMD-limited transmission distance of about 400 km for STM-64 systems.

Systems with lower bit rate distance products can tolerate higher values of PMD coefficient without impairment.

7 Elementary cable sections

An elementary cable section usually includes a number of spliced factory lengths. The requirements for factory lengths are given in clause 6. The transmission parameters for elementary cable sections must take into account not only the performance of the individual cable lengths, but also, amongst other factors, such things as splice losses and connector losses (if applicable).

In addition, the transmission characteristics of the factory length fibres as well as such items as splices and connectors, etc. will all have a certain probability distribution which often needs to be taken into account if the most economic designs are to be obtained. The following subclauses should be read with this statistical nature of the various parameters in mind.

7.1 Attenuation

The attenuation A of an elementary cable section is given by:

$$A = \sum_{n=1}^{m} \alpha_n \cdot L_n + \alpha_s \cdot \chi + \alpha_c \cdot y$$

where:

- α_n = attenuation coefficient of nth fibre in elementary cable section;
- L_n = length of nth fibre;
- m = total number of concatenated fibres in elementary cable section;
- α_s = mean splice loss;
- χ = number of splices in elementary cable section;
- α_c = mean loss of line connectors;
- y = number of line connectors in elementary cable section (if provided).

A suitable allowance should be allocated for a suitable cable margin for future modifications of cable configurations (additional splices, extra cable lengths, ageing effects, temperature variations, etc.).

The above expression does not include the loss of equipment connectors.

The mean loss is used for the loss of splices and connectors. The attenuation budget used in designing an actual system should account for the statistical variations in these parameters.

7.2 Chromatic dispersion

The chromatic dispersion in ps 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 and system source characteristics (see 6.2).

APPENDIX I

Spectral attenuation modelling

The attenuation coefficient of a fibre across a spectrum of wavelengths may be calculated by means of a characterizing matrix M and a vector v. The vector contains the measured attenuation coefficients at a small number (3 to 5) of predictor wavelengths (e.g. 1300 nm, 1330 nm, 1370 nm, 1380 nm, and/or 1550 nm). The matrix M multiplies vector v to yield another vector w that predicts the attenuation coefficients at many wavelengths (such as at 10 nm wavelength intervals from 1240 nm to 1600 nm).

The matrix M is given by:

$$\begin{pmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{2n} \\ \dots & \dots & \dots & \dots \\ A_{m1} & A_{m2} & \dots & A_{mn} \end{pmatrix}$$

where m is the number of wavelengths where the attenuation coefficients have to be estimated and n is the number of predictor wavelengths. The matrix M then multiplies a vector v (n elements) containing the measured attenuation coefficients for the specific fibre: the result is a new vector w (m elements), giving the estimated values of the attenuation coefficients over the given range, i.e.:

$$w = M \cdot v$$

The numerical values in this generic matrix are under consideration. The standard deviation of the difference between the actual and predicted attenuation coefficients is to be better than 0.xx dB/km in the second window and better than 0.yy dB/km in the third window. The values of xx and yy are under consideration.

Alternatively, the fibre supplier may provide a specific matrix that describes its particular fibre more accurately than the generic matrix. Standard deviations of the difference between actual and predicted values should be quoted. An illustrative example of a specific matrix is presented in Appendix II.

Due to the dependence of the attenuation spectra on the fabrication process, a generic matrix may permit only a rough estimate of the attenuation coefficients. A better approximation can sometimes be obtained by adding another suitable "correction" vector e to be given by each fibre supplier. Therefore, the estimated attenuation coefficients are the elements of the w vector:

$$w = M \cdot v + e$$

If the estimate is obtained by using the supplier-specific or fibre type specific matrix M, then no correction vector e is necessary.

The elements of both M and e are achieved on a statistical basis, so the w vector elements shall be interpreted as statistical. To indicate the accuracy of the predicted attenuation coefficients, the fibre suppliers shall give a vector containing the standard deviation of the differences between the actual and predicted attenuation coefficients in both windows together with M and/or e.

NOTE 1 – In order to facilitate use of this matrix, the fibre should be routinely measured at the predictor wavelengths. The predictor wavelengths should number from 3 to 5, with a strong preference given to the lower number if sufficient accuracy can be achieved. The specific wavelengths (e.g. 1300 nm, 1330 nm, 1370 nm, 1380 nm, and/or 1550 nm) are an item for further study.

NOTE 2 – This model considers only uncabled fibre attenuation. An additional vector must be added to w to take account of cabling effects and environmental effects.

APPENDIX II

Example of the matrix model

The following is an example of an $m \times n = 38 \times 3$ matrix. Please note it is given for illustrative purposes only.

If the spectral attenuation is to be estimated over the range of 1240 nm to 1600 nm (in steps of 10 nm) using 1310 nm, 1380 nm, and 1550 nm as predictor wavelengths, an example of matrix elements which has been shown to be applicable[1] for some G.652 fibres follows:

[1] HANSON (T.A.): Spectral Attenuation Modelling with Matrix Models, *Conference Digest NPL Optical Fibre Measurement Conference*, pp. 8-11, York, the United Kingdom, 1991.

Output wavelength (µm)	Predictive wavelengths		
	1310 nm	1380 nm	1550 nm
1.23	1.46027	–0.04235	–0.20771
1.24	1.35288	–0.01493	–0.13289
1.25	1.31704	–0.00412	–0.14768
1.26	1.26613	–0.00997	–0.13715
1.27	1.20167	–0.00843	–0.10635
1.28	1.14970	–0.01281	–0.06363
1.29	1.11290	–0.01059	–0.06245
1.30	1.03600	–0.00711	0.00711
1.31	0.96276	0.00342	0.05412
1.32	0.90437	0.01435	0.08572
1.33	0.86168	0.02098	0.11776
1.34	0.83194	0.05500	0.05849
1.35	0.73415	0.08336	0.14196
1.36	0.83266	0.11032	–0.10694
1.37	0.69137	0.22596	–0.05961
1.38	0.01006	0.99798	–0.01126
1.39	–0.25502	0.94764	0.48887
1.40	0.00227	0.58463	0.51813
1.41	0.25780	0.33834	0.40811
1.42	0.29085	0.20419	0.49620
1.43	0.29329	0.13569	0.54995
1.44	0.33133	0.09266	0.51936
1.45	0.31608	0.06343	0.55905
1.46	0.24183	0.04483	0.68361
1.47	0.29207	0.03019	0.59222
1.48	0.19214	0.02196	0.75669
1.49	0.18650	0.01132	0.76122
1.50	0.21242	0.00541	0.70722
1.51	0.16884	0.00648	0.75347
1.52	0.11484	–0.00091	0.84972
1.53	0.09334	0.00419	0.85304
1.54	0.07231	–0.00021	0.88512
1.55	0.03111	–0.00115	0.94957
1.56	0.07054	–0.00321	0.87414
1.57	–0.03723	–0.01127	1.08140
1.58	–0.02543	0.00556	1.01041
1.59	–0.01370	0.00457	0.99389
1.60	–0.06916	–0.00107	1.11623

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