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TRANSMISSION MEDIA CHARACTERISTICS

CHARACTERISTICS OF A SINGLE-MODE OPTICAL FIBRE CABLE

ITU-T Recommendation G.652

(Previously "CCITT Recommendation")

FOREWORD

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, established the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

ITU-T Recommendation G.652 was revised by the ITU-T Study Group XV (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

NOTES

1 As a consequence of a reform process within the International Telecommunication Union (ITU), the CCITT ceased to exist as of 28 February 1993. In its place, the ITU Telecommunication Standardization Sector (ITU-T) was created as of 1 March 1993. Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

In order not to delay publication of this Recommendation, no change has been made in the text to references containing the acronyms "CCITT, CCIR or IFRB" or their associated entities such as Plenary Assembly, Secretariat, etc. Future editions of this Recommendation will contain the proper terminology related to the new ITU structure.

2 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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CHARACTERISTICS OF A SINGLE- MODE OPTICAL FIBRE CABLE

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988 and at Helsinki, 1993)

The CCITT,

considering

(a) that single-mode optical fibre cables are widely used in telecommunication networks;

(b) that the foreseen potential applications may require several kinds of single-mode fibres differing in:

- geometrical characteristics;
- operation wavelength;
- attenuation, dispersion, cut-off wavelength and other optical characteristics;
- mechanical and environmental aspects;

(c) that Recommendations on different kinds of single-mode fibres can be prepared when practical use studies have sufficiently progressed,

recommends

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.

1 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.

1.1 Mode field diameter

The nominal value of the mode field diameter at 1310 nm shall lie within the range of 9 to 10 μm. The mode field diameter deviation should not exceed the limits of ± 10% of the nominal value.

NOTES

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.

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.

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.

1.2 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.

1.3 Mode field concentricity error

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

NOTES

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

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.

1.4 Non-circularity

1.4.1 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.

1.4.2 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.

1.5 Cut-off wavelength

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

a) the cut-off wavelength λ_c of a primary coated fibre according to the relevant fibre RTM;

b) the cut-off wavelength λ_{cc} of a cabled fibre in a deployment condition according to the relevant cable RTM.

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 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 can be approached in two alternate ways:

1) recommending λ_c to be less than 1280 nm: when a lower limit is appropriate λ_c should be greater than 1100 nm:

2) recommending the maximum value of λ_{cc} to be either 1260 nm or 1270 nm.

NOTES

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}.

2 To prevent modal noise effects and ensure single mode transmission in fibre jumpers of any length and under any deployment condition, fibres should be selected with sufficiently low cut-off wavelength. Considering the worst-case conditions, the maximum λ_c for fibres to be used in jumpers should not be higher than 1240 nm when measured under the conditions of the relevant RTM of Recommendation G.650.

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

When the user chooses to specify λ_{cc} as in 2), it should be understood that λ_c may exceed 1280 nm.

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

In the case where the user chooses to specify λ_{cc}, it may be permitted that λ_c be higher than the minimum 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.

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

1.6 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 not be less than 1.0 dB.

NOTES

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

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 systems installations to avoid static-fatigue failure.

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

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.

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.

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.

1.7 Material properties of the fibre

1.7.1 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.

1.7.2 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.

1.7.3 Proofstress level

– The proofstress σ_p shall be at least 0.35 GPa (which approximately corresponds to a proofstrain ~0.5%).

– The dwell-time t_d shall be 1 s. A shorter alternate dwell-time t_a may be chosen; then a larger alternate proofstress σ_a must be chosen according to the following equation:

$$\sigma_a = \sigma_p \left[\frac{t_d}{t_a} \right]^{\frac{1}{n_d}}$$

– The value of the dynamic fatigue parameter n_d is determined by a dynamic fatigue test method.

– For some applications, such as local networks or submarine systems, higher values of proofstress (or proofstrain) may be desired. Values such as 0.7 GPa or 1.4 GPa (or ~1% and ~2%) are for further study.

1.8 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.

1.9 Longitudinal uniformity

Under study.

1.10 Examples of fibre design guidelines

Supplement No. 33 to the *Blue Book* gives an example of fibre design guidelines for matched-cladding fibres used by two organizations.

2 Factory length specifications

Since the geometrical and optical characteristics of fibres given in clause 1 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.

2.1 Attenuation coefficient

Optical fibre cables covered by this Recommendation generally have attenuation coefficients below 1.0 dB/km in the 1310 nm wavelength region, and below 0.5 dB/km in the 1500 nm wavelength region.

NOTES

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 0.15-0.25 dB/km, in the 1550 nm region have been achieved.

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.

2.2 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/(nm^2 · 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

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

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

NOTES

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
1550	20 (approx.)

2 Use of these equations in the 1550 nm region should be approached with caution.

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.

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

3 Elementary cable sections

An elementary cable section usually includes a number of spliced factory lengths. The requirements for factory lengths are given in clause 2. 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 in this clause should be read with this statistical nature of the various parameters in mind.

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

3.1 Attenuation

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

where

- α_n is the attenuation coefficient of *n*th fibre in elementary cable section;
- L_n is the length of *n*th fibre;
- m is the total number of concatenated fibres in elementary cable section;
- α_s is the mean splice loss;

χ is the number of splices in elementary cable section;

α_c is the mean loss of line connectors;

y is the 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.

3.2 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 2.2).

Appendix I

Spectral attenuation modelling

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

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:

$$\begin{matrix} A_{11} & A_{12} \cdots A_{1n} \\ A_{11} & A_{22} \cdots A_{2n} \\ \cdot & \cdot\cdot \\ \cdot & \cdot\cdot \\ \cdot & \cdot\cdot \\ A_{m1} & A_{m2} \cdots A_{mn} \end{matrix}$$

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*.

NOTES

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.

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

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

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

Output wavelength (µm)	Predictive wavelengths		
	1.31 µm	1.38 µm	1.55 µm
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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