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

Transmission media characteristics – Optical fibre cables

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

ITU-T Recommendation G.654

(Previously CCITT Recommendation)

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ITU-T RECOMMENDATION G.654

CHARACTERISTICS OF A CUT-OFF SHIFTED SINGLE-MODE OPTICAL FIBRE CABLE

Summary

This Recommendation covers the characteristics of a cut-off shifted single-mode optical fibre cable. This Recommendation was approved by the WTSC (Helsinki, 1-12 March 1993). Amendments have been made taking into account the establishment of new Recommendations relevant to the fibres and systems.

Source

ITU-T Recommendation G.654 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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The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 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.

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As of the date of approval of this Recommendation, the ITU had/had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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Recommendation G.654

CHARACTERISTICS OF A CUT-OFF SHIFTED SINGLE-MODE OPTICAL FIBRE CABLE

(revised in 1997)

1 Scope

The purpose of this Recommendation is to provide characteristics of a cut-off shifted single-mode optical fibre cable.

This Recommendation describes a single-mode fibre which has the zero-dispersion wavelength around 1300 nm wavelength which is cut-off shifted and loss minimized at a wavelength around 1550 nm and which is optimized for use in the 1500-1600 nm region.

This very low loss Cut-off Shifted Fibre (CSF) can be used for long distance digital transmission applications. The geometrical, optical (attenuation, cut-off wavelength, dispersion etc.), transmission and mechanical characteristics of this CSF are described below.

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. The characteristics of this CSF, including the definitions of the relevant parameters, their test methods and relevant values, will be refined as studies and experience progress.

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.652 (1997), *Characteristics of a single-mode optical fibre cable*.

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

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

3 Terminology

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

4 Abbreviations

This Recommendation uses the following abbreviations:

CSF Cut-off Shifted Fibre

D	Chromatic Dispersion Coefficient (ps/nm · km)
GPa	GigaPascals
MFD	Mode Field Diameter (µm)
PMD	Polarization Mode Dispersion (ps, ps$\sqrt{km}$)
λ_c	Fibre Cut-Off Wavelength (nm)
λ_{cc}	Cable Cut-Off Wavelength (nm)
λ_{cj}	Jumper Cable Cut-Off Wavelength (nm)
S	Dispersion Slope (ps/nm^2 · km)
SDH	Synchronous Digital Hierarchy
STM	Synchronous Transfer Module
τ	Group Delay per unit fibre length (ns/km)
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 (MFD)

The nominal value of the mode field diameter at 1550 nm shall be 10.5 µm. The MFD deviation should not exceed the limits of ±10% of the 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 1550 nm should not exceed 1 µm.

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

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) fibre cut-off wavelength λ_c,

b) cable cut-off wavelength λ_{cc},

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

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 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 1600 nm: when a lower limit is appropriate λ_c should be greater than 1350 nm;

2) recommending the maximum value of λ_{cc} to be 1530 nm.

NOTE – The above values ensure single-mode transmission at around 1550 nm. For WDM applications requiring operation at a wavelength of (1550 nm-x), the above values should be reduced by x nm.

These two specifications need not both be invoked. Since specification of 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 1600 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.

5.6 1550 nm bend loss performance

The loss increase for 100 turns of fibre, loosely wound with a 37.5 mm radius and measured at 1550 nm shall be less than 0.5 dB.

For SDH and WDM applications the fibre may be used at wavelength 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 radius 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 0.5 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 0.5 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.

5.9 Longitudinal uniformity

Under study.

5.10 Examples of fibre design guidelines

Supplement No. 33 to the *Blue Book* gives an example of fibre design guidelines for the cut-off shifted fibres used by one organization (KDD).

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.

Environmental 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 coefficient in the 1550 nm region below 0.22 dB/km.

NOTE – The lowest values depend on fabrication process, fibre composition and design, and cable design. Values of 0.15 to 0.19 dB/km in the 1550 nm region have been achieved.

6.2 Chromatic dispersion coefficient (D)

The measured group delay per unit fibre length $\tau(\lambda)$ versus wavelength shall be fitted by the quadratic expression:

$$\tau(\lambda) = \tau_{1550} + (S_{1550} / 2)(\lambda - 1550)^2 + D_{1550}(\lambda - 1550)$$

Here, τ_{1550} is relative group delay per unit fibre length minimum (ns/km) at wavelength $\lambda = 1500$ nm. The chromatic dispersion coefficient $D(\lambda) = d\tau/d\lambda$ (ps/nm · km) can be determined from the differentiated quadratic expression:

$$D(\lambda) = S_{1550}(\lambda - 1550) + D_{1550}$$

Here, S_{1550} is the dispersion slope (ps/nm^2 · km) at 1550 nm wavelength, i.e. the value of the dispersion slope S_{1550} $(\lambda) = dD/d\lambda$ at $\lambda = 1550$ nm. Also D_{1550} denotes the dispersion values at $\lambda = 1550$ nm.

NOTE 1 – These equations for $\tau(\lambda)$ and $D(\lambda)$ are sufficiently accurate over the 1500-1600 nm range. They are not meant to be used in the 1310 region.

NOTE 2 – Alternatively, the chromatic dispersion coefficient can be measured directly, for example by the differential phase shift method. In this case, a straight line shall be fitted directly to dispersion coefficient for determining S_{1550} and D_{1550}.

The maximum chromatic dispersion coefficient D_{1550} and the maximum dispersion slope S_{1550} at 1550 nm in single-mode fibres covered in this Recommendation shall be around 20ps/(nm · km) and around 0.07ps/(nm^2 · km), respectively.

6.3 Polarization Mode Dispersion (PMD) coefficient

Under study.

NOTE – Optical fibre cables covered by this Recommendation generally have a PMD coefficient below $0.5 \text{ps} / \sqrt{\text{km}}$. 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:

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

Where:

α_n	=	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).

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